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Consumer perception and sensory profile of rice-based products with a low glycaemic index

Diva Cabral

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Doctoral Program in Agrarian Sciences
Department of Geosciences, Environment and Spatial Planning
Faculty of Sciences of the University of Porto
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Consumer perception and sensory profile of rice-based products with a low glycaemic index

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Thesis carried out as part of the Doctoral Program in Agrarian Sciences

Department of Geosciences, Environment and Spatial Planning

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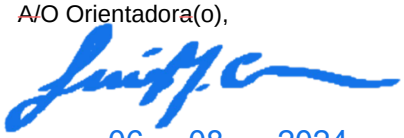
Todas as correções determinadas pelo júri, e só essas, foram efetuadas.

A/O Orientadora(o),



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Resumo

Portugal é o maior consumidor de arroz na Europa, produzindo quase exclusivamente a subespécie japónica. A composição nutricional do arroz, face ao seu índice glicémico (IG), tem-se tornado uma preocupação para os consumidores comprometidos com a saúde, colocando em risco a produção nacional de arroz. Impõe-se assim à indústria alimentar o desenvolvimento de novos produtos (DNP) ou a melhoria dos produtos existentes, de modo a responder as novas tendências do consumo, muito focado na saúde, bem-estar e conveniência. Atendendo ao facto de Portugal ser o segundo país europeu com maior incidência de diabetes, bem como com um elevado número de pré-obesos e obesos, no contexto da política de saúde pública, é importante promover formas mais saudáveis de consumir arroz. As perceções do consumidor são os melhores preditores das escolhas alimentares. Portanto, o objetivo principal desta investigação foi estudar a perceção do consumidor, incluindo perfis sensoriais e atitudes do consumidor em relação ao arroz e produtos à base de arroz de baixo IG, através da aplicação integrada de metodologias qualitativas e quantitativas avançadas, visando gerar informações relevantes para DNP a base de arroz com baixo IG, bem como contribuir para o desenho de programas de educação alimentar, nutricional e de bem-estar da população portuguesa. Os resultados foram apresentados na forma de quatro artigos apresentados no Capítulo III.

O artigo I apresenta de forma sistemática e metódica a perceção do arroz (comum) e do arroz com baixo IG. O estudo também avaliou o impacto de fatores socioeconômicos e relacionados ao consumo de arroz na perceção desse produto. Os dados da associação livre de palavras permitiram-nos derivar léxicos de conceptualização experienciais, utilitários e simbólicos para arroz e arroz com baixo IG através da aplicação da teoria da tipologia do valor de consumo. Os entrevistados associaram principalmente “arroz” a pratos de arroz, atributos sensoriais e nutrição, enfatizando o cumprimento de requisitos nutricionais e hedônicos. Os consumidores expressaram expectativas positivas em relação aos atributos funcionais do “arroz com baixo IG”. Os padrões de consumo de arroz, a idade, o nível educacional e as informações demográficas impactaram as perceções em relação ao "arroz" e "arroz com baixo IG".

O artigo II avalia o comportamento e atitudes do consumidor em relação ao arroz com alguma abordagem ao consumo tradicional dos consumidores portugueses, em que os principais objetivos foram explorar e compreender os hábitos de consumo de arroz e os

determinantes da escolha de produtos de arroz com baixo IG. Este trabalho baseia-se numa metodologia mista, em que a avaliação dos comportamentos dos consumidores, avaliados através de medidas explícitas de autorrelato, um questionário, complementada por entrevistas em profundidade. Este artigo complementa o Artigo I com pesquisas mais aprofundadas sobre o tema apoiadas por análises temáticas de entrevistas em profundidade, até a saturação. Os resultados mostraram que, embora o conceito de IG fosse desconhecido por metade dos participantes, foi percebido como interessante e positivo para a prática de uma alimentação saudável. Os consumidores demonstraram preocupação com o sabor e a naturalidade do produto, preferindo que fosse o mais próximo possível de um prato convencional/caseiro. As perceções negativas que se verificaram pode ter sido devido ao desconhecimento do conceito de IG, portanto, são recomendadas campanhas de sensibilização e informação para promover produtos de arroz com baixo IG.

O Artigo III teve como objetivo avaliar a aceitabilidade, o perfil sensorial e a perceção de bem-estar de diferentes tipos de arroz pronto a comer, e compreender o efeito da informação do produto antes do consumo na aceitabilidade e na perceção do bem-estar. Este estudo introduziu uma avaliação quantitativa da perceção do bem-estar dos produtos de arroz pronto a comer, melhorando a compreensão de como as variedades e os ingredientes afetam o bem-estar e a aceitabilidade. Estes resultados permitiram-nos compreender que alguns ingredientes e o estado de processamento do arroz (grão integral ou branqueado) são fatores críticos na preferência e no bem-estar de arroz pronto a comer. Confirma-se que os consumidores preferem arroz pronto a comer mais próximo do arroz convencional a que estão habituados.

No artigo IV foram avaliados atributos de embalagem importantes para a aceitação de um produto de arroz com baixo IG, nomeadamente a variedade, o processamento e as informações do rótulo. Os resultados mostraram que o processamento influenciou significativamente a vontade de experimentar o arroz pronto a comer, revelando uma maior preferência dos consumidores pelo grão integral do que pelo arroz branqueado com adição de farelo. As reivindicações foram menos relevantes; no entanto, o “baixo IG” teve um impacto positivo, indicando o seu potencial para influenciar as atitudes de compra dos consumidores e promover formas mais saudável de consumo de arroz. Os participantes foram segmentados em três grupos com base nas suas atitudes, onde grupos orientados para a naturalidade e orientados para a conveniência foram os mais propensos a experimentar arroz pronto a comer.

No geral, este trabalho abordou os hábitos de consumo de arroz dos portugueses, permitindo compreender o comportamento e as atitudes durante o processo de abastecimento do arroz (desde a aquisição até às práticas de consumo), fornecendo insights importantes e específicos em cada ponto de interação do consumidor com o produto.

Confirmou-se que o arroz continua a ser um alimento básico em Portugal, muito utilizado como acompanhamento ou prato principal, e apreciado pelas suas propriedades sensoriais que trazem deleite e prazer aos consumidores. Verificou-se que ao selecionar novas variedades de arroz, os consumidores portugueses priorizam os aspetos sensoriais, o preço e a conveniência como os fatores mais importantes a considerar.

Concluiu-se que embora o arroz de baixo IG incite algo novo, os consumidores geralmente têm uma perceção positiva do seu valor funcional/utilitário, contrariamente à dimensão sensorial. Como os hábitos tradicionais (familiaridade), os atributos sensoriais e a naturalidade têm sido destacados como motivadores da escolha do arroz com baixo IG, os fabricantes de alimentos devem ter o cuidado de oferecer produtos de arroz mais saudáveis, que se assemelhem a pratos de arroz convencionais e que sejam sensorialmente atraentes. É essencial empregar tecnologias de processamento natural e incorporar ingredientes naturais sustentáveis que são comumente usados no quotidiano.

Este projeto de pesquisa utilizou diferentes análises estatísticas para interpretar dados provenientes de diferentes métodos de coleta de dados. Os resultados e a discussão revelam informações essenciais para as partes interessadas promoverem e desenvolverem formas mais saudáveis de consumir arroz. Além disso, fornece informações iniciais sobre a perceção dos alimentos ricos em hidratos de carbono com rotulagem IG em Portugal.

Palavras-chave: arroz, índice glicêmico, arroz pronto a comer, hábitos de consumo de arroz, pratos de arroz, bem-estar, nutrição, naturalidade, conveniência.

Abstract

Portugal is the largest consumer of rice in Europe, producing almost exclusively japonica subspecies. The nutritional composition of rice, due to its glycaemic index (GI), has become a concern for consumers who are committed to health, putting the national rice production at risk. Therefore, the food industry is required to develop new products (DNP) or improve existing products to respond to new consumer trends, focusing on health, well-being, and convenience. Given the fact that Portugal is the second European country with the highest rate of diabetes, as well as a high number of pre-obese and obese people, in the context of public health policy, it is important to promote healthier ways of consuming rice. Consumer perceptions are the best predictors of food choices. Therefore, the main aim was to study consumer perception, including sensory profiles and consumer attitudes towards rice and low GI rice-based products, through the integrated application of advanced qualitative and quantitative methodologies, aiming to generate relevant information for DNP based on low GI rice, as well as to contribute to the design of food, nutritional, and well-being education programs for the Portuguese population. The results were presented in the form of four articles presented in Chapter III.

Paper I systematically and methodically presents the perception of traditional rice and rice with a low glycaemic index. The study also assessed the impact of socioeconomic factors and factors related to rice consumption on the perception of this product free word association (FWA) data allowed us to derive experiential, utilitarian, and symbolic conceptualization lexicons for rice and rice with low GI through the application of typology of consumption value theory. Respondents primarily associated "rice" to rice dishes, sensory attributes, and nutrition, emphasizing the fulfilment of both nutritional and hedonic requirements. Consumers expressed positive expectations concerning the functional attributes of "rice with low GI". Consumers' rice consumption patterns, age, educational level, and demographic information impacted their perceptions of "rice" and "rice with low GI".

Paper II presents research on consumer behaviour and attitudes towards rice with some approach to the traditional consumption of Portuguese consumers. The main goals of this study were to explore and understand rice consumption habits and determinants of choice for rice products with a low glycaemic index, based on a study of Portuguese consumers. This work is based on a mixed methodology in which the evaluation of consumers' behaviours, assessed through a self-reported questionnaire composed of

FWA and evaluation of rice frequency consumption, was complemented by in-depth interviews. This paper complements Paper I with deeper research on the topic supported by thematic analysis of in-depth interviews until saturation. The results showed that, although the GI concept was unknown to half of the participants, it was perceived as interesting and positive for healthy eating. Consumers showed concern about the taste and naturalness of the product, preferring it to be as close to a homemade dish as possible. The negative perceptions we verified were attributed to a lack of knowledge of the GI concept. Therefore, awareness and informative campaigns are recommended to promote low GI rice products.

Paper III aimed to evaluate the overall liking, sensory profile, and well-being perception of different ready-to-eat rice (RTE-rice) types, and to understand the effect of product information before consumption on liking and well-being perception. This study introduced a quantitative well-being perception evaluation of RTE-rice products, enhancing the understanding of how varieties and ingredients affect well-being and liking. These results allowed us to understand that some ingredients and the state of rice processing (whole grain or milled) are critical factors in the liking and well-being of ready-to-eat rice. It confirms that consumers prefer RTE-rice, which is closer to the conventional rice they use.

In paper IV, important packaging attributes for the acceptance of a low GI rice product were evaluated, namely, variety, processing, and label information. The results showed that processing significantly influenced the willingness to try RTE rice, revealing consumers' greater preference for whole grain than for milled rice with added bran. Claims had the least relevant importance; however, "low GI" had a positive impact, indicating its potential to influence consumer purchasing attitudes and promote healthier rice consumption. Participants were segmented into three groups based on consumer attitudes, where naturalness-oriented and convenience-oriented groups were more likely to try ready-to-eat rice.

This work covered Portuguese rice consumption habits, allowing an understanding of the behaviour during the rice-provisioning process (from acquisition to consumption practices) and providing important and specific insights at each point of consumer interaction with the product. It has been confirmed that rice continues to be a staple food in Portugal, widely used as a side dish or main dish, and appreciated for its sensory properties that bring delight and pleasure to consumers. When selecting new rice

varieties, Portuguese consumers prioritized sensory aspects, price, and convenience as the most important factors to consider.

It was concluded that although low GI rice incites something new, consumers generally have a positive perception of its functional/utilitarian value as opposed to the sensorial dimension. As traditional habits (familiarity), sensory attributes, and naturalness have been highlighted as drivers of choosing low GI rice, food manufacturers must be careful to offer healthier rice products that resemble conventional rice dishes that are sensorially appealing. It is essential to employ natural processing technologies and to incorporate sustainable natural ingredients that are commonly used in everyday cooking.

This research project used different statistical analyses to interpret data originating from different data collection methods. The results and discussion reveal essential information for stakeholders to promote and develop healthier ways of consuming rice. Moreover, it provides initial insights into the perception of carbohydrate-rich foods with GI labelling in Portugal.

Keywords: rice, glycaemic index, ready-to-eat rice, rice consumer habits, rice dishes, well-being, nutrition, naturalness, convenience.

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List of Abbreviations

CA	CONJOINT ANALYSIS
CATA	CHECK-ALL-THAT-APPLY
CFLS	CONVENIENCE FOOD LIFESTYLE
CHO	CARBOHYDRATE
DRVS	DIETARY REFERENCE VALUES
EFSA	EUROPEAN FOOD SAFETY AUTHORITY
FAO	FOOD AND AGRICULTURE ORGANIZATION
FWA	FREE WORD ASSOCIATION
GI	GLYCAEMIC INDEX
GIF	GLYCAEMIC INDEX FOUNDATION
GL	GLYCAEMIC LOAD
ICQC	INTERNATIONAL CARBOHYDRATE QUALITY CONSORTIUM
IDF	INTERNATIONAL DIABETES FEDERATION
MDA	MULTIDIMENSIONAL ALIGNMENT ANALYSIS
NNS	NEW NATURALNESS SCALE
RS	RESISTANT STARCH
RTE-RICE	READY-TO-EAT RICE
SPSS	STATISTICAL PACKAGE FOR SOCIAL SCIENCES

Chapter 1 - General introduction

Rice (*Oryza sativa* L.) is a grain widely consumed worldwide. It is the third largest food crop (1st wheat, 2nd maize) in production; though, about 78% of its production is intended for human consumption, compared to 64% and 14% for wheat and maize, respectively (Rice Knowledge Bank, 2018).

Rice provides approximately 25% of the daily caloric needs of the world's population, whereas wheat and maize supply 19 and 5%, respectively (Birla et al., 2017; FAO, 2023; Fitzgerald et al., 2009a; Jones & Sheats, 2016). Rice accounts for 60 to 70% of energy intake for more than 2 billion people in Asia and has become critical for food security in Latin America and Africa (Mohidem et al., 2022). In twenty-four countries, rice provides at least one-third of the daily caloric intake, that is, 70 kg *per capita* per year or 200 g per day (Piccoli et al., 2012). Therefore, rice has been viewed over the years as a solution to eradicate hunger in countries with limited resources (Yadav & Kumar, 2018). In addition to its role in food security, rice is considered one of the most strategic commodities because of its low price and high yield, being the subsistence for many families in the rural areas of developing countries (Yadav & Kumar, 2018). It is also an excellent vector to be fortified with micronutrients (Dipti et al., 2012).

The amount and nature of carbohydrates present in rice (rich in starch) makes it a fast-digesting food, causing a rapid increase in blood glucose after ingestion (Foster-Powell et al., 2002; Jenkins et al., 1981). The human digestive tract hydrolyses starch to produce glucose, which is used by cells to produce energy for metabolic functions and excess energy is stored as glycogen/fats for later use (Reynolds et al., 2019).

High rice consumption has been associated with non-communicable chronic diseases such as diabetes, obesity, and cardiovascular disease (Golozar et al., 2017; Hu et al., 2012; Jenkins, Kendall, Augustin, Franceschi, et al., 2002; Meyer et al., 2000; Saneei et al., 2017; Se et al., 2015; Seah et al., 2018). According to the International Diabetes Federation, it is estimated that 463 million individuals worldwide are living with diabetes, and this figure is expected to increase to 700 million by 2045 (IDF, 2021). Portugal ranks second among European Union countries, in terms of diabetes prevalence, affecting 13.6% of the population aged between 20 and 79 (Bhavadharini et al., 2020).

Thus, it is vital to develop and enhance sustainable food-focused interventions to address increasing health concerns that have significant socioeconomic consequences (Jukanti et al., 2020; WHO, 2013). The EAT-Lancet Commission (2019, 2023) emphasizes making staple foods healthier as a key component of its comprehensive action plans, aimed at

transforming food systems and promoting sustainable and nutritious diets (Willett et al., 2019, 2023).

The theme of this doctoral thesis falls within the scope of the Arroz-BIG Project financed by the European Regional Development Fund (ERDF) through the Operational Program Portugal 2020 / Compete 2020. The Arroz-BIG project involved the collaborative work of five entities (four universities and one company) using the concept of integrated action throughout the entire chain, allowing results to be obtained in each element of the chain in addition to integrated results. The overall aims of the project was to develop a rice product with a low glycaemic index (GI), due to the increase of a market segment concerned with controlling energy intake, often due to health-related issues such as obesity, diabetes, and other chronic diseases and on the other hand, due to concerns about the sustainability of the national rice sector, as Carolino rice varieties are those that best adapt to the country's soil and climate conditions, as well as the preservation of the Portuguese gastronomic heritage, which is characterised by numerous dishes with Carolino rice as the base. For example, to obtain desirable sensory characteristics in a dish of *malandro* rice[1], Carolino rice must be used; just as in Italy, to obtain a good risotto, a specific rice must be used for this purpose.

Several methods have been suggested to achieve low GI rice, including genetic modifications (Fitzgerald et al., 2009b; Fitzgerald et al., 2011; Huang & Hu, 2021; Mohan, Anjana, et al., 2016). However, this has negative effects on yield and culinary and textural properties (Jukanti et al., 2020). Therefore, the most effective way to address the issue of reducing the GI of rice may be through formulation and processing.

Ready-to-eat rice (RTE-rice) poses a challenge in terms of consumer acceptance. As it is a staple food that they are used to eating traditionally. For this reason, depending on the market, it can generate interest or complete disinterest. Dixon et al. (2020) identified the lack of knowledge of consumer attitudes towards RTE-rice as one of the barriers to successful acceptance of RTE-rice; therefore, conducting consumer-focused studies to understand their perceptions and expectations regarding GI concepts and low GI products is important.

The Arroz-BIG project involved several stakeholders, with the Faculty of Sciences of the University of Porto (FCUP) playing a key role. Specifically, the FCUP was tasked with assessing consumer perceptions of low GI rice products, as the success of these products

[1] *Malandro* rice is a typical gastronomic practice of Portuguese cuisine, traditionally made with Carolino rice (long grain Japonica variety) cooked in plenty of water, which results in a creamy dish with a lot of broth rich in flavour derived from the added ingredients, such as vegetables, meat, fish, or seafood.

depends not only on their low GI rating but also on the values that consumers attach to them. To this end, the FCUP's research into consumer perception was comprehensive, including sensory studies, attitudes, preferences, and evaluations of product images. This multidimensional approach addresses both affective and cognitive factors that influence the decision-making process, thereby providing a comprehensive understanding of the complex dynamics involved.

In product development, the primary objective is to gain an understanding of consumer behaviour, attitudes, and values to create a product that meets expectations and needs through a process known as consumer-driven development (Linnemann et al., 2006). To achieve this goal, a methodology has been developed that incorporates various data collection techniques to complement or validate information.

This study focuses on the consumer perspective of rice and low GI rice, excluding the processing and measurement of GI. The findings provide input for the development of low GI rice products, as well as an understanding of how to communicate/report the use of GI information as a beneficial tool in the management of metabolic syndrome.

1.1. Objectives

This work aimed to characterize Portuguese rice consumer habits and to develop and evaluate the sensory profiles and the importance of the extrinsic characteristics of healthy RTE-rice using a mixed methodology. This study has the broad purpose of promoting healthier forms of rice consumption and the consumption of local Carolino rice, two characteristics that seem ambivalent, given the high GI of *Carolino* rice and the high frequency of *per capita* consumption of rice. Specifically, the following were intended:

- To evaluate Portuguese consumer habits and behaviour towards rice and its varieties.
- To determine the sensory profile of ready-to-eat low GI rice products.
- To assess the perception of well-being associated with rice and rice products with a low GI.
- To evaluate the impact of the best combination of packaging elements, namely, rice type, processing, and information (nutritional claim vs. GI claim) on willingness to try.
- To evaluate the importance of the perception of naturalness, wellbeing, and convenience orientation in the preference for RTE-rice.

1.2. Thesis structure

This thesis is organised into four chapters. This chapter includes a general justification for the study as well as the objectives and structure of the work. Chapter II includes the state-of-the-art grouped according to the two major topics of the framework: I - Rice and II - Consumer perception and preference. The “Rice” topic includes the state-of-the-art reflecting its production/cultivation, quality criteria, composition, and consumption habits. In the “Consumer” topic the methodology of consumer perception was considered. Chapter III contains the results of this research, which are presented in four research papers arising from this PhD project. Chapter IV provides an overview discussion of the findings, future work, and conclusions. This study was conducted using a mixed-methods integrative approach with four tasks; these were carried out sequentially, with the completion of earlier tasks serving to inform and support subsequent tasks, as illustrated in Figure 1.

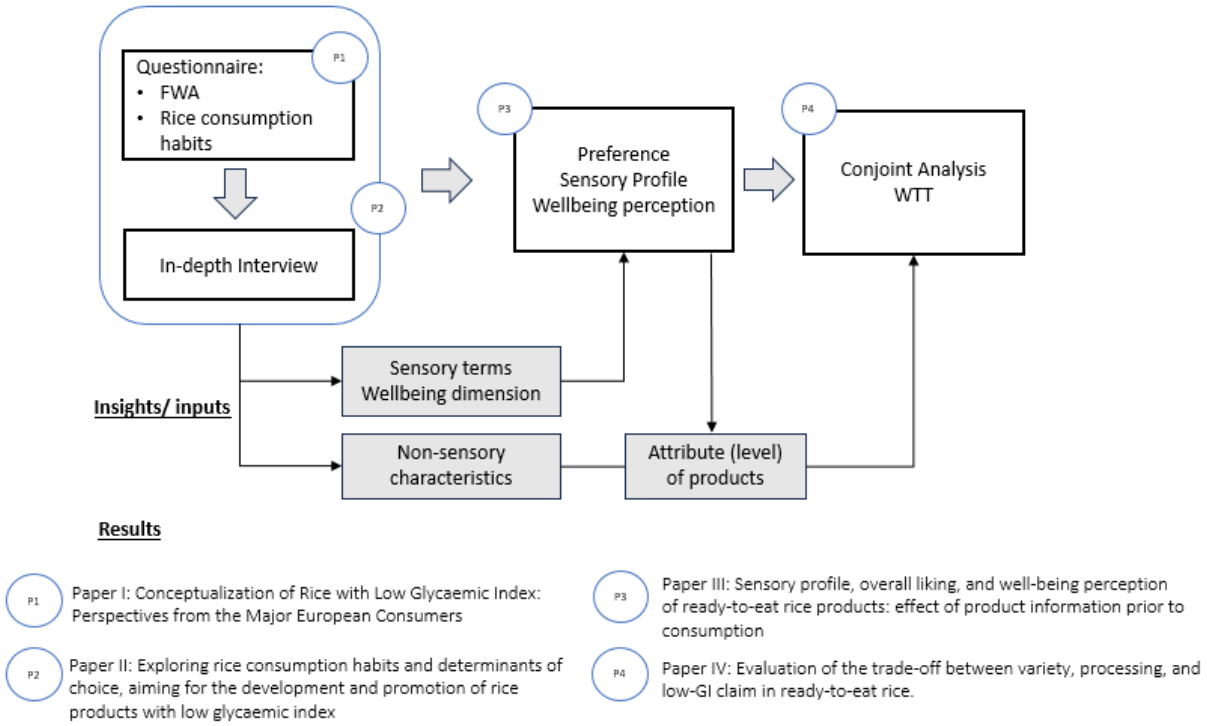

Figure 1 – Overview of the methodological approach and results by task.

Chapter 2 – Framework

I. Rice

2.1. Origin, cultivation, and variety of rice

Rice is estimated to have been domesticated in Southeast Asia between 9,000 and 13,000 years ago (Fuller et al., 2010; Lu et al., 2022; Molina et al., 2011; Vaughan et al., 2008). However, the exact location of the beginning of cultivation is controversial, with several nations claiming this role as rice is rooted throughout Asia and has become a cultural identity in several countries on this continent (Fuller et al., 2010). Nevertheless, the earliest archaeological evidence comes from Central and Eastern China and dates from 7,000 to 5,000 BC (Britannica, 2022).

There are more than twenty wild species of the genus Oryza, but only two are cultivated. *O. sativa*, which is cultivated in Asia and is widespread throughout the world, and Oryza *glaberrima*, which is cultivated in West Africa (Vaughan et al., 2008). Japonica and Indica are the main subspecies of *Oryza sativa* (Fuller et al., 2010). The spread of Japonica rice to different regions resulted in the emergence of two distinct ecotypes: the cultivar that moved from Southern to Northern China became Temperate Japonica rice, and the cultivar that moved from South Asia to Southeast Asia and from there to West Africa and Brazil became Tropical Japonica (Khush, 1997). Indica subspecies are usually divided into two subpopulations: Indica and *Aus*. Domestication of the Indica subspecies is thought to have begun in Eastern India, in the foothills of the Himalayas, while that of the Japonica subspecies began in China.

Rice was known in Europe in 329 BC, brought back by Alexander the Great after his expedition to India. However, culture was only introduced in the Iberian Peninsula by the Arabs in the 7th century. In Portugal, during the reign of D. Dinis (1279-1325), there were the first written references to the cultivation of rice, which at that time was reserved for the nobility. Cultivation began in *Baixo Mondego*, in *Montemor-o-Velho* (Silva, 1969). During the reign of D. José I (1750-1777), this crop received a strong boost in terms of production (18th century), with the swamp lands and the regions of the estuaries of the main rivers being used for its cultivation (Silva, 1969). However, the real expansion of the crop occurred around 1909, following the establishment of rules for land preparation and the improvement of irrigation and drainage techniques, when different varieties of rice began

to be cultivated. From the 1920s onward, rice began to play an increasingly important role in the Portuguese diet (Brites et al., 2006).

Rice is an herbaceous plant that belongs to the grass family (*Poaceae*) and the monocotyledonous class. It is well adapted to hot and humid areas and aquatic environments. It can be grown by irrigation or in rainfed conditions, where it is much more dependent on abiotic conditions. It is usually an annual crop, but in the tropics, it can survive as a perennial plant, producing new tillers after harvest (GRISP, 2013). Rice plant growth takes 3 to 6 months, depending on the sowing season, growing region, varieties, and soil fertility conditions (Juliano, 2016a). This growing cycle can be divided into two phases: vegetative (including germination, initial seedling growth and tillering) and productive (including panicle initiation and maturation phases) (GRISP, 2013).

The plant has thin, long, and fibrous roots that allow it to be quickly anchored to the ground, from which it produces numerous stems formed by a series of nodes and internodes, and several stalks with well-marked nodes, covered by the leaf sheaths that surround them. The plant is characterised by long, thin leaves, with multiple inflorescences at the end, known as panicles, from which the seeds that give rise to the rice grains are produced. Rice is harvested when the moisture content of the panicles is between 18% and 22%, and it is considered that a moisture content of 14% is adequate for the safe storage of the grains. This parameter is particularly important for the preservation and processing of the grain (GRISP, 2013).

→ Rice grain structure

The rice grain has four layers: the husk/hull, the bran, the germ /embryo, and the endosperm. The husk accounts for about 20% of the grain´s weight and acts as a protective layer, containing antioxidants that protect the seed from oxidative stress. The bran represents 5-8% of the weight of brown rice and 10% of paddy rice. The bran is formed by the pericarp, tegument, and aleurone, and contains fibres, lipids, proteins, vitamins, and minerals and is a good source of bioactive phytochemical compounds with beneficial health properties (Sharif et al., 2014; Tan et al., 2023). Brown rice is obtained by separating the husk from the bran, while milled rice also removes the bran layer to improve consumer acceptance, as the bran prevents the starch granules from swelling during cooking. The milling process also removes the germ from the rice, reducing its nutritional value and improving its shelf life (Bhattacharya, 2013).

The endosperm forms most of the grain (89-94% of brown rice) and consists of starch-rich cells with some protein bodies. The germ is located on the ventral side at the base of the

grain and is rich in proteins and lipids, making up 2-3% of the whole grain (Juliano, 2016a). Figure 2 shows the rice grain anatomy. The percentages of husk/bran/endosperm of the grain are only reference values as this composition varies according to the rice variety, the pre-treatment of the rice before blanching/husking, the type of blanching/system and the degree of husking/bleaching (Sharif et al., 2014).

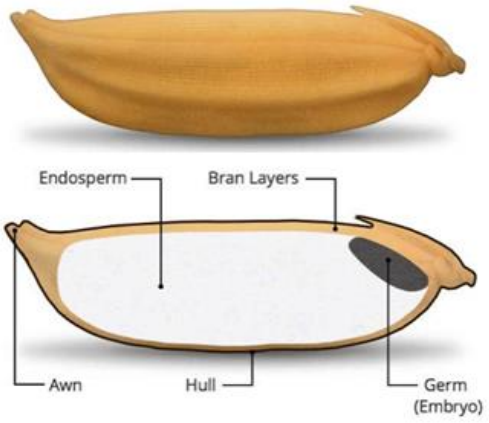

Figure 2 - Structure of rice grain, outside and inside.
Source: Riceland (2020)

→ Rice grain varieties

There are about 100,000 varieties of rice, of which only a small proportion is widely cultivated (Brites et al., 2006). The indica subspecies accounts for 80% of rice production and is widely grown in Asia, while the Japonica subspecies is grown and consumed mainly in Australia, China, Taiwan, Korea, the European Union, Japan, Russia, and the USA (OECD-FAO, 2021).

Rice can be classified according to its physical state, which is related to the postharvest or pre-processing treatment it receives before being marketed. It can therefore be classified as: (i) Paddy/rough rice is rice wrapped in husk after threshing; (ii) Husked rice (whole grain or semi-husked) is rice from which only the husk has been removed; (iii) Semi-milled rice is rice from which the husk, part of the germ and all or part of the outer layers of the pericarp, but not the inner layers, have been removed; (iv) Milled rice is rice from which the husk, all of the outer and inner layers of the pericarp and all of the germ (in the case of long-grain and medium-grain rice) or at least a part of the germ (in the case of round-grain rice) have been removed, but from which longitudinal white streaks may remain on not more than 10 % of the grains.

The classification of varieties is based on physical properties, such as size, shape and colour, and chemical properties, such as the amount and type of carbohydrate in the grain (amylose/amylopectin ratio), which determines the cooking behaviour of rice (Brites et al., 2006). The Codex Standard 198-1995 establishes the classification that traders must adopt for husked rice, milled rice, and parboiled rice intended for direct human consumption, presented in packaging, or sold in bulk directly to the consumer. This Codex standard establishes three specification options for this classification in which traders must indicate the chosen option:

1. Kernel length: medium-grain rice - kernel length of 6.6 mm or more; medium-grain rice - kernel length of 6.2 mm or more, but less than 6.6 mm; short-grain rice - kernel length of less than 6.2 mm.
2. Kernel length/width ratio: Long grain rice - husked rice or parboiled husked rice with a length/width ratio of 3.1 or more, or milled rice or parboiled milled rice with a length/width ratio of 3.0 or more; Medium grain rice - husked rice or parboiled husked rice with a length/width ratio of 2.1–3.0, or milled rice or parboiled milled rice with a length/width ratio of 2.0–2.9; short grain rice - husked rice or parboiled rice with a length/width ratio of 2.0 or less, or milled rice or parboiled milled rice with a length/width ratio of 1.9 or less.
3. Combination of the kernel length and the length/width ratio: Long grain rice - kernel length greater than 6.0 mm and length/width ratio greater than 2 but less than 3, or kernel length greater than 6.0 mm and length/width ratio equal to or greater than 3. Medium grain rice - kernel length of more than 5.2 mm but not more than 6.0 mm and a length/width ratio of less than 3. Short grain rice - kernel length of 5.2 mm or less and a length/width ratio of less than 2.

Rice varieties contain starch with varying amounts of amylose and amylopectin, which are the main factors influencing food quality. Starch is a polymer of glucose units with covalent linkages of the α-(1,4) type, which gives rise to amylose, and of the α-(1,6) type, which is found in amylopectin. Amylose has a constant linear shape, whereas amylopectin has a highly branched structure due to the presence of both α-(1,4) and α-(1,6) bonds, (Sanders & Lupton, 2012).

According to starch content and type (amylose vs. amylopectin), rice is classified as: waxy (1-2% amylose), very low (2-9% amylose), low (10-20% amylose), intermediate (20-25%) and high (25-33% amylose) categories (IRRI, 2006; Li et al., 2016). Japonica rice tends to

be low amylose, tropical japonica tends to be intermediate or high, and Indica rice falls into all amylose classes (IRRI, 2006).

In Portugal, the marketing conditions and the characteristics of commercially suitable rice grains and their designation are currently established by D.L. 157/2017. Within the naturally occurring rice varieties, commercial rice varieties are designated according to the size of the grains, their culinary suitability, and the type of treatment they have undergone. Regarding the size and shape of the grains, Portuguese legislation distinguishes three categories of rice: (i) round grain rice (grain length < 5.2 mm, length/width ratio < 2); (ii) medium grain rice (grain length between 5.2 mm - 6.0 mm, length/width ratio < 3); (iii) long grain rice “Category A” (length > 6.0 mm, length/width between 2-3) and long grain rice “Category B” (length > 6.0mm, length/width ≥ 3).

Depending on the type of treatment, rice can be characterised as follows:

- Brown rice (wholegrain): dehusk rice which contains bran layers and germ, therefore retaining additional fibre, vitamins, and minerals that are retained in the bran layer. All grain types (short, medium, and long) can be prepared as whole-grain rice.
- Milled/polished / white rice: rice from which the husk is removed, and which undergoes a polishing process. During the whitening process, in addition to the husk, the rice loses the film (bran layer), where most of the minerals and vitamins are concentrated, leaving few nutrients in the grain.
- Parboiled rice: rice that has undergone a series of pre-treatments such as immersion in water, steaming and drying, before being processed industrially for human consumption. The final product has completely gelatinized starch. Any variety can undergo this process, but *Agulha* is more commonly used.
- Pre-cooked rice: rice that has undergone a physical treatment to significantly reduce the cooking time.
- Glazed rice: milled rice wrapped in a film of glucose and talc suitable for human consumption. This category also includes milled rice wrapped in a layer of edible oil following current legal and regulatory standards.
- Puffed rice - also known as "rice popcorn", brown or blanched rice, which is subjected to high pressure and heat, forcing the grain to expand due to the loss of moisture inside the grain, making it swollen/inflated and fluffy, and can be used in cereal bars, crackers, or other products.

In addition to these commercial classifications, there are two more common sales names in Portugal: *Carolino* rice, which is the most produced variety in Portugal and belongs to

the long-grain japonica subspecies, and *Agulha* rice, which belongs to the indica subspecies. The *Carolino* Rice produced in Portugal includes the following varieties: *Ariete*, *Ceres*, *Diana*, *Euro, Luna Clearfield, Ronaldo*, *Presto*, *Teti* and *Caravela*, which is the latest Portuguese variety to be included in the National Catalogue of Varieties (2021) (Agriterra, 2022). Varieties closer to the indica subspecies have also been produced, such as *Maçarico*.

The Portuguese market also has more exotic varieties, mostly imported, which are characterized by their culinary suitability and form a commercial group categorized as "specialities", such as:

- Basmati: Indica aromatic rice, very slender, considered of high quality, produced in India and Pakistan. It has an intense and pleasant characteristic natural aroma, and its long grains, when cooked, are dry and slender, with a very white colour, and must expand to at least twice their initial length.
- Jasmine: Indica long-grain rice, known for its natural jasmine flavour, comes from Thailand and Vietnam. It differs from Basmati rice in that it has a stickier texture and is not as dry and expansive. The flavour of aromatic rice is imparted by the natural aromatic compound 2-acetyl-1-pyrroline (2AP), which is reminiscent of the scent of pandan leaves, popcorn, and nuts (Wakte et al., 2017). This compound was discovered by Buttery and co-workers in 1982.
- Rice for risotto: varieties such as Arbóreo, Carnaroli, and Vialone Nano, which have rounded and short grains with white, non-crystalline parts. It is a Japonica subspecies with low amylose content, high amylopectin content and high-water absorption capacity and is firm and creamy after cooking.
- Glutinous or waxy rice: typical of Asian cooking, characterized by short, round, dull, and white grains with a maximum amylose content of 1 to 2%. It has a special cooking process; it is soaked for some time, steamed, and then cooked to make it viscous and sticky.
- Wild rice: These are the seeds of a wild aquatic plant from North America, belonging to the species *Zizania aquatica* and *Zizania palustris*. The beans were long, slender, and black in colour. It is commercially presented as "rice," although it is not of the *Oryza sativa* L. species and is usually sold mixed with other varieties such as Basmati. Historically consumed in China, wild rice is a delicacy in North America for its flavour and nutritional value and has spread to Europe, with production in Hungary.

- Pigmented rice: has a natural colour and is usually eaten or unhusked. Black varieties can be either glutinous or aromatic, and their dark colour is due to the presence of a powerful antioxidant, known as anthocyanin. These rice varieties are native to various regions of Asia including Thailand, China, and Indonesia. Red rice varieties also have a reddish layer of bran instead of a typical brown layer. Both Indica and Japonica subspecies boast red varieties (Carcea, 2021).

2.2. World and Portuguese rice production data

Rice is a global crop, grown on five continents in 116 countries, in both tropical and temperate regions. The total area under rice cultivation is estimated at 158.5 million hectares, resulting in a production volume of 753,411 million tonnes of paddy rice (FAO, 2023).

During the 1960s and the 1970s, rice underwent intensive genetic improvement to increase production and yield, mainly in developing countries, especially in Asia. It began to be produced more intensively, transforming traditional production systems through greater investment in labour and financial capital. This phenomenon became known as the Green Revolution, which brought about profound changes in food security in low-income countries (GPP, 2016). Over the years, new varieties have been developed, with improvements in agronomic, technological, commercial, and eating quality characteristics. The complete sequencing of the rice genome in 2002 accelerated the use of molecular markers for these improvements (Juliano, 2016a).

Between 1961 and 2019, world rice production increased, from around 215 million tonnes to around 750 million tonnes. The Green Revolution played a crucial role in this growth, leading to a significant improvement in global productivity, which increased from less than 2 to 4.66 tons/hectare. In North America and Europe, productivity is higher than the world average. Productivity gains have been achieved with high-yielding varieties, improved irrigation systems, and the adoption of new farming techniques (Bin Rahman & Zhang, 2022). From 2002 to 2022, the area under cultivation will increase slightly by 13%, global production will increase by about 36% and productivity will increase by about 20%. According to the OECD-FAO Agricultural Outlook, milled rice production is expected to increase by 11.4% to 567 million tonnes by 2030 (FAO, 2023; USDA, 2022).

Approximately 90% of the world´s rice production comes from Asia, which is home to the world's top ten rice-producing countries. China, India, Bangladesh, and Indonesia are the

world's four largest rice producers, with recorded productions of 214, 195, 57, and 54 million tonnes, respectively (FAO, 2023).

Europe accounts for only 0.5% of global rice production (FAO, 2023). The European production area is 430 000 ha, and a 2.3% decrease in this area is estimated by 2030, resulting in an 11% increase in imports (GPP, 2020). Forecasts point to a decline in the global area under cultivation, particularly in countries with a significant urbanization process, where there is a lack of skilled labour and water scarcity. As a result, the pace of growth in rice production is expected to slow, with Asian production expected to increase by only 1% (USDA, 2022). According to the OECD-FAO Agricultural Outlook, by 2030, production in the most developed countries should remain stable or decline, and the area under cultivation of the main Asian producers, namely China, India, and Vietnam, will decrease; however, global production will increase due to improvements in yields.

The largest European rice producer is Italy, followed by Spain, which together account for approximately 80% of European rice production, followed by Greece and Portugal. The main rice varieties produced in Europe belong to the japonica subspecies, but due to market demand, the production of a long and conical bulk rice variety like the indica type also started in the 80s (sustainableeeurice.eu, 2020). These hybrid varieties of Indica and Japonica, with biometrics like those of Indica rice, are being developed to adapt to temperate climates, which are more suitable for Japonica rice production. Currently, 75% of the rice produced in the EU is of the Japonica subspecies and the remaining 25% is of the Indica subspecies, to supply the market in Northern European countries (GPP, 2020).

Portugal, the fourth largest European producer, has a cultivated area of 29,000 hectares, which corresponds to the production of 175.9 thousand tonnes of paddy rice or approximately 123 thousand tonnes of milled rice (Agriterra, 2022; INE, 2022).

According to the FAO data, between 2010 and 2021, rice production in Portugal was irregular, with constant increases and decreases. Between 2017 and 2018, there was a more pronounced decrease in production of 11%, with the largest increase between 2020 and 2021 (Figure 3).

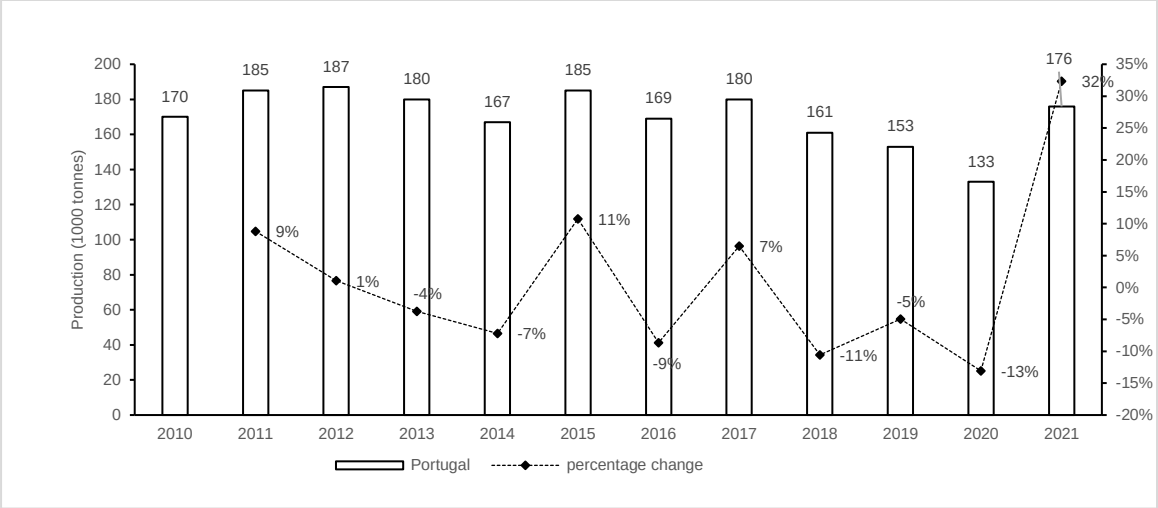

Figure 3 - Evolution of rice production in Portugal (2010-2021).

Data source: FAO (2023)

National data show a decrease in the area under rice in Portugal over the years; however, this decrease has not affected production, as the productivity of cultivated areas has remained stable owing to improvements in seeds, technology, growing conditions, and processing (GPP, 2020). In 2021, production increased by 8.5% compared to the average production of the last five years, due to the increase in the area sown in Vale do Sado following the requalification of the irrigation infrastructure. However, in 2022, the cultivated area decreased by 7% compared with the previous year (INE, 2022).

The production areas are concentrated in the Tagus and Sorraia (55 %), Sado (24%), and Mondego (21%) valleys. *Carolino* long A varieties account for 77 % of the sown area, *Agulha* (long B/indica) for 12%, medium varieties for 10%, and round varieties for 1% of the total sown area. The national average yield is around 6.0 tonnes per hectare (Agriterra, 2022; Almeida et al., 2023).

Due to soil and climate conditions, Portugal mainly produces *Carolino* rice, a Japonica subspecies; however, the market demand for indica rice has increased and consumers prefer *Agulha* rice. As a result, some *Carolino* rice (*Oryza sativa* japonica) production areas have been converted to *Agulha* rice (*Oryza sativa* indica), particularly in the Alentejo region (Rio Sado). Of the national rice production, 87% corresponds to japonica rice (commercial type *Carolino*, identified as long grain A) and 8% to indica rice (commercial type *Agulha*, long grain B) (GPP, 2019).

2.3. World rice consumption

Rice is a staple food and a major source of energy for more than half of the world´s population, accounting for about 21% of the calories and 14% of the protein ingested globally (FAO, 2018). Of the three major cereal crops (wheat, maize, and rice), rice accounts for the largest share of production for human consumption (Awika, 2011). Consumers typically consume rice in its cooked grain form, with only a small percentage processed into flour or flakes (Mohapatra & Bal, 2012; Park et al., 2012; Srisawas & Jindal, 2007).

The global average rice consumption from 2010 to 2021 was 80.5 (± 1.3) kg *per capita* per year. Figure 4 shows global rice consumption by continent. About 90% of rice consumption is accounted for by Asian countries, followed by remarkable differences between the African and American continents (see Figure 4). Although China has the largest domestic supply of rice (205,973,000 tonnes) and high consumption (127.7 kg/capita/year), it does not rank among the top ten global rice consumers, which are all Asian countries. According to the Food and Agriculture Organization of the United Nations (FAO, 2023), the three largest rice consumers in the world are Bangladesh (261 kg *per capita* per year), Cambodia (258 kg *per capita* per year), and the Lao People's Democratic Republic (223 kg *per capita* per year).

Europe has the lowest rice consumption. European countries have an increasing preference for this food, where consumption is much higher than production, making Europe the fourth-largest importer in the world. Imports are mainly Indica rice, which is growing strongly; the main importers are the United Kingdom (12%) and France (8%), which import mainly Basmati from India and Pakistan (GPP, 2020).

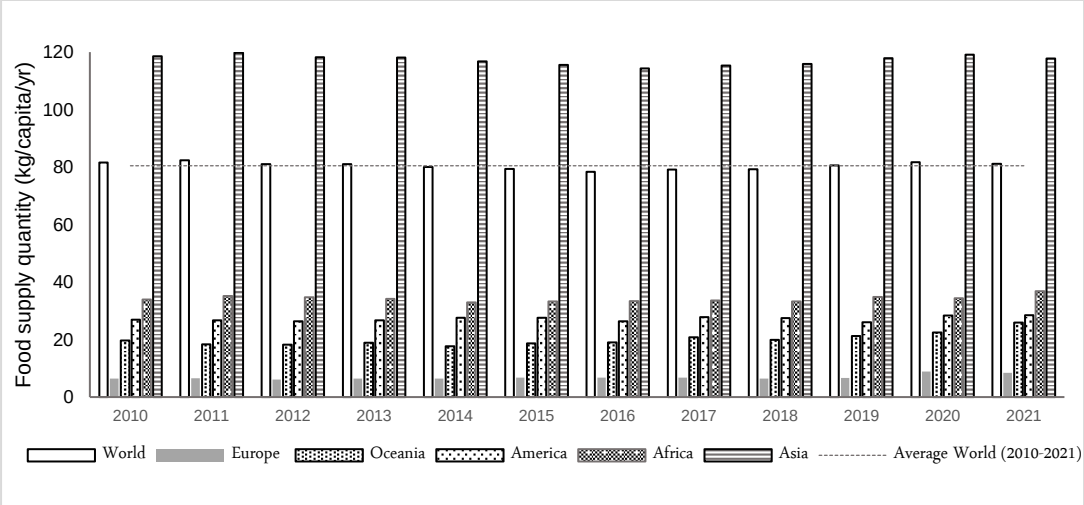

Figure 4 - Comparison between world rice consumption and rice consumption by continent, between 2010 to 2021.
Data source: FAO (2023)

Data from 2005 to 2020 and projections up to 2030 for the European Union, highlight the increase in *per capita* rice consumption and imports due to the growing popularity of rice, including aromatic and long-grain rice (European Commission, 2020).

From 2010 to 2021, the region recorded its lowest consumption rate of 6.2 kg/capita/year in 2014, and its highest rate of 8.9 kg/capita/year in 2020 (as shown in Figure 5). Throughout this period, consumption patterns in Europe are characterized by irregular fluctuations, with the largest increase in consumption occurring between 2019 and 2020, followed by the largest decrease between 2020 and 2021 (FAO, 2023).

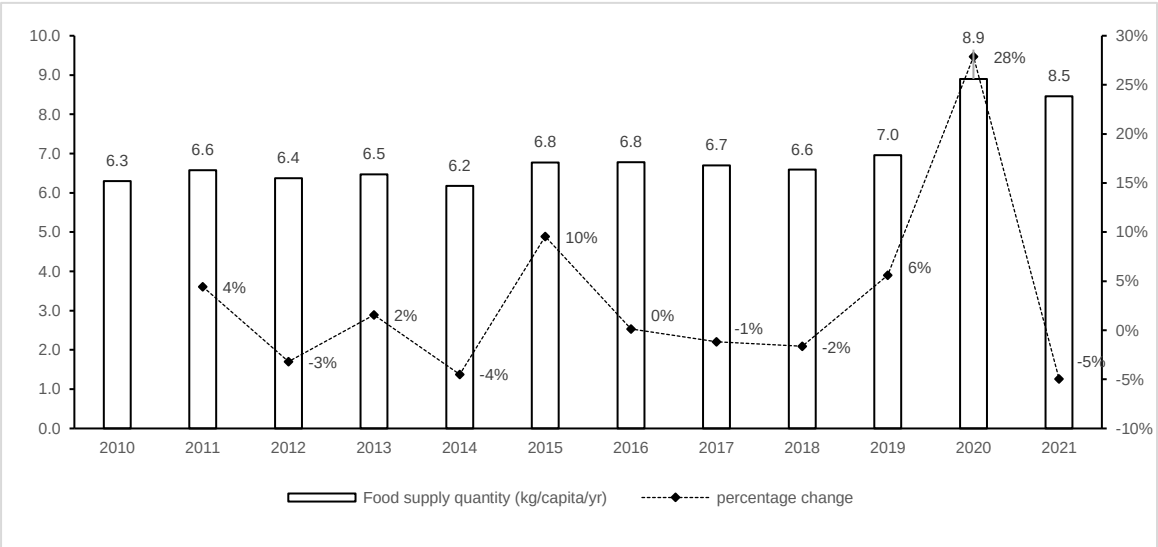

Figure 5 - Europe's evolution of *per capita* rice consumption (kg/*capita*/year) between 2010 and 2021.
Data source: FAO (2023)

The current *per capita* consumption of rice in the European Union countries (27) is 8.6 kg per year, which is comparable to the average consumption of the continent in 2021 according to the Food and Agriculture Organization (FAO) (Figure 6). For many years, Southern European countries have been the largest consumers of rice, but recent data show that there have been significant changes in consumption patterns. For example, the Netherlands has almost tripled its rice consumption between 2010 and 2021, from 5.9 kg/capita/year to 15.3 kg/capita/year. In addition, other Nordic countries such as Finland, Sweden, Denmark, and Austria have recorded consumption levels above the EU average, confirming the projections that stated the trend towards greater rice consumption in European countries that are not typically rice consumers due to the diversification of traditional diets (European Commission, 2016).

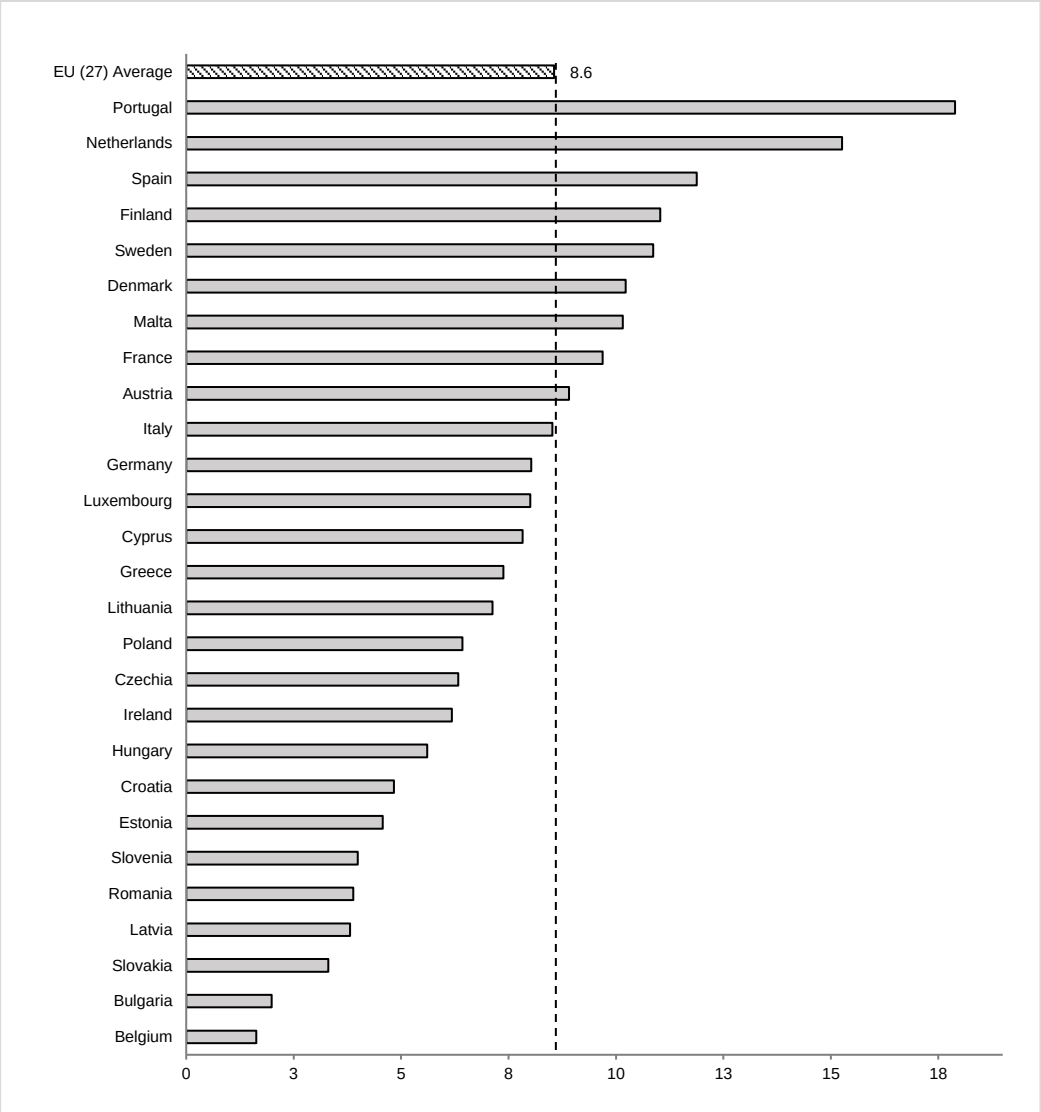

Figure 6 - Average rice consumption (kg/capita/year) of EU countries. The dashed line corresponds to the average *per capita* consumption in the European Union.
Data source: FAO (2023).

2.4. Portuguese rice consumption

Portugal is the largest rice consumer in Europe, with an average of 18 kg *per capita* in 2021. The most significant decrease in rice consumption in Portugal was observed between 2018 and 2019, followed by an increase in rice consumption of almost 50% between 2019 and 2020 (Figure 7).

However, despite being the first European consumer, Portugal's consumption has been declining. The latest data (2021 consumption: 18 kg/capita/year) reflect a 25% decrease compared to the *per capita* consumption in 2010 (24 kg/capita/year). There are various reasons for this behaviour, one of which could be dietary diversification, a common trend in Europe, where the quantity of food consumed has decreased and the variety of foods consumed has increased (European Commission, 2016; Gracia & Albisu, 2001). This diversification is manifested in the increased production and purchase of specialized products, including new and exotic rice varieties.

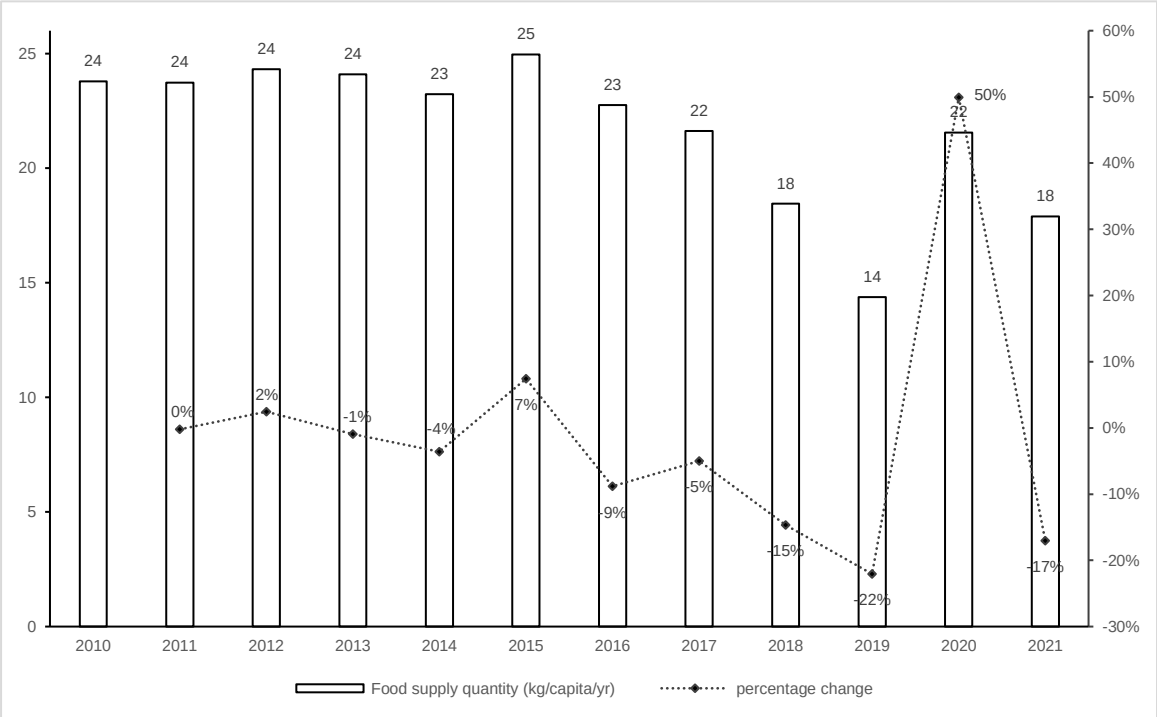

Figure 7 - Evolution of rice consumption in Portugal in the last decade (kg/*capita*/year).
Data source: FAO (2023)

→ Rice as Staples in Portugal

In the 18th century, rice cultivation was encouraged by D. José I (1714-1777), which led to its spread to the country´s major estuaries and its subsequent rise in popularity as a staple food (Faísca et al., 2021).

Staple foods are foods that provide a significant portion of a population's daily energy needs and are regularly consumed (Su et al., 2017). These foods are typically consumed at each meal and account for approximately 90% of global calorie intake (FAO, 2010). The main staple groups include cereals (e.g., rice, wheat, oats, and maize), pulses, seeds, nuts, roots, and tubers; rice, maize, and wheat account for two-thirds of global consumption. However, staple diets vary between cultures and countries due to factors such as climate and economics, which affect food availability and accessibility (FAO, 2010).

The diet of individuals in Western Europe is mainly composed of animal products, cereals, roots, and tubers (FAO, 2010). Figure 8 shows the apparent values of kilocalories *per capita* per day derived from specific staple foods and their estimated relative contributions to the total caloric intake in the EU and Portugal. The data in this figure were calculated from the food supply data (kcal/capita/day) for each food item available on the FAO Food Balance Sheets (2020). To calculate the contribution to daily caloric intake (%), the total daily calorie intake was 3511 kcal/capita/day and 3524 kcal/capita/day for EU and Portugal, respectively (FAO, 2020).

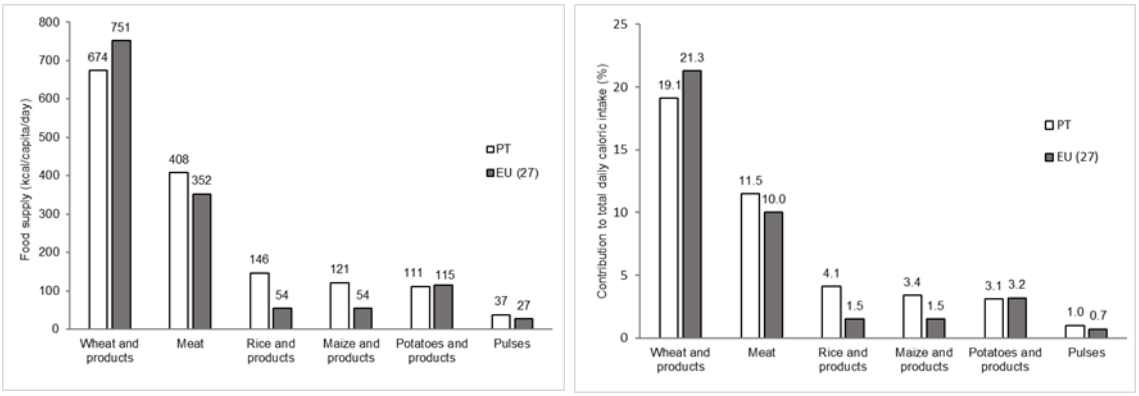

Figure 8 – Main staples and their calorie contribution: comparison between EU and Portugal.

Data source: FAO (2020)

In both Portugal and the European Union, wheat and its products were the staple food with the highest contribution to calorie intake. In Portugal, the second cereal with the highest caloric contribution was rice, with 4.1%, while potatoes contributed 3.1%. This is lower than the value reported in the National Food Survey (2015-2016), which showed a contribution of 5.2% to total energy intake, and higher than its main carbohydrate competitors, potatoes, and pasta, which contributed 4.6% and 3.0% respectively (Lopes et al., 2017).

According to the latest information from INE in 2021, the average daily food supply *per capita* has increased compared to the averages recorded between 2012 and 2015, with the average content of proteins, fats, and carbohydrates being 131.1 g/capita/day, 155.0 g/capita/day, and 489.9 g/capita/day respectively (INE, 2021). The main source of carbohydrates is cereals, which account for 30.2% of daily calorie intake. Wheat had a share of 68.7% of the total amounts of cereals available for consumption in 2016-2020, and rice is the second most important cereal, accounting for an average of 17.8% of the total amounts of cereals available for consumption in 2016-2020, registering an apparent consumption of 61.7 g/capita/day in 2020, equivalent to 22.5 kg/person/year (INE, 2021). For the same year, the FAO reported an apparent *per capita* consumption of 19.3 kg/year, which was lower than that reported in national data (FAO, 2020).

Although the difference in consumption between wheat and rice is considerable, it is important to bear in mind that wheat (flour) is used as an ingredient in a wide range of foods, such as bakery products, pastry, cakes, and pasta, whereas rice is mainly consumed in its original form, including recipes for main courses or side dishes. This is confirmed by the classification of food categories in the National Food Survey report, which reported that the largest source of carbohydrates came from the “bread and toast” category, with 25%, while pasta and potatoes contributed 3% and 8%, respectively, less than the 10% contribution of rice (Lopes et al., 2017).

The data suggest that the average caloric intake provided by wheat is higher in Europe than in Portugal, while the opposite is true for rice, indicating that Portugal shares wheat as a staple food with other European countries, but that rice can be a staple food for Portugal, as opposed to being a staple food for the whole Europe.

Rice plays a relevant role in Portuguese cuisine, being used as a main dish, side dish, and dessert (Dias & Dias, 2018). There are two main commercial rice types: Carolino, a long-grain Japonica subspecies; and *Agulha*, a long-grain Indica subspecies. *Carolino* rice is made from different cultivars, of which *Ariete* is the most common and is traditionally used to make rice dishes with a creamy texture. The traditional method of cooking *Carolino* rice often involves the use of a large amount of water, which allows the rice to absorb the broth and extract rich flavours from ingredients such as tomatoes, vegetables, pulses, meat, fish, and shellfish. This method of cooking seems to "produce more food" with just water, which is why it is traditionally called as *Malandro*, meaning cheater.

In a review of traditional Portuguese cuisine by Dias and Dias (2018), in which they examined recipes published in cookbooks, they found 103 main dishes with other cereals (not rice) or tubers as the main ingredient and 63 references to main dishes with rice as

the main ingredient, of which 34 included meat and 28 included fish or seafood. In addition, they found several dishes that had rice in their name, even though rice was not the main ingredient. These findings confirm the role of rice as a staple food in everyday Portuguese cuisine.

2.5. Trends and determinants of rice consumption

Over the years, there have been important changes in dietary patterns, with a shift in the consumption of staple foods towards a more diversified diet (Kearney, 2010). Changes in dietary patterns are influenced by factors known as determinants of consumption, and these determinants in turn dictate trends in food consumption.

Factors such as sensory appeal, health, weight control, price, naturalness, mood, convenience, familiarity, and ethical issues are the main reasons behind food choices (Cunha et al., 2018; Steptoe et al., 1995). The factors underlying rice consumption vary across cultures; for example, in the study by Son, Kim, et al. (2014a), French consumers indicated sensory and convenience as the main reasons for choosing rice, and Japanese consumers were sensory and health, while nutrition was the main reason for choosing rice in Thailand and Korea. The latter also indicated the safety of rice was one of the main reasons for choosing it.

According to Cuevas et al. (2016), the drivers of rice choice can be classified into three categories: search, experience, and credence attributes. Search attributes, such as price, appearance, brand, and packaging, are used to evaluate the product before purchase. After purchasing or using a product, experience attributes such as taste, texture, and ease of cooking can be evaluated. Credence attributes relate to the production, processing, and content of a product, which depend on institutions such as government controls or industry claims.

Demand for rice can be influenced by demographic, economic and attitudinal factors (Maclean et al., 2002). It is estimated that the world population will grow by about 44.165 million per year to reach 9.7 billion inhabitants by 2050 (ONU, 2019). Therefore, it is estimated that rice production and consumption will increase by 2050, in line with population growth, and will continue to be an important ally in the fight against hunger and malnutrition. It is expected that at least 700 million tonnes of rice will be needed to meet global demand if current *per capita* consumption is maintained (USDA, 2022). This increase in consumption will be driven mainly by population growth, as global *per capita* consumption is forecast to stagnate (Durand-Morat & Bairagi, 2021).

By 2030, rice consumption in West Asia and Sub-Saharan Africa will increase in at a rate of 3% to 4% per year, with consumption of tubers and coarse grains giving way to rice consumption (OECD-FAO, 2021). This increase is projected for the whole Latin America, except for Brazil, where *per capita* consumption will fall by 11.9%, corresponding to a 6.2% decline in rice consumption by 2028–2030 (Durand-Morat & Bairagi, 2021). On the other hand, several Asian countries that are major rice consumers, such as Japan, South Korea, and Thailand, are estimated to experience a significant decline in *per capita* consumption by 2030.

These variations in rice consumption in these regions are due to sociodemographic changes such as economic growth, rural-urban migration, urbanization, *per capita* income, relative prices of rice and other foods (Maclean et al., 2002). Some authors have argued that the change in rice consumption pattern will occur in two ways, namely, substitution between foods - in which the consumption of animal protein increases, and the consumption of cereals decreases; and within foods - in which the consumption of aromatic rice and brown rice will increase at the expense of ordinary white rice (Bairagi, Mohanty, et al., 2020; Mottaleb et al., 2018). In other words, in these rice-consuming countries, rising incomes have encouraged the substitution of rice for other more expensive foods, and the choice of higher quality rice. This trend was also observed in the West African population where those living in urban areas, with high income and educational levels tended to purchase higher quality rice for its nutritional value (Tomlins et al., 2005). This poses new challenges for the scientific community, which, in addition to investigating crop productivity to cope with population growth, will also have to guarantee excellent sensory and nutritional quality of rice to meet the demands of new consumers.

Over the decade, global demand for rice remained constant, with consumption in 2019 consumption slightly lower than at the beginning of the decade. This variation is mainly due to the Asian continent, where consumption falls between 2010 and 2019. In Asia, two main reasons have been identified for the stagnation or even decrease in rice consumption: i) the diversification of diets due to rising incomes, and ii) the globalization of diets and the associated westernization. Sociodemographic changes, namely the increase in the number of women in the labour market and the rise in incomes, have also led to a demand for more convenient foods, thus jeopardizing the daily consumption of rice in these countries (Pingali, 2007).

For the EU, rice consumption is expected to increase to 2.8 million tonnes by 2030, while the production area is expected to decrease slightly (420 000 ha in 2030) due to agroclimatic constraints and strong competition from other agricultural uses so imports will

continue to increase. The increase in rice consumption in Europe is mainly due to improved rice quality, changes in consumer attitudes towards rice, advertising, cooking advice and the versatility of rice (Chataigner, 1992; D'Hauteville, 1992). When comparing attitudes and beliefs towards rice and the main rice substitutes in Europe, potatoes and pasta, taste, calorie content, price, versatility, perception of healthiness, content of harmful substances, digestibility, and allergenicity put rice an advantage, ensuring an increased propensity to consume it (Supakornchuwong & Suwannaporn, 2012). In the United Kingdom, the increase in rice consumption has been explained by the shift from traditional meals to international dishes, such as Indian, Mexican, or Asian foods (Hogg & Kalafatis, 1992), where traditional dishes are based on rice.

Currently, some factors have become more influential, increasing adherence to trends that were less relevant before, or even triggering new consumption trends. The search for health and well-being through the choice of foods that provide these benefits and the adoption of a more sustainable lifestyle, where people look for foods that have a lower environmental impact and promote the conservation of nature, are examples of these new food trends (CBI, 2022; Jones & Sheats, 2016). Nowadays, ethical concerns related to food production practices also exert a greater influence on food choices (Feucht & Zander, 2017; Mancini et al., 2017; Yadav & Kumar, 2018). Asian rice-exporting countries have used criteria such as sustainable production, environmentally correct practices, and fair trade as valuable attributes to promote their rice in Europe (Tu et al., 2021; Vinci et al., 2023; Yadav & Kumar, 2018).

Suwannaporn and Linnemann (2008a) examined a limited number of purchase criteria for rice and found that marketing activities, price, and country of origin were the best discriminators between typical and non-typical rice-consuming countries, while quality was a poor discriminator. Quality plays a key role for both groups of consumers, but it may have a different meaning. The impulses given by marketing activities and the messages given to the product are particularly important for European consumers, who want to be more involved with the product and its environmental footprint in the market (CBI, 2017).

Asian countries such as Malaysia, Japan, Korea, North China, and Taiwan prefer local rice due to its lower price compared to imported rice (Musa et al., 2011; Suwannaporn & Linnemann, 2008b). While in Ghana and Nigeria they prefer imported rice due to the general presentation of the product, such as the absence of foreign materials, whiteness, and packaging (Agbogo, 2013; Danso-Abbeam & Baidoo, 2014; Ogundele, 2014). In France, Greece, Spain and Italy, local rice is of better quality than imported rice (D'Hauteville et al., 1997), while in Türkiye, imported rice is of higher quality than local rice,

and the hygienic aspect is a reason for quality, which was considered the most important criterion after price. For these consumers, the place of purchase also determines the type of rice consumed; consumers who choose local markets are limited to what is available (Azabagaoglu & Gaytancıoğlu, 2009). In the case of Portugal, there is a growing trend towards the consumption of rice from indica varieties (mostly imported) to the detriment of *Carolino* rice (local rice), which belongs to the Japonica subspecies. This trend is due, in addition to convenience, to price, since the opening of the market meant that distributors began to buy rice directly from exporters at a lower price than that on the domestic market (Dias & Rocha, 2012).

Dietary diversification and the search for healthier foods are currently identified as the main drivers of food consumption in Europe (CBI, 2022); as consumers, reach their maximum consumption in terms of quantity, they substitute one food for another to eat in a more varied and healthier way (Gracia & Albisu, 2001). This dynamism in the food pattern of Europeans means that products, previously considered exotic are becoming part of everyday consumption (CBI, 2021).

The diversification and search for healthier foods is confirmed by import statistics, which show that 62% of imported husked rice is Basmati and that there has been an increase in the consumption of wild rice (rich in protein, amino acids, lysine and dietary fibre), black rice (rich in antioxidants, vitamin E and iron), red rice (rich in fibre and antioxidants), brown rice and organic rice (CBI, 2021), varieties that are considered healthier. Increased awareness of healthy eating habits and dietary needs among European consumers offers commercial potential for a wide range of grains, pulses, and oilseeds, such as quinoa, chia, and pea protein (CBI, 2022). This awareness has led to several health-related trends, such as organic, plant-based, free-from, clean-label, no additives, functional foods, dietary fibre, and low-carbohydrate diets, among others, which are influencing the consumption of cereals (CBI, 2022). The trend towards low-carbohydrate diets, or even the fad to exclude carbohydrates (Jones and Sheats, 2016), penalizes the consumption of some grains, particularly rice in its usual form of intake. Despite this, the versatility of rice allows it to be included in healthier recipes, where it can be combined with pulses, ancient grains, and vegetables, resulting in foods that can be used both in meals, for breakfast or as a snack (Arribas et al., 2019; Asare et al., 2012; Carvalho et al., 2013). Rice is also a particularly interesting raw material for the formulation of gluten-free products (Jones & Sheats, 2016).

Convenience is also a factor in the decline in consumption observed in rice-consuming countries. For example, in Korea and Japan, where rice consumption has fallen sharply,

researchers are developing rice-based convenience products to counter this trend, aiming to provide RTE-rice that meets the quality criteria expected by consumers (Cha et al., 2012b; Yu et al., 2017; Yu et al., 2010). Convenience also influences the choice between the types of rice, as in the case of brown rice, where the difficulty and time of cooking are barriers to consumption (Ziegler et al., 2018). The indica subspecies has a larger market than Japonica, partly because of its ease and speed of cooking (Carvalho et al., 2013). Indeed, sociodemographic changes have led to a tendency to look for more convenient foods with better eating quality and ease of preparation (Dixon et al., 2020; Kwak et al., 2015).

Portugal follows the global trend of consumption of ready-to-eat foods (W.H.O., 2014), where according to the report “The Quest for Convenience” by Nielsen (2020), between the years 2018 and 2019 had an increase of 8% in terms of business volume (Marcela, 2020). Specifically, for RTE-rice an increase of 31% in business volume between the years 2014 and 2016 was verified, but it still has low expression in the market (Nielsen, 2017).

In 2018, the rice category registered a decrease in the purchase volume (-2%, for a total of 83.3 million kilos), while it recorded an increase in value (+2%), due to a greater weight of sales of rice types with a higher average price (Costa, 2019). The most common types of rice, *Agulha* rice and *Carolino*, although still the most consumed, recorded a fall in sales of 3% and 8%, respectively, giving way to the purchase of less common or exotic types of rice, namely sushi rice, risotto rice, wild rice, basmati, brown rice, and pigmented rice. These types of rice are more expensive, which shows that although price is important, consumers are looking for differentiating attributes such as health, convenience, and premium quality, in line with global trends (CBI, 2022; Nielsen, 2015a; W.H.O., 2014). In addition to the various trends mentioned above, the European consumers are seeking for authenticity in their food, which has created a market for new flavours and ingredients (Carroll, 2015). This demand has opened possibilities for ethnic and traditional cuisines, creating opportunities for rice as a raw material.

2.6. Rice quality and preference

2.6.1. Rice quality along the supply chain

Rice quality is the main driver of rice choice, and its perception depends on socio-demographic and cultural backgrounds (Choi et al., 2018). The quality of rice depends on several intrinsic factors and factors inherent to its processing until the final consumer

stage, such as physicochemical properties intrinsic to the varieties, growing conditions, harvesting, drying, storage conditions, milling processes, and culinary methods (Butardo & Sreenivasulu, 2016; Unnevehr et al., 1992; Wedgwood & Duff, 1992).

The concept of rice quality is weighted according to the stakeholders. Figure 9 presents the different aspects of quality in general according to the stage and stakeholder.

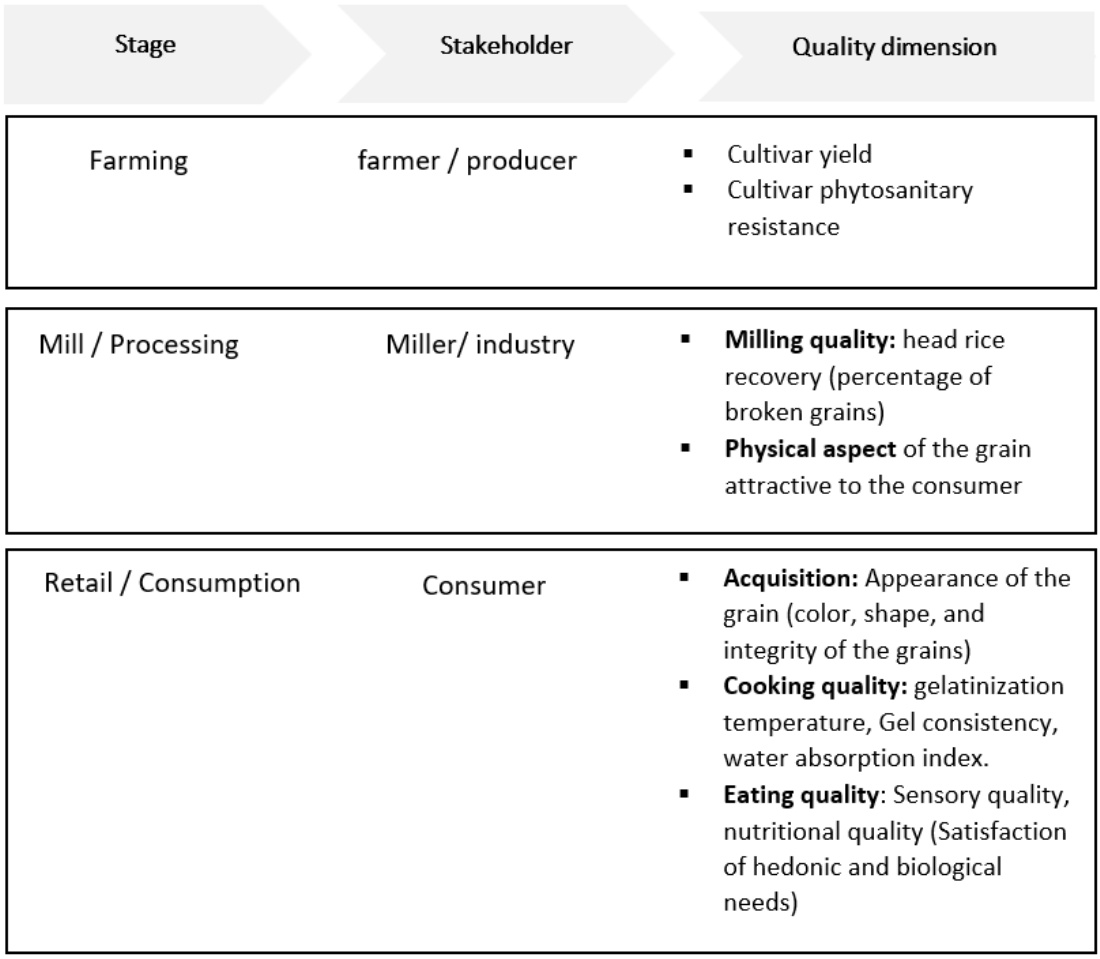

Figure 9 - Aspects of rice quality according to stakeholders (production and supply chain).

For a producer, quality is related to the yield of rough rice and the phytosanitary resistance of the cultivar (Wedgwood & Duff, 1992). Drying and time intervals between stages, such as harvesting, threshing, cleaning, and drying, are considered the most relevant criteria, ensuring both sensorial and sanitary quality in the subsequent stages of the rice value chain. Drying affects the conservation and physical quality of the rice, such as colour, and the proportion of cracked or broken grains and the time interval between stages of processing should be as short as possible to guarantee quality.

For the industry, milling quality is the main criterion. Milling quality can be defined as the ability of rice grains to resist breakage during mechanical husking. Millers consider physical properties such as head rice recovery, grain size and shape, translucency, degree of milling, percentage of broken, proportion of damaged grain, coloured grain, and impurities as well as moisture level in the assessment of milling quality (Kaosa-Ard & Juliano, 1992). The milling quality determines the final yield and the broken kernel rate of the milled rice, which is one of the relevant issues for the industry (Qiu et al., 2016).

The quality of retail rice depends on the quality of the rice milled by the millers, which in turn depends on the rough rice quality used for processing. All these players work according to consumer demand, to ensure that the intended financial return is achieved at the end of the chain (Wedgwood & Duff, 1992). While the consumer evaluates rice quality in terms of its physical, cooking, and sensory characteristics, they also consider health traits quality (Saleh et al., 2019; Se et al., 2015). The consumer focuses on the physical aspects at the acquisition stage, predicting the desired result of the cooked rice. In this context, when rice quality is evaluated, quality is considered in all its dimensions and stages of the supply chain until it reaches the final consumer.

The physical characteristics of the grain determine its price in the market, while the cooking and eating quality and its predictability during use determine the reputation of a variety (Fitzgerald et al., 2009b). Table 1 summarizes the main rice quality criteria at the market level (Miller and distributor) with their respective attributes and definitions.

Table 1 - Criteria for measuring rice quality throughout the rice value chain.

Dimension	Quality criterion	Attribute	Definition	Physical state of grain / chain stage	References
Physicochemical	Physical	Size	Grain length. Long grain: greater than 6 mm; medium grain: 5–6 mm; short grain: 4-5 millimetres long and 2.5 millimetres thick.	raw / miller, retail	Suwannaporn & Linnemann, 2008; Kaosa-Ard & Juliano, 1992.
		Milling degree	Percentage of bran removed from brown rice kernels. Milling affects the general quality, appearance, and palatability of rice.	raw / miller, retail	Puri et al., 2014; Bhattacharya, 2013.
		Head rice recovery	Measure of the percentage of unbroken grains after milling and is one of the factors for evaluating milling quality along with brown rice ratio, and milled rice ratio. Head rice normally includes broken kernels that comprise 75-80% of the whole kernel. High-head rice yield is one of the most important criteria for measuring milled rice quality.	raw / miller	Fitzgerald et al., 2009.
		Whiteness	It is a combination of varietal and physical characteristics as well as the degree of milling. It is often used to determine the milling degree.	raw / miller, retail	IRRI, 2010

Dimension	Quality criterion	Attribute	Definition	Physical state of grain / chain stage	References
Sensory		Hardness	Resistance offered by rice kernels after being subjected to force. It is measured using instrumental techniques.	raw or cooked / miller, retail	Calingacion et al 2014; Oppong Siaw et al., 2021
		Percentage of brokens / proportion of damaged grain	Percentage of white rice grains that were damaged during the milling process.	raw / miller	Kaosa-Ard & Juliano, 1992.
		Coloured grain	Grains with atypical colours for the rice variety under evaluation.	raw / miller, retail	Tomlins et al., 2005.
		Chalkiness grains	Part of the ground rice grain that is opaque rather than translucent.	raw / miller, retail	Birla et al., 2017.
		Deformed grains	Presence of roughness, deformations on the surface of the grains and/or curvature of the grains, and/or fork shape of the end of the grain (visual assessment).	raw / consumer	Mestre et al., 2011.
	Chemical	Moisture content	Moisture content (MC) is the weight of water contained in paddy or rice expressed in percent. Normally around 12-14% moisture content is allowed.	raw / miller, retail	Donlao & Ogawa, 2017.
		Amylose content	Linear glucose polymer that influences the volume expansion, hardness, and looseness of cooked rice. Based on amylose content, milled rice is classified: waxy (1-2% amylose), very low amylose (2-9% amylose), low amylose (10-20% amylose), medium amylose content (20-25% amylose) and high amylose content (25-33% amylose).	raw / miller, retail	IRRI, 2010
		Gelatinization temperature	It is the water temperature at which starch granules begin to swell irreversibly, measured by an alkaline test. The gelatinization temperature of milled rice is divided into three main groups: low (<70C), intermediate (70–74C), and high (>74C).	cooked/ retail	Kaosaard & Juliano, 1992; Jennings et al., 1979.
		Gel consistency	Measures the tendency of cooked rice to harden after cooling. Rice cooked with a hard gel consistency hardens faster than rice with a soft gel consistency. Rice with a soft gel consistency cook soft and remains soft even after cooling (Juliano 1979).	cooked/ retail	Kaosa-Ard and Juliano, 1992.
			Hardness of cooked rice: soft (61–100 mm), medium (41–60 mm), and hard (27–40 mm).		Calingacion et al., 2014.
	Appearance	Shape	Determined by the length/width ratio. There are elongated, oval, long, and thin grains. It is used internationally to describe the shape and categories of the variety	raw / miller, retail	IRRI, 2006; Tomlins et al., 2005.
		Colour	They can be characterized as white, translucent, yellow, yellowish, plastered, uniform, and stained.	raw / miller, retail, consumer	Tomlins et al., 2005.
		Glossiness	The intensity of the shine on the surface of rice kernel.	raw / retail, consumer	Tomlins et al., 2005; Yau et al., 1996.
		Presence of impurities	Foreign materials such as pebbles, husk residue, and other organic matter foreign to the milled rice.	raw / retail, consumer	Tomlins et al., 2005.
		Swelling ratio / volume expansion ratio	Ratio of the volume of rice after cooking to the volume of rice before cooking.	cooked / consumer	Mestre et al., 2011.
	Texture	Hardness	The force needed to bite through the rice kernels at the first bite	cooked / consumer	Lee et al., 2015.
		Stickiness	The degree of adhesion of rice kernels to each other (visual assessment) or to the teeth or mouth wall during or after chewing.	cooked / consumer	Yau & Huang, 1996.
		Cohesiveness	The degree of formation of a bulk of rice, including between and within rice kernels.	cooked / consumer	Mestre et al., 2011.

Dimension	Quality criterion	Attribute	Definition	Physical state of grain / chain stage	References
		Roughness	Degree of perceived roughness of chewed rice.	cooked / consumer	Yau et al., 1996.
		Kernelness	The degree of perception of rice kernels as a bulk rice held in the mouth.	cooked / consumer	Yau et al., 1996; Ohtsubo et al., 2016.
		Grainy	Samples of rice containing kernels or bits with a rougher surface or texture.	cooked / consumer	Tomlins et al., 2005.
		Tooth-pull	The force required to separate the jaws during chewing is perceived through two to three chews.	cooked / consumer	Lee et al., 2015; Suwansri et al., 2002
		Tooth-pack	Amount of product stuck in the crowns of teeth after chewing.	cooked / consumer	Lee et al., 2015
		Looseness	The degree of looseness among the rice kernel after cooked	cooked / consumer	Yau & Huang, 1996.
		Chewiness	The degree of endurance against chewing.	cooked / consumer	Yau & Huang, 1996.
		Balance degree	Relationship between Stickiness and hardness.	cooked / consumer	Okabe, 1979.
	Odour	Brown-rice aroma	The intensity of the odour of cooked brown rice.	cooked / consumer	Yau & Huang, 1996.
		Hot-rice aroma	The odour intensity of the cooked rice at 60°C	cooked / consumer	Yau & Huang, 1996.
		Typical odour / cooked rice aroma	The general term is used to describe the aroma of raw or cooked grains which does not give any specialty to the rice.	cooked / consumer	Suwansri et al., 2002
		Cold-rice aroma	The Odor intensity of the cooked rice at 18°C.	cooked / consumer	Yau &Huang, 1996.
		Feedy	The aromatics associated with a mixture of grains Chicken feed; Bran buds reminiscent of animal feed (dusty, musty, sharp).	Raw, cooked / retail, consumer	Suwansri et al., 2002.
		Starchy	The aromatics associated with the starch of a particular grain source.	Cooked / consumer	Suwansri et al., 2002
		Scorched	The aromatic is associated with scorching.	Cooked / consumer	Suwansri et al., 2002
		Nutty	The aromatics associated with nuts or nutmeats, which cannot be tied to a specific origin.	Cooked / consumer	Suwansri et al., 2002
		Sweet	The aroma attached to substances that also possess sweet flavours, such as molasses, caramelized sugar, cotton candy, maple syrup, and maltol.	Cooked / consumer	Suwansri et al., 2002
		Sulfury	Aromatics associated with hydrogen sulfide boiled or rotten eggs.	Cooked / consumer	Suwansri et al., 2002
		Metallic	Aromatics associated with metals, tinny or irony.	Cooked / consumer	Suwansri et al., 2002
		Woody	The aromatics associated with dry fresh cut wood.	Cooked / consumer	Suwansri et al., 2002
		Dairy	Reminiscent of soured or old dairy products.	Cooked / consumer	Suwansri et al., 2002
		Wet Cardboard/Paper	The aromatics associated with the early stages of oxidation	Raw, cooked /Miller, retail, consumer	Suwansri et al., 2002
		Hot Plastic	The aromatics reminiscent of warm rubbers, vinyl, or plastic.	Raw, cooked /Miller, retail, consumer	Suwansri et al., 2002
	Flavour	Sweetness	The sweetness intensity of the chewed rice after chewings	cooked / consumer	Yau & Huang, 1996.
		Astringency	The chemical sensitivity factor associated with the shrinkage and contraction of the tongue caused by substances such as tannins or alum.	cooked / consumer	Suwansri et al., 2002
		Popcorn	Flavour associated with toasted corn or popcorn.	cooked / consumer	Tomlins et al, 2005
		Metallic	Flavour associated with metals, tinny, or irony.	cooked / consumer	Tomlins et al, 2005.

Dimension	Quality criterion	Attribute	Definition	Physical state of grain / chain stage	References
		wet wood	Flavour associated with moist wood.	cooked /consumer	Kwak et al., 2015.
		Aftertaste	Flavour that remains on the palate after chewing and swallowing (Bitter, Sour, salty, sweet)	cooked / consumer	Suwansri et al., 2002.
		Salty	The basic taste on the tongue stimulated by sodium chloride.	cooked / consumer	Suwansri et al., 2002.
		Acid	The basic taste on the tongue stimulated by acids.	cooked / consumer	Suwansri et al., 2002.
		Bitter	The basic taste on the tongue stimulated by solutions of caffeine in substances such as quinine and some other alkaloids	cooked / consumer	Suwansri et al., 2002; Tomlins et al., 2005.

2.6.2. Estimation of cooking and eating quality

Cooking and eating quality depend on the chemical characteristics of the variety, such as the protein content, type, and amount of starch. The physical properties of cooked rice grains include hardness and stickiness, and the physical properties of raw grains include grain uniformity and cracking (Champagne et al., 2010; Fitzgerald et al., 2009b; Li et al., 2016; Tao et al., 2019). The latter influences the degree and homogeneity of cooking and the water absorption during cooking. Smaller grains absorb water more quickly, resulting in a softer texture, while larger grains absorb water more slowly, resulting in a firmer texture (Ohtsubo & Nakamura, 2017).

Physicochemical measurement is an indirect method that estimates the eating quality based on the chemical composition, cooking quality, gelatinization properties, and physical properties of cooked rice (Ohtsubo & Nakamura, 2017). Eating quality refers to the perception of the sensory qualities of cooked rice and generally includes palatability characteristics such as appearance, cohesiveness, tenderness, flavour and its retention after cooking, and the ability to remain soft for several hours after cooking (Calingacion et al., 2014; Muthayya et al., 2014). The sensory evaluation of cooked rice can be divided into sequential analysis phases, starting with a visual evaluation, odour, and taste (during chewing), and sensations after chewing and swallowing (Calingacion et al., 2014; Mestres et al., 2019; Ohtsubo & Nakamura, 2017; Suwansri et al., 2002; Tomlins et al., 2005).

Typically, before rice is submitted for acceptance evaluation by a sensory panel, the physicochemical and nutritional quality parameters of rice are determined using standardized and/or instrumental analytical methods to assess cooking quality based on the functional properties of starch (Lau et al., 2015).

Different instruments are used to measure the functional properties of starch, namely the Amylograph®, Falling Number® System, Ottawa Starch Viscometer, and Consistometer.

More recently, the Rapid Visco Analyzer (RVA) has shown high indicators of reliability, repeatability, and versatility (Balet et al., 2019). Using the RVA as a means of evaluation, studies have shown that cooking quality is better correlated with peak viscosity, breakdown, and setback (Allahgholipour et al., 2006; Champagne et al., 1999).

There are two types of starch in rice: amylose, which is a polymer with a short, sparsely branched chain, and amylopectin, which is shorter and highly branched (Juliano, 1993). Because of the strong influence of amylose on the texture of cooked rice, genetic engineering has been used to improve food and cooking quality by manipulating the amylose content. Researchers have successfully incorporated the Wx allele (Wx-op/hp, Wx-mq, and Wx-mp) into rice varieties to control amylose content in low and very low amylose varieties (Mikami et al., 2008; Sato et al., 2002; Yang et al., 2013). Recently, a rare Wx allele, Wx-mw, has been identified that can improve cooking and eating quality while improving grain appearance. This study was validated in japonica rice, resulting in rice with intermediate AC, soft grains, and endosperm transparency (Zhang et al., 2021).

Amylose content can be estimated using methods such as iodine staining or colorimetry, in which amylose reacts with iodine to produce a blue-black colour. The intensity of the colour can be used to determine the amylose content of rice (Cagampang & Perez, 2015). High amylose content in rice results in firmer, less sticky cooked rice, while low amylose content results in softer, stickier rice. Amylose is also responsible for starch retrogradation, a reaction in which gelatinized starch polymers reorganize to form a more crystalline structure, making cooked rice harder after some cooling (Wang et al., 2015).

The water absorption index determines the expandability during cooking, the higher it is, the more the grain expands. The ability of rice grains to absorb water during cooking can be determined by measuring the weight gain of rice grains before and after immersion in water. A new method was developed to evaluate water absorption by analysing a projected image of soaked rice in a scanner in real time. This method was able to analyse the water absorption characteristics of each rice grain (Hu et al., 2020).

Amylose content is negatively correlated with water absorption and volume expansion during cooking, while the appearance of cracks in the grains accelerates water absorption (Hu et al., 2020). Higher amylose content in rice results in greater expansion and scaling of the grains, drier, less fluffy grains and hardens on cooling, and at lower amylose content, cooked rice grains are moister and stickier (Okadome et al., 1999). In most cultures, higher water absorption capacity is associated with better rice cooking quality, resulting in soft, well-cooked rice (Juliano, 2016a).

Texture characteristics are the main attribute quality attribute considered by consumers in cooked rice (Calingacion et al., 2014; Gondal et al., 2021; Okabe, 1979; Suwannaporn & Linnemann, 2008a; Wan et al., 2004) and are influenced by the amount and type of starch, fibre, and protein content (Li et al., 2016; Yu et al., 2019). Cooked rice with high protein content tends to be hard and non-sticky (Honjyo, 1971). The higher the amount of protein, the more yellowish the rice and the lower its ability to be refract light, which reduces the translucency (Honjyo, 1971; IRRI, 2006). There are several methods for assessing protein content in rice: the Kjeldahl and Dumas methods, in which the protein content is estimated by the amount of nitrogen present in the sample; the Biuret method, in which the protein reacts with a solution containing copper ions; and near-infrared spectroscopy, which uses light in the near-infrared range to analyse the composition of a sample and correlates the spectral data with the protein content measured by one of the above methods (Cozzolino, 2021).

The cooking time of rice is determined by the temperature at which the crystalline structures of the starch begin to melt and is called the gelatinization temperature (GT). For rice, the gelatinization temperature ranges from 55 to 85 °C (Tan & Corke, 2002), and rice with a high GT requires more cooking time and results in an unappealing cooked rice texture. This indicator is extremely important to consumers who focus on product convenience, as well as those who are concerned with environmental sustainability (Fitzgerald et al., 2009b).

The gelatinization temperature can be measured using techniques such as differential scanning calorimetry, which consists of measuring the energy required for form the amylose/Lys-phospholipid complex, or RVA, but these more reliable methods require expensive equipment. An alternative method is digital photometry, which uses a digital camera and freely available image processing software to determine the alkaline scattering value and subsequently the gelatinization temperature using a seven-point scale (1 = intact to 7 = highly dispersed), corresponding to the gelatinization temperature as follows: 1 - 2, high (74.5 - 80 °C); 3, high-medium; 5, medium (70–74 °C); and 6 - 7, low (< 70 °C) (Ahmad & Noomhorm, 2019; Unnevehr et al., 1992). Cooking time can also be measured by monitoring the time taken it takes for rice grains to reach a certain level of tenderness or texture using sensory evaluation (Champagne, 2008). In addition, the firmness or viscosity of rice can be assessed by measuring the gel consistency. This parameter is very important because it determines the mouthfeel and overall palatability of cooked rice (Woo et al., 2015) and can be measured using methods such as RVA or texture analysis. The RVA measures the viscosity of the rice slurry as it is heated and

cooled, while texture analysis measures the force required to compress the rice (Pang et al., 2016).

The texture profile can be comprehensively evaluated by combining these analyses with the sensory evaluation techniques used to measure the texture of cooked rice, including hardness, cohesiveness, gumminess, and chewiness. Sensory analysis allows for the evaluation of factors that also play a role in rice quality, such as flavour, aroma, and overall palatability, using a panel of tasters. Aroma can also be analysed using methods such as gas chromatography-mass spectrometry, where the volatile compounds are extracted from the rice and analysed them using chromatography and mass spectrometry to identify the aroma compounds present in the rice (Cagampang & Perez, 2015; Wei et al., 2021).

The physicochemical properties of rice that can predict eating and cooking quality are measured separately using different instruments and analytical techniques (Xia et al., 2021). Therefore, efforts have been made to develop rapid methods based on artificial intelligence, artificial neural networks, and machine learning (Aznan et al., 2022; Deng et al., 2023; Rahimzadeh et al., 2019; Xu, Liu, et al., 2021).

In addition to traditional evaluation methods, such as sensory evaluation, physical and chemical indicators, and instrumental analysis, new technologies have been used to rapidly evaluate the rice aroma and flavour, such as the electronic nose and tongue. (Lu et al., 2015; Lu et al., 2016; Xu, Liu, et al., 2021). These technologies are also based on the analysis of volatile compounds present in rice, which contribute to its flavour and aroma. However, these compounds are usually present at low concentrations, making their detection and identification challenging (Lu et al., 2016; Xu, Liu, et al., 2021). Studies have shown that electronic tongue technology can effectively differentiate different rice varieties based on their flavour profiles (Lu et al., 2016; Lu et al., 2021). This technology has also been used to evaluate the effects of different cooking methods and storage conditions on the flavour of rice and to characterize rice ageing during storage (Rahimzadeh et al., 2019; Xu, Liu, et al., 2021).

Instrumental methods have some disadvantages: they are not sensitive enough to differentiate cooked rice within the same amylose type, and they are not able to detect differences in the sensory characteristics of the grains, as can be done by trained tasters (Juliano & Duff, 1991), or consumers who know and appreciate rice (Champagne et al., 2010). Champagne et al. (2010) verified that a panel was able to discriminate between two similar premium quality rice based on the flavour and softness of the surface of the cooked grains, concluding that consumers are meticulous in their food choice and can distinguish subtle differences in attributes.

Most studies that have evaluated the validity of instrumental assessments to predict the quality of cooked rice agree that routine indicators must be complemented by descriptive profiles obtained through sensory evaluation panels (Custodio et al., 2019; Maleki et al., 2020; von Borries et al., 2018; Wei et al., 2021). Thus, despite the importance of these techniques, sensory analysis is also essential because it is the only way to obtain a hedonic evaluation of the product (liking and disliking).

2.6.3. Rice preference across cultures

Rice preferences and quality perceptions vary from country to country (Calingacion et al., 2014; Chen, 2019; Custodio et al., 2019; Son, Kim, et al., 2014b; Suwannaporn & Linnemann, 2008b). Physical characteristics, cooking, and eating quality were weighted differently for different cultures.

Grain size in combination with amylose content is closely related to consumer preferences. The variety of the Indica subspecies has a firmer texture after cooking and cooling due to its medium to high amylose content. The grains cook easily, remain loose, and have difficulty absorbing cooking water. In the case of the Japonica subspecies, with a lower amylose content than the Indica variety, the grains have a good capacity for absorbing water and flavours and to bind with other ingredients and have a less firm texture after cooking. This is the subspecies typical of southern European countries and included the Italian varieties Arborio, Carnaroli, and Vialone Nano, known on the market as rice for risotto. They are characterized by wide grains and non-crystalline white parts, low amylose content, high water absorption capacity and become firm and creamy after cooking. Waxy or glutinous rice, characteristic of Asian cuisine, is characterized by short, round, dull, and white grains. It is usually soaked rice for a period before being steamed, resulting in a slimy and sticky rice. The aromatic varieties Basmati and Jasmine share intense and pleasant natural aromas that remain after cooking, but they have different cooking results. Basmati rice is very slender and after cooking, its grains expand to at least twice their initial length; they are dry and very thin, with a very white colour, whereas Jasmine rice is less dry and expands less than Basmati and has a stickier texture. Basmati rice has been preferred by most South Asians and is widely used in Europe (Suwannaporn & Linnemann, 2008b).

Calingacion et al. (2014) conducted a comprehensive study to determine the demographics of rice quality, as preferences are the main market drivers. The study identified 18 combinations of quality characteristics, revealing the complexity and degree

of specificity of consumer preferences. For example, Taiwan, Cambodia, Thailand, parts of the Lao Democratic Republic, northern and southwestern provinces of China, southern Vietnam and Japan were found to prefer low amylose rice (Calingacion et al., 2014; Ohtsubo & Nakamura, 2017), while Iran, Pakistan, Malaysia and the Philippines prefer medium amylose and high amylose rice is more popular in Myanmar, Sri Lanka certain states of India and Indonesia (Calingacion et al., 2014; Custodio et al., 2019). Philippines also preferred rice with greater whiteness, shorter grains, less damaged grains/foreign matter, low amylose content, and greater volume expansion during cooking (IRRI, 1992). Therefore, consumers in northern China and Japan prefer soft and sticky cooked rice, while consumers in southern China prefer hard rice (Ohtsubo & Nakamura, 2017; Zhang et al., 2015). In terms of grain size and shape of the grain, a short and round rice grain is preferred by northern China, Taiwan, Korea, and Japan, while consumers in Southern China, the USA, South and Southeast Asian countries generally prefer a long and slender rice grain (Juliano, 2016a; Unnevehr et al., 1992). For example, Thais prefer indica rice with long and well milled grains that are soft but flaky when cooked (Kaosa-Ard & Juliano, 1992).

In addition to the cross-cultural differences in variety preferences, there are also differences in the importance of sensory attributes. For example, colour is an important indicator of rice choice. Different markets require different degrees of bran removal, and the whiter the rice have higher market value (Lamberts et al., 2007). In general, the presence of broken grains is seen as a lack of quality, being penalized in price; therefore, the milling process has evolved significantly so that the product is not devalued (Cuevas et al., 2016). The connection between the first actors in the chain (producers, millers, and traders) and consumers helps establish quality standards suited to the preferences of each market.

Brown rice consumption is very low compared to white/milled rice due to its lower acceptability in terms of texture, colour, and flavour (Gondal et al., 2021; Zhou et al., 2019); and this preference varies mainly according to gender and education level (Cho & Lim, 2016; Tomlins et al., 2005). Countries with the highest intakes of whole grains in Europe, including brown rice, are Germany (130 g/day), the Netherlands (86 g/day), Sweden (79 g/day), Denmark (73 g/day), and Finland (71 g/day). It is consumed as a healthier alternative to milled white rice, as the rice bran contains important minerals, vitamins, and fibre (CBI, 2021).

Bairagi, Demont, et al. (2020) conducted a cross-cultural study on rice preferences in seven Asian countries and found that the evaluation of rice sensory attributes was

significantly heterogeneous between geographically close regions such as South and Southeast Asia. Appearance was the most preferred rice attribute by consumers in Bangladesh and India, while texture was the most preferred attribute in Thailand, Vietnam, Cambodia, the Philippines, and Indonesia. This hierarchization of sensory attributes directly influences variety preference; for example, consumers in Southeast Asia (Vietnam, Cambodia, Thailand, Indonesia), had a greater preference for jasmine rice (Ahmad & Noomhorm, 2019). Consumers in South Asia, on the other hand, prefer parboiled rice (Bairagi, Demont, et al., 2020), which is rice that has a consistent, dry, and firm texture due to processing, and whose aroma is largely eliminated (Custodio et al., 2019).

In northern China, preference for japonica rice is based on taste and appearance, while in Japan it is based on appearance and texture (Zhang et al., 2015). In general, consumers in South Asia prefer hard rice grains (medium to high amylose), while those in Northeast Asia prefer soft, sticky rice grains. It seems that Turkish consumers also place a high value on appearance, preferring rice with a shiny and uniform grain length that is also easy to cook (Azabagaoglu & Gaytancıoğlu, 2009).

European countries prefer long-grain rice, which is harder and less sticky (Juliano, 1993; Kaosa-Ard & Juliano, 1992; Suwannaporn & Linnemann, 2008b). This preference may be the result of the familiarity with the first commercialized and advertised types of rice imported from the United States. Since then, most European consumers consider quality rice to be non-sticky and loose (Supakornchuwong & Suwannaporn, 2012).

Portuguese consumers appreciate long to medium grains, fine to medium thickness, medium amylose content, and medium to high gelatinization temperature (Calingacion et al., 2014). Medium amylose content varieties are also popular in Latin America and North America (Custodio et al., 2019). In terms of eating quality, Portuguese consumers prefer non-sticky rice, white and with unbroken grains, with taste being the most important sensory evaluation parameter, although they appreciate aromatic rice (D'Hauteville et al., 1997). Taste is also the most important parameter for Spanish and Greek consumers, while the British are more concerned with texture and appearance (D'Hauteville et al., 1997). In fact, British consumers consume a lot of parboiled rice (Hogg & Kalafatis, 1992; Suwannaporn & Linnemann, 2008b), which is rice that does not add flavour to the other foods in the dish.

Rice texture is the most important indicator of eating quality and the attribute that most influences and differentiates the preference across cultures (Li et al., 2016; Okabe, 1979; Suwannaporn & Linnemann, 2008b). Although flavour was not a decisive attribute for rice choice in general, it was highly desirable for jasmine rice consumers (Suwannaporn &

Linnemann, 2008a). Differences in cooked rice preferences are mainly based on stickiness and hardness, which are the main characteristics used to describe rice texture (Li et al., 2016). Acceptance of rice has been shown to be negatively correlated with the content of components that influence texture, such as amylose and protein (Hori et al., 2016; Wangcharoen et al., 2016).

Another cultural difference that has also been observed is in the way in which rice is cooked. Studies suggest that familiarity with local cuisine and culinary practices plays an important role in shaping rice preferences, highlighting the importance of considering cultural background when studying food preferences (Choi et al., 2018; Kim, 2010; Son et al., 2013). Son et al. (2013) found that the most familiar cooking process is the one most associated with sensory quality. For example, a cooked rice that is sensory acceptable for a Korean consumer is pressure cooked, for Japanese consumers it must be soaked first, resulting in a firm and sticky rice, while for the French it is rice cooked quickly by boiling. In turn, Choi et al. (2018) found that the level of familiarity with the rice dish was a pronounced positive driver of preference for American and Korean consumers, and that cultural background influenced texture perception. In addition, grain size is closely related to consumer preference. Therefore, different grain sizes are preferred for different rice dishes, depending on the desired texture and purpose. For example, long-grain rice may be more suitable for pilaf and curries, while short-grain rice may be more suitable for sushi and risotto.

Although the physical qualities are important in the first contact with the product, future choices will be based on eating and cooking quality. For example, Philippine Consumers chose modern varieties based on physical quality, but traditional varieties based on cooking quality (IRRI, 1992).

Some countries prefer fewer common types of rice targeted at these markets, which they refer to as speciality rice. For example, fragrant rice is highly prized by consumers in India, Pakistan, and Thailand, whereas fragrant rice is considered spoiled or contaminated by non-traditional consumers (Efferson, 1985). There is also the example of *matizado* rice (rice treated with edible oil), which is very popular in Jordan and some Arab countries, but not in other markets. Of all the specialities, the most common is parboiled, which is widely consumed in England, Bangladesh, Nigeria, and Liberia (Kaosa-Ard & Juliano, 1992).

Custodio et al. (2019) in their review highlighted the urgency in standardizing the definition of rice quality, however, it does not seem appropriate to us, because, as they found, what is a premium characteristic for consumers in a region can be good or even poor to other geographically close consumers.

Understanding the heterogeneity of consumer preferences is crucial for developing products and designing variety development programmes that incorporate regional and national specificities as quality attributes to preserve the agricultural and gastronomic heritage of each region. In general, good rice for a particular culture depends on historical factors, such as familiarity with the variety, and socio-cultural factors, such as gastronomy and forms of consumption, considering the sustainability of the entire production chain.

Table 2 presents a compilation of rice preferences across cultures, with their respective reference.

Table 2 - Rice preferences across culture

Region/Country*	Colour	Size/ Shape	Texture and appearance	Flavour	Amylose content	Most important sensory attributes	examples of rice type	Reference
European countries		long-grain rice	hard, fluffy, and non-sticky				indica rice	Suwannaporn & Linnemann, 2008b.
Northeast Asia	white grain	short and round rice grain	soft, sticky rice grains.	mild flavour	low amylose	appearance and texture	japonica rice	Azabagaoglu & Gaytancıoğlu, 2009; Calingacion et al., 2014; Kaosa-Ard & Juliano, 1992.
South Asians	white colour	different grain sizes, slender	dry, soft, and very thin, consistent, dry, and firm	aromatic varieties	medium to high amylose	Appearance	Basmati, parboiled rice	Suwannaporn & Linnemann, 2008b; Custodio et al. 2016; Bairagi, Demont, et al., 2020; Custodio et al., 2019.
Southeast Asia	white colour	uniform size and shape	Soft and shiny	fragrant rice	medium amylose	texture and aroma	jasmine rice	Ahmad & Noomhorm, 2019; Custódio et al. 2016; Calingacion et al. 2014.
China	white	medium to short grain	soft and sticky		low amylose	Texture	japonica rice	Calingacion et al., 2014; Ohtsubo & Nakamura, 2017; Zhang et al., 2015; Zhang et al., 2015.
Indonesia	white colour	long, thin grains	Soft and shiny		high amylose	Texture	jasmine rice	Custódio et al., 2019; Ahmad & Noomhorm, 2019.
Japan	white grain	short and round rice grain	soft and sticky	mild flavour	low amylose	appearance and texture	japonica rice	Calingacion et al., 2014; Zhang et al., 2015; Kaosa-Ard & Juliano, 1992.
Korea		medium to short grain,	sticky visual sticky, soft		low amylose to medium amylose			Choi et al., 2018.
Vietnam		long grain	soft texture, sticky	fragrant rice	low amylose to medium amylose	Texture	jasmine rice	Calingacion et al., 2014; Bairagi, Demont, et al., 2020.
Philippines	high degree of whiteness	long grain	greater volume expansion, soft texture		medium amylose	Texture	jasmine rice	Custódio et al., 2019; Ahmad & Noomhorm, 2019; IRRI, 1992.
Thailand	white colour	uniform size and shape, long grain	Soft, shiny, flaky, integrity of the rice grain, swelling of the grains and glossiness	non-sticky rice	low amylose	texture and aroma	jasmine rice	Calingacion et al., 2014; Custódio et al., 2019; Kaosa-Ard & Juliano, 1992; Ahmad & Noomhorm, 2019; Son et al., 2014.

Table 2 - Rice preferences across culture

Region/Country*	Colour	Size/Shape	Texture and appearance	Flavour	Amylose content	Most important sensory attributes	examples of rice type	Reference
France	white	Long-grain rice	loose, fluffy, integrity of the rice grain, swelling of the grains and glossiness				Parboiled rice	Son et al., 2014 ; D'Hauteville et al., 1997.
Italy		short grain to medium grain	creamy, firm, "al dente"			texture and flavour	japonica rice	Suwannaporn & Linnemann, 2008b.
Portugal	white	long to medium grains, unbroken grains,	non-sticky to medium thickness.		medium amylose	taste		Calingacion et al., 2014; D'Hauteville et al., 1997.
Spain		uniform grain shape	non-sticky		medium amylose	taste	japonica rice	D'Hauteville et al., 1997.
Greece						taste	parboiled rice	D'Hauteville et al., 1997.
UK			loose, harder, non-sticky			Texture	parboiled	D'Hauteville et al., 1997.
Turkish		uniform grain length	shiny grains			appearance		Azabagaoglu & Gaytancıoğlu, 2009.
Latin America					Medium amylose	appearance	parboiled to milled rice	Custodio et al., 2019.
North America					Medium amylose			Custodio et al., 2019.
Nigeria	white,	uniform appearance, absence of foreign materials	firm and non-sticky	creamy and sweet flavour		Flavour and texture	parboiled	Ogundele, 2014.
Ghana	brown colour (cooked rice)	bright, clean, uniform appearance, unbroken grains,			high amylose		parboiled	Priestly,1994, Tomlins et al, 2005.
Senegal		broken rice	grain uniform		high amylose		imported rice	Demont et al, 2013.
US	white	long grain	non-sticky, firm, fluffy		high amylose	Flavour and texture	indica rice	Kaosa-Ard & Juliano, 1992.

*Some countries are also included in the classification by region since there are studies that present results by region and others that present results by country.

2.6.4. Nutritional Composition and optimization

It is important to note that not all types of rice provide the same nutritional value. Table 3 shows the differences in nutrient concentrations between brown rice and milled rice, and between milled *Carolino* rice and milled *Agulha* rice, the most consumed rice types in Portugal.

Milling reduces the nutrient content; therefore, the nutritional composition of milled rice is different from that of brown rice (Gondal et al., 2021). Milled rice is 95% starch, 5% - 7% protein, and 0.5 - 1% lipids (Fitzgerald et al., 2009b). Brown rice, pigmented rice, and wild rice are generally a healthier choice than milled rice because they contain more fibre, vitamins, minerals, lutein, and phytochemicals. However, rice is mostly consumed in its milled form (Fukagawa & Ziska, 2019), which loses most of these compounds. Many phytochemicals present in rice have been identified as bioactive compounds with high biological activities, including antioxidant, anticancer, antidiabetic and anti-inflammatory activities (Verma & Srivastav, 2020). However, brown rice is less appreciated than its milled counterpart due to its less desirable sensory attributes, namely texture and flavour, which are influenced by the presence of bran, and contains lipids responsible for the deterioration of the nutritional quality of brown rice during storage, and the development of off-flavour due to its oxidation (Kaewnaree et al., 2011; Park et al., 2012; Pingret et al., 2013).

Table 3 - Nutritional composition of brown rice and milled rice (100 g).

Compound	Milled *Agulha* rice (raw)	Milled *Carolino* rice (raw)	Brown rice (raw)*	Milled Rice (boiled)**
Macronutrients (g)				
Water	13.9	10.7	12.2	68.4
Protein	6.7	7.4	8.6	2.5
Fat	0.4	0.5	2.8	0.2
Carbohydrates	78.1	79.6	71.6	28
Fiber	2.1	2.2	3.8	0.8
Micronutrients (mg)				
Niacin (vitamin B3)	2	2	4.1	0.6
Tryptophan	1.4	1.6	1.9	0.5
α - tocopherol	0.1	0.1	0.7	0
Thiamine (vitamin B1)	0.6	0.07	0.4	0.01
Riboflavin (vitamin B2)	0.03	0.03	0.1	0.01
Pyridoxine (vitamin B6)	0.29	0.3	0.6	0.08
Minerals (mg)				
Potassium	94	110	250	36
Phosphorus	87	92	270	33
Magnesium	32	13	110	15

Compound	Milled *Agulha* rice (raw)	Milled *Carolino* rice (raw)	Brown rice (raw)*	Milled Rice (boiled)**
Calcium	13	11	9	7
Sodium	6	6	3	310
Zinc	1.3	1.3	1.4	0.6
Iron	0.6	0.6	1.7	0.2
α-tocopherol			0.7	0
Anti-nutrients (µg)				
Folates	19	20	55	5.8
Energy				
kcal	347	357	351	125
kJ	1470	1520	1490	532

Source: INSA - Food composition table. (INSA, 2021)

* A pool of 12 brown rice subsamples available in the Portuguese market; ** Average composition of *Agulha* and *Carolino* cooked in water and salt.

Brown rice has higher energetic value than milled rice due to the presence of fat in the layers that are removed during milling. Although brown rice has more vitamins, minerals, and fibre than white rice (Table 3), its greatest advantage is in terms of B vitamins, as the presence of phytate reduces mineral absorption (Juliano, 2016b). Phytic acid and salt phytate account for 80% of phosphorus in rice seeds. In the absence of the digestive enzyme phytase, phytate forms a complex with divalent cations, including Fe2+, Zn2+, Ca2+, and Mg2+, which are neither hydrolysed nor absorbed by monogastric animals. Minerals, such as iron, zinc, and calcium are lost when these compounds are excreted (Birla et al., 2017).

Rice contains a complex mixture of proteins, including albumin, globulin, prolamin, and glutelin. Of these, glutelin is the major protein fraction, accounting for about 80% of the total protein in rice grains. Glutelin is composed of several subunits, including α-, β-, γ-, and δ-subunits, which are further subdivided into acidic and basic forms (Amagliani et al., 2017). The unique properties of these subunits, such as solubility and digestibility, determine the functionality of rice proteins. Rice protein extraction has a high potential for the food industry in the production of hypoallergenic foods (Amagliani et al., 2017).

The limited amount of micronutrients and their low bioavailability is one of the nutritional problems for rice, especially for populations where diversified diets are not available (Birla et al., 2017). To overcome this limitation, several techniques can be used to improve the nutritional value of rice, including agronomic biofortification, fortification, rice breeding (conventional breeding or transgenic and gene editing approaches), processing techniques (in the industry) and culinary practices (in industry and domestic practices)

(Birla et al., 2017; Das et al., 2020; Fitzgerald et al., 2009b; Saltzman et al., 2013; Tiozon et al., 2021; Ufaz & Galili, 2008). It is important to note that the effectiveness of these approaches may vary depending on the specific nutritional deficiencies and the environmental conditions in which rice is grown. A combination of approaches may be required to achieve significant improvements in the nutritional value of rice.

Agricultural practices can play an important role in improving the nutritional quality of rice. Some examples of agricultural practices that can affect the nutritional quality of rice are: i) soil management - improving soil fertility through the use of organic fertilizer, crop rotation and other techniques can help to improve the nutritional content of rice (Fang et al., 2008; Xiao et al., 2022); ii) irrigation - irrigation management and crop management can also help to improve the nutritional value of rice by promoting healthy plant growth and development (Qiu et al., 2022). Increasing air or water temperature increases the protein content, while low water temperature or sunshade during the ripening stage decreases the protein content of rice (Honjyo, 1971).

Examples of this practice include the direct incorporation of iron and zinc into soil and nitrogen fertilizer to increase the niacin content (Mozafar, 1993; Tiozon et al., 2021), and foliar application of zinc fertilizer to increase zinc concentration in grains (Fang et al., 2008).

Rice fortification is the addition of one or more micronutrients to foods during processing to enhance specific nutrients or to restore nutrients lost during the processing. Fortification has been adopted as a public health intervention strategy to improve vitamin and mineral intakes of populations in countries where rice is the main daily source of energy (Kennedy et al., 2002; Piccoli et al., 2012; Tiozon et al., 2021).

There are four established technologies for rice fortification: i) dusting rice grains with micronutrient premix powder; ii) coating - fortified mix and liquid made of waxes and gums are sprayed on the surface of rice kernels in several layers; iii) cold extrusion - dough made of rice flour, fortified mix and water is passed through a simple pasta press to produce fortified rice kernels; iv) hot extrusion - dough made of rice flour, fortified mix, water and steam is formed into fortified kernels by a single- or twin screw extruder. In fortification by cold and hot extrusion, the dough is made from broken or low-quality rice (Piccoli et al., 2012).

Rice has been fortified with micronutrients such as vitamin A, vitamin B1 (thiamine), vitamin B2, vitamin B3 (niacin), vitamin B6, vitamin B12, vitamin C, vitamin D, vitamin E, vitamin K, folic acid, biotin, pantothenic acid, zinc, and iron. The selection of micronutrient

(fortifier) depends on the legal status, stability, price, expected bioavailability, and sensory acceptability, as well as the suitability of the product for the fortification technology applied (Piccoli et al., 2012).

In comparison with other methods of improving micronutrients, fortification has the major advantage of being cheaper. However, fortification can be lost during the washing, storage, and handling of the food, and can alter the natural appearance of the rice, making it less acceptable (Allen et al., 2006). With the latest technology, hot extrusion, fortified rice grains are difficult to distinguish from unfortified rice, increasing the likelihood of acceptance (Piccoli et al., 2012).

The discovery of the rice genomic sequence has led to major advances in the identification, isolation and characterization of new genes and their regulation to improve rice nutrition and quality. Rice breeding programmes are currently paying more attention to the nutritional quality of rice, thus opening the research target beyond breeding programmes focused on increasing rice yield to meet population growth (Juliano, 2016a).

Rice breeding is not just about biofortification, which involves increasing the nutrient content through genetic engineering techniques and introducing new genes that promote the synthesis of these nutrients (Saltzman et al., 2013). Rice breeding focuses on improving a range of traits, including nutritional value, whereas biofortification specifically targets nutrient content. Rice breeding involves methods aimed at producing new rice varieties with desirable traits, such as improved yield, disease resistance, and nutritional content. Rice breeding can be done through crossbreeding, mutation breeding, or genetic engineering, among other methods (Das et al., 2020).

Genetic manipulation has already been used to target several nutrients in rice, including vitamins, minerals, and secondary metabolites. Other metabolites such as thiamine, magnesium, and calcium have been studied for rice fortification (Birla et al., 2017). A target nutrient is selected according to its regulatory status, price, bioavailability, stability, and sensory acceptability, as well as its compatibility with the fortification technology applied (Piccoli et al., 2012).

The process of biofortification involves crossing parent lines with high levels of vitamins and minerals over several generations to produce plants with the desired nutrients. The International Rice Research Institute (IRRI) has developed high-zinc rice varieties using this breeding approach. A high-zinc rice variety was registered by EMBRAPA in Brazil in 2012, and a high-iron rice variety was released by EMBRAPA in China in 2011 using this conventional technique (Saltzman et al., 2013).

Transgenic approaches are advantageous when the nutrient is not naturally present in a crop or when sufficient bioavailable micronutrients cannot be effectively introduced by crossbreeding. However, it is a time-consuming technique, requiring several years of conventional breeding to ensure that the transgenes are stably inherited and to incorporate the transgenic line into the desired varieties (Das et al., 2020). Other barriers to this approach include legal restrictions on marketing liberalization and consumer concerns. Although this practice has shown meaningful results in improving nutritional and other desired rice traits, the biggest challenge to the transgenic approach is public concern about the acceptance and biosafety of genetically modified plants (Raven, 2010).

The first example of the transgenic approach in rice breeding was golden rice, which was first developed at the Swiss Federal Institute of Technology, which produced a variety high in beta-carotene, the precursor of vitamin A (Burkhardt et al., 1997). In addition, IRRI and the University of Melbourne have developed a transgenic high-iron rice variety (14 ppm iron in the white rice grain) that translocate iron to the endosperm, where it is unlikely to be bound by phytic acid and is therefore expected to be bioavailable (Johnson et al., 2011). Mutagenesis has been used to generate low phytate mutants, but these lines often have problematic characteristics, such as lower yields, reduced seed viability, and poor emergence compared to wild-type parents (Tan et al., 2013). However, more studies have been developed that have identified a low phytic acid rice mutant without an inferior performance (Kim & Tai, 2014; Qamar et al., 2019).

Before it is milled, a rice grain consists of the hull, pericarp, endosperm, germ, or embryo. After milling, the hull and pericarp are lost, leaving the endosperm (rich in starch) and the embryo, which consists of minerals (most of the minerals in the grain), a quarter of the protein, almost all the vitamins, and about three-quarters of the fat (Birla et al., 2017). Therefore, one way to improve the nutritional composition is to increase the size of the rice embryo, the most nutritious part of the polished grain, through genetic manipulation to obtain rice genotypes with more phytochemicals than genotypes with regular endosperm/embryo proportions (Nagasawa et al., 2013).

2.7. Glycaemic index

2.7.1. Glycaemic index of food

The concept of glycaemic index (GI) was introduced by Jenkins et al. in 1981, to classify different foods according to their glycaemic response. According to the FAO/WHO, “the GI is defined as the incremental area under the blood glucose response curve of a 50 g

carbohydrate portion of a test food, expressed as a percentage of the response to the same amount of carbohydrate (CHO) from a standard food ingested by the same subject" (FAO/WHO, 1998). The standard food is usually white bread or glucose. In a simplified way, the GI is the increase of blood glucose after ingestion of a given food and can range from less than 20% to more than 120% (Foster-Powell et al., 2002). Higher GI values indicate a more rapid rise in blood glucose levels. Carbohydrates with a high GI are digested and absorbed rapidly, resulting in a rapid rise in blood glucose, whereas those with a low GI are digested and absorbed more slowly, resulting in a slower and more gradual rise in blood glucose.

From the intrinsic point of view of the food, the glycaemic response is related to the amount and nature of the CHO that constitute it (Miller et al., 1992). CHO can be classified according to their polarization as: i) monosaccharides (e.g. glucose, fructose, galactose); ii) disaccharides, which are two monosaccharides linked by a covalent bonding (e.g. sucrose and lactose); iii) polyols, which result from the hydrogenation of mono and disaccharides; iv) oligosaccharides, which are CHO with 3 to 9 degrees of polymerization; v) polysaccharides, which have the highest degree of polymerization (from 10) and can be divided into starchy and non-starchy polysaccharides (Davidson, 2023; Sanders & Lupton, 2012).

Based on the physiological properties of the different classes of CHO, it has been proposed that they can be divided into glycaemic, which are absorbed in the small intestine and promote a rise in blood glucose, and non-glycaemic, which are not digested and pass to the colon, where they can be fermented, thus providing energy that does not interfere with blood glucose levels (Sanders & Lupton, 2012). This classification confirms and complements the hypothesis of Burkitt and Trowell (1977) on dietary fibre, which suggested that foods that are absorbed more slowly may have beneficial metabolic effects in relation to diabetes and cardiovascular risk reduction.

This is a more physiological rather than a structural approach to classifying carbohydrates and assessing the effect of different carbohydrate sources on blood glucose concentration (Jenkins et al., 1981). Therefore, based on the glycaemic response (using glucose as the standard food), foods are classified as follows: i) high GI (GI ≥ 70) are foods in which CHO are rapidly digested, absorbed and metabolized; ii) intermediate GI (56 ≤ GI ≤ 69); and (iii) low GI (GI ≤ 55), are foods in which CHO are slowly digested, absorbed and metabolized (Brand-Miller et al., 2006; ISO, 26642 - 2010).

To understand the full effect of food on blood glucose, the glycaemic load (GL) must be considered. GI and GL are both measures used to assess the impact of CHO on blood glucose levels. Although related, they are slightly different concepts. GL considers both the GI of a food and the amount of CHO consumed. The GL therefore incorporates both the quality (GI) and quantity (GL) of carbohydrates in a food. It is expressed as a numerical value as follows: high-GL - foods and beverages with a GL value of 20 g or more per serving, medium-GL - foods and beverages with a GL value between 11 and 19 g per serving, and low-GL - foods and beverages with a GL value of 10 g or less per serving. It provides a more accurate measure of a food's effect on blood glucose levels by considering the total amount of CHO in a typical serving. This concept was introduced in 1997 by researchers at Harvard University to quantify the overall glycaemic effect of a portion of food (Liu et al., 2000; Venn & Green, 2007), and for epidemiological studies the GL is adjusted for intake of energy, in line with other macronutrients and fibres (Salmerón et al., 1997).

These concepts raised controversies regarding their usefulness in the chemical classification of CHO and in dietary control (Ludwig & Eckel, 2002), with some of the most credible bodies in the field of food and nutrition did not falling to recognize the role of GI in the prevention or treatment of disease, namely the American Dietetic Association, the American Heart Association, and the American Diabetes Association (ADA, 1999; Association, 2002; Krauss et al., 2000). However, over the last four decades, a large body of evidence has demonstrated the usefulness and applicability of GI in health control and maintenance, and its specific role in supporting diabetes prevention and management (Barclay et al., 2008; Livesey et al., 2019a; Salmerón et al., 1997; Thomas & Elliott, 2009). Therefore, other qualified bodies have joined the WHO and FAO in recognizing GI and GL as reliable methods for assessing the quality of CHO in diets for the control of metabolic diseases, such as the International Diabetes Federation, the American Diabetes Association, the Diabetes UK, and the Diabetes Canada (Dyson et al., 2018; Evert et al., 2019; Greenwood et al., 2013; Mohan, Ruchi, et al., 2016; Sievenpiper et al., 2018).

The rapid digestion and absorption of type of food with a high GI triggers a response in the body that favours the storage of calories in adipocytes (Durão et al., 2017). On the other hand, a low GI food leads to a reduction in the gastric inhibitory peptide (GIP) response, which is responsible for inhibiting gastric motility and secretion, as well as increasing insulin secretion and prolonging the suppression of fatty acids (Jenkins, Kendall, Augustin, & Vuksan, 2002).

Researchers found that switching from high GI to low GI foods had a clinically important effect on medium-term glycaemic control in diabetic patients (Brand-Miller et al., 2003). Consumption of low GI foods leads to a slower and more gradual rise in blood sugar levels, reducing the risk of insulin spikes and promoting better glycaemic control. A recent meta-analysis confirmed the importance of eating low GI foods in maintaining and preventing of diabetes (Livesey et al., 2019b).

Foods with a high GI can cause rapid spikes in blood glucose and subsequent insulin secretion. These fluctuations can contribute to increased hunger, overeating, and weight gain (Zhu et al., 2021). In contrast, consuming of low GI foods may promote satiety, enhance weight loss efforts, and aid in weight management (Larsen et al., 2010).

Elevated blood glucose levels and insulin resistance due to long-term exposure to high GI diets may contribute to inflammation, dyslipidaemia, and endothelial dysfunction, all of which have been implicated in the development of cardiovascular disease (Augustin et al., 2002; Henry & Thondre, 2011; Jenkins, Kendall, Augustin, Franceschi, et al., 2002; Ludwig, 2002; Schwingshackl & Hoffmann, 2013).

The blood glucose response is not only dependent on the quantity and quality of ingested CHO. Instead, it is related to several factors that affect digestion and absorption, and consequently the degree to which glucose is returned to the blood. Thus, even when the amount of CHO is fixed, the blood glucose response can vary considerably (Kirwan et al., 2001). The observation of this variation in postprandial glycaemic response between CHO sources has been showed that the appropriate selection of CHO sources could represent a strategy for the prevention and treatment of chronic metabolic disorders (Atkinson et al., 2021; Augustin et al., 2002; Augustin et al., 2015; FAO/WHO, 1998; Jukanti et al., 2020; Yu et al., 2022).

2.7.2. Methods of evaluation of GI

The GI of a food may vary in the literature due to differences in the method of analysis and the variety and processing of the food, which in turn often depends on local customs (FAO/WHO, 1998; Foster-Powell et al., 2002). Therefore, the FAO/WHO Expert Council on CHO in Human Nutrition (FAO/WHO, 1998) recommends that endemic foods and traditional dishes from the respective regions should be included in all GI studies.

GI and GL values for many foods are now available in a searchable online database developed and continuously updated by the University of Sydney, Australia (University of Sydney, 2023). The first International Tables of GI and GL Values were published in a scientific journal in 1995 with a list of 565 foods, and in 2002 the table was updated to

include 1,300 foods (Foster-Powell et al., 2002). In 2008, the literature review was updated to include 2,487 different foods (Atkinson et al., 2008). The most recent compilation includes more than 4,000 items, divided into 21 food categories, resulting from a review of published and unpublished scientific literature (Atkinson et al., 2021). Similarly to the previous list in the 2008 version, the items have been grouped into two lists according to the quality of the data, using the accuracy and robustness of the analysis method as criteria. The first list contains data obtained using the method recommended by the International Standard Organization, which researchers consider to be the most reliable GI values. The second list includes values determined and obtained using less robust methods, which are considered reliable but not optimal for nutritional epidemiology and research.

As calculating the GI of mixed meals is somewhat more complex, this compendium considers the GI of each meal component separately, except for the more traditional dishes. In general, fruits, pulses, pasta, and dairy products have low GI, while most potatoes and processed cereals have higher GI. The values for rice, whole grains and savoury snacks were not consistent, with values falling within the three ranges of the GI. There is another table that compiles the GI of 949 non-Western foods (Henry et al., 2021). This compendium includes various endemic foods and traditional mixed dishes from Asian countries such as China, Hong Kong, Indonesia, India, Japan, Korea, Malaysia, Philippines, Taiwan, Thailand, and Sri Lanka.

The GI of a mixed meal considers the combined effect of all the foods in the meal on blood sugar levels. It starts by listing all ingredients in the meal and their quantities. Then, once the GI of each ingredient is known, the GI of the meal is calculated by taking the weighted average of the GI values based on the proportions of the foods in the meal [weighted Average GI = (GI of food 1 × amount of food 1) + (GI of food 2 × amount of food 2) + ...], then the sum of (GI × amount) for each food must be divided by the total amount of the mixed meal (Wolever & Bhaskaran, 2012). The formula to calculate the GL is as follows: GL = (GI × carbohydrate content per serving) / 100.

The GI and GL of individual foods may not accurately predict the glycaemic response (Alfenas & Mattes, 2005; Ballance et al., 2019; Flint et al., 2004; Glicksman et al., 2019; Jenkins, Kendall, Augustin, Franceschi, et al., 2002; Vetrani et al., 2022) because it is influenced by several factors, both food and individual (González-Rodríguez et al., 2019; Vega-López et al., 2007). For example, different foods in a meal can interact with and affect the overall glycaemic response. The presence of certain nutrients, such as fat, protein, and fibre, can affect the rate of digestion and absorption of carbohydrates,

leading to a slower and more gradual increase in blood glucose levels (González-Rodríguez et al., 2019; Gümüş et al., 2021). However, researchers continue to advocate the use of GI and GL in dietary assessment as reliable determinants of the glycaemic response to meals (Ballance et al., 2019; Brand-Miller et al., 2006; Rozendaal et al., 2018; Wolever & Bhaskaran, 2012; Wolever et al., 2006), because despite the influence of other components in the body and the interaction between ingredients, these do not affect the relative differences between foods containing CHO (González-Rodríguez et al., 2019; Jenkins et al., 1988; Wolever et al., 1985).

In addition to food factors, the glycaemic response to food is also influenced by genetics (Carpenter et al., 2015), insulin sensitivity (Himsworth, 1934), exocrine pancreatic and glucose transporter activity levels (Gibbs et al., 1995), lifestyle (Dunstan et al., 2012), and the gut microbiome (Berry et al., 2020; Zeevi et al., 2015). This means that even if two people consume the same mixed meal, their glycaemic responses may differ. Therefore, personalized diets have been advocated to reduce glycaemic response to control metabolic diseases (Berry et al., 2020; Mendes-Soares et al., 2019; Vega-López et al., 2007; Vrolix & Mensink, 2010; Zeevi et al., 2015).

Another factor that should not be neglected when assessing postprandial glycaemic response is meal sequence. There is evidence that the tolerance of a second meal of CHO may be improved if the preceding meal has a low GI, and that there may also be reduced food intake at the subsequent meal (Jenkins, Kendall, Augustin, Franceschi, et al., 2002; Wee & Henry, 2020). Consumption of protein and/or fat before CHO stimulates gut glucagon-like peptide-1 secretion, improves insulin and glucagon secretion, delays gastric emptying, and improves postprandial glucose excursions. Glucagon-like peptide-1 is important for weight control because it suppresses appetite by acting on the hypothalamus (Kubota et al., 2020). Therefore, although the GI and GL values provide valuable information, it is important to consider the context of the overall meal composition and individual factors for a more accurate assessment of glycaemic response.

The FAO/WHO (1998) recommended that the standard methods and reference foods (glucose or white bread) should be used for GI analysis (Foster-Powell et al., 2002). Some authors have advocated the use of white bread as reference food because it has a greater effect on stimulating insulin release (Jenkins, Kendall, Augustin, Franceschi, et al., 2002; Jenkins et al., 1988; Wolever et al., 1985). On the other hand, it is argued that the amount of CHO in white bread is much less rigorous than that of glucose, mainly because its composition varies between regions (Pi-Sunyer, 2002). In 2010, the

International Standards Organization published a detailed and rigorous methodology for the determination of GI, considering both standard foods (ISO, 26642 - 2010). However, the most used reference is glucose on a 100-point scale; when bread is used as a reference, the GI value is multiplied by 0.71 to obtain the GI value with glucose as the reference food (Atkinson et al., 2008). White rice has also been used as a reference food in GI determinations (Sugiyama et al., 2003), which is acceptable because the ISO standard allows other specific carbohydrate foods of consistent composition. To convert the values to the 100-point glucose scale, the GI obtained is multiplied by 0.82, as glucose has a GI of 122 compared to white rice (Atkinson et al., 2021).

The postprandial GI can be measured both *in vivo* and *in vitro*. The ISO 26642/2010 standard recommends the following steps to determine the glycaemic response *in vivo*:

- The selection criteria of the subjects for the study have been established. Normally, a group of healthy individuals (without any metabolic disease) is used, unless the objective of the study requires a different selection.
- Participants are required to fast for a period before the start of the test (10 h or more before the test), usually overnight, to establish a baseline.
- Participants are given a specific amount of test food containing a fixed amount of available carbohydrate. The food is consumed within a set time frame.
- Blood samples are taken at regular time intervals to determine blood glucose levels over time following ingestion of test food.
- The glycaemic response is determined by calculating the area under the blood glucose curve for the test and reference foods.
- The GI is calculated by dividing the area under the blood glucose curve of the test food by the area under the curve of the reference food and multiplying by 100 to give a percentage.

Capillary blood is collected after fasting and eating. Six time points are specified for blood sampling: 0, 15, 30, 45, 60, 90, and 120 minutes. The ISO (26642:2010) recommendations include repetition of the reference food to reduce the effect of daily variations in glucose tolerance and the use of standardized time points for blood sampling.

The digestibility of food starch can be better explained by *in vivo* studies; however, this approach has certain ethical and consumer availability challenges (Sivakamasundari et al., 2022). Given the complexity and cost of consumer time and availability, various digestion models have been developed to mimic the human gastrointestinal tract, thereby popularizing the in vitro approach. The *in vitro* approach is faster and more cost-

effective and is therefore useful for food GI screening during the development and optimization of processes that precede *in vivo* GI testing (Germaine et al., 2008).

There are two different types of *in vitro* digestibility assessment: restricted and unrestricted. Restricted *in vitro* digestibility limits access of digestive enzymes to food samples. Typically, food samples are subjected to short exposures to digestive enzymes under specific conditions, such as low pH (acidic environment) and limited incubation time (Englyst et al., 1992; Goñi et al., 1997). This method uses a dialysis membrane-based approach to analyse *in vitro* glucose release behaviour. Researchers have proposed the use of dialysis tubes and bags to mimic the small-intestinal phase of digestion (Kumar, Sahoo, Baisakha, et al., 2018; Rajkumar et al., 2020). In contrast, the unrestricted method allows for full access to digestive enzymes in food samples. This method uses laboratory dishes are used for food mixing and digestion. Food is exposed to a wider range of digestive enzymes, including pepsin, pancreatin, and intestinal brush border enzymes such as amylases, for longer periods of time (Brennan et al., 1996; Jenkins et al., 1984). This method aims to mimic the complete digestive process of the human digestive system. This provides a more comprehensive assessment of food digestibility. Typically, enzymes such as α-amylase, which breaks down starch into smaller fragments, and amyl glucosidase, which hydrolyses starch fragments into glucose, are used (Sivakamasundari et al., 2022).

2.7.3. Glycaemic Index of Rice

The GI of rice has been tested several times over time, with different results even for the same variety. Rice has the highest average GI, surpassed only by potatoes, where 58% of the varieties are high GI foods, while 38% of rice varieties fall into this category (Atkinson et al., 2021). In the International Table of GI and GL Values (2021), 126 rice entries were collected, with a mean GI (± SD) of 67 (± 17). This included brown rice, milled rice, and even low GI rice such as *Doongara* rice from Australia and Mighty rice from Mauritius. Milled rice (white rice) had an average GI of 73, while brown rice had an average GI of 65. This difference could be due to several factors; it could be due to the presence of fibre, the variety difference, or even the method of cooking or industrial processing (Boers et al., 2015).

This compendium does not include any Portuguese rice varieties, but it does report the GI of some Japonica varieties from other countries. This subspecies, due to its low amylose content, has a GI ranging from 69±7 to 91±7. A study evaluating some rice varieties in the Portuguese market, including local rice such as *Ariete* and *Ronaldo*

estimated GI values, 74 and 71, respectively (Pereira et al., 2023). The GI was estimated using the *in vitro* starch digestion method proposed by Goñi et al. (1997).

Prasad et al. (2018) evaluated the nutritional composition of eleven popular Indian rice varieties and found that Lalat was the only one with low GI, high iron, and riboflavin content, and moderate phytate content, suggesting it as a good option for a balanced diet and diabetes prevention. Among the Indian varieties, some Basmati specialities have a medium or low GI. In the international GI table, polished basmati rice (white, polished, cooked) ranged from 50±6 to 80±8, while unpolished basmati rice had 75±8, parboiled basmati 52±6, and mixed basmati (brown and white, or white and wild) ranged from 59±9 to 63±8.

The glycaemic properties of rice depend on intrinsic factors such as amylose/amylopectin ratio and micronutrient and macronutrient interactions (Augustin et al., 2002; Khatun et al., 2022; Prasad et al., 2018; Tao et al., 2019), and extrinsic factors such as processing (e.g. milling, parboiling) (Boers et al., 2015; Islam et al., 2002; Nakamura et al., 2022; Park et al., 2022) and cooking methods (Jenkins, Kendall, Augustin, Franceschi, et al., 2002; Park et al., 2012; Yu et al., 2010).

The amylose/amylopectin ratio is inversely related to the GI of rice; amylose is negatively correlated with an increase in GI (Prasad et al., 2018). Starches with high amylose content are digested more slowly, require higher gelatinization temperatures and are more prone to retrogradation reactions (FAO/WHO, 1998; Fitzgerald et al., 2011; Prasad et al., 2018). Therefore, rice with a higher amylose content has a lower GI (Goddard et al., 1984; Kataoka et al., 2013; Ohtsubo et al., 2016).

There are three types of starch in foods: rapidly digestible starch, slowly digestible starch, and resistant starch (RS) (Englyst et al., 1992). It has been confirmed that the higher content of slowly digestible starch or RS contents plays a crucial role in reducing of postprandial blood glycaemic response (Xu et al., 2012; Zhang et al., 2022). Therefore, improving the content of slowly digestible starch and RS has attracted much attention.

Most starch is digested and absorbed in the small intestine, however, a small portion escapes digestive enzymes and passes into the colon where it can be fermented. This portion of starch is the RS and can occur naturally (AR1 and AR2) or because of food processing (AR3 and AR4) (DeMartino & Cockburn, 2020; Raigond et al., 2015; Sanders & Lupton, 2012).

As RS is not hydrolysed in the upper gastrointestinal tract, it reaches the colon, where it is fermented by the microbiota to release short-chain fatty acids, which feed colorectal

cells and microflora. RS fermentation also produces acetate and propionate, which influence glucose and cholesterol metabolism in humans (Li et al., 2020).

The presence of fibre, fat, protein, and phytochemicals in rice grains influences the postprandial response (Nakamura et al., 2022; Verma & Srivastav, 2020). The mixture of fat and carbohydrate acts as a glycaemic response reducer due to the formation of an inclusion compound between lipid and amylose, with the hydrocarbon portion of the lipid located in the helical cavity of amylose, with the hydrocarbon portion of the lipid located within the helical cavity of the amylose, which prolongs the hydrolysis of amylose and slows the postprandial serum glucose and insulin response (Guraya et al., 1997; Larsson & Miezis, 1979; Murray et al., 1999). The phytic acid present in rice has a beneficial effect on starch hydrolysis, reducing blood glucose levels, improving colon health, and reducing gastric emptying. The hypoglycaemic effect can be attributed to the reduction of intestinal amylase activity and, consequently, poor digestion and absorption of carbohydrates (Kumar, Sahoo, et al., 2022). According to Kumar et al. (2020), the higher the phytic acid content, the lower the starch hydrolysis rate, and consequently, the lower the GI. Ye et al. (2018) found that endogenous dietary proteins led to a reduction in the rate of starch hydrolysis, thereby reducing the GI in Indica rice cultivars. They also found that proteins and lipids reduce starch swelling, probably by forming a coating around the starch granules that prevents swelling and reduces digestive enzyme action, and that lipids are more effective than proteins in decreasing starch digestibility.

Using this knowledge, researchers have presented rice with a high amylose content as a strategy for the prevention of diabetes (Fitzgerald et al., 2011; Ohtsubo et al., 2016), and it is important and urgent to improve the genetic factors that influence GI to obtain rice that is nutritionally adequate for the current food scenario (Fitzgerald et al., 2009b; Fitzgerald et al., 2011; Huang & Hu, 2021; Mohan, Anjana, et al., 2016).

Ohtsubo et al. (2016) suggested the replacement of the commonly high GI varieties with a rice variety with a high amylose content, fibre, and resistant starch content. Ordonio and Matsuoka (2016) also suggested the addition of resistant starch to rice as a strategy to improve the health of populations with high rice consumption. Meanwhile, high-fibre white rice has been developed in India to address the high rice consumption and incidence of metabolic disorders (Mohan, Anjana, et al., 2016). Although genetically modified varieties with low GI have been developed, their palatability is lower, resulting in rice with high hardness.

A rice mutant with high 5RS content was developed by Zhou et al. (2016). The 5RS type is an amylose-lipid complex that is immiscible in water and inhibits the expansion of

starch granules during cooking, thereby limiting their digestion (Kumar, Sahoo, Baisakha, et al., 2018).

2.7.4. Extrinsic factors affecting GI of rice

Genetic engineering has advanced the development of low GI rice (Jukanti et al., 2020; Mohan, Anjana, et al., 2016; Ohtsubo et al., 2016; Ordonio & Matsuoka, 2016). However, studies have found that genetic modification of this trait leads to reduced rice yield, penalty on cooking quality, and textural qualities (Jukanti et al., 2020; Tao et al., 2019). Nonetheless, it is also possible to moderate GI values through external factors, such as cooking conditions, recipe formulation, and processing methods (Baggio et al., 2023; Chelliah et al., 2019; Kim et al., 2019; Ritudomphol & Luangsakul, 2019; Sun et al., 2014; Tamura et al., 2016).

Manipulation of external factors seems to be faster and more effective for several reasons. Firstly, because the adaptation of a new cultivar depends on the climatic conditions of a given country, and secondly, because the local variety of a country is part of a cultural and gastronomic heritage that needs to be preserved. Finally, the integration of a new cultivar depends on consumer acceptance. In Portugal, for example, traditional rice dishes are made with *Carolino* rice to obtain the desired and long-established sensory characteristics; just as in Italy, to make a good risotto, genuine rice is used for this specific dish, such as Arborio, Carnaroli or Vialone.

For most starchy foods, a decrease in GI appears to be accompanied by an increase in resistant starch (RS) content, through retrogradation of the amylose component or even starch crystallization and incomplete gelatinization, which reduces the rate of starch digestion (Björck et al., 2000; Prasad et al., 2018).

The following topics relate to the main external methods that can be used to reduce the GI of rice.

→ Harvest and postharvest conditions

The content and nutritional quality of CHO can be altered by harvesting and postharvest processing conditions. Variation in amylose content of the same rice variety can vary depending on several cropping factors, such as the location of the field, growing season, time and rate of nitrogen fertilizer application, solar radiation during grain development and herbicide application (Aboubacar et al., 2006; Ahmed et al., 2007; Beckles & Thitisaksakul, 2014; Kale et al., 2015). This affects the GI of rice, because the amylose/amylopectin ratio is inversely related to the GI of rice.

To ensure the safety and organoleptic quality of wet paddy, it must be dried to below 14% humidity before milling (Rice Knowledge Bank, 2022). Different methods were used to dry the paddy and the drying conditions were found to influence the final GI of the rice. Compared to sun-dried rice, cooked rice obtained from hot air drying has a lower GI; moreover, the higher the drying temperature, the lower the GI, with 90 °C being the optimum temperature to obtain the lowest GI (Donlao & Ogawa, 2017).

In raw paddy and milled rice, temperature and moisture conditions have been manipulated to reduce the GI of postharvest rice. Thuengtung et al. (2023) found that mild heat-moisture increased RS without affecting rice hardness when applied for a long time. Oh et al. (2018) investigated the effect of dry heat treatment and found that heating temperature was negatively correlated with starch digestibility *in vitro*. However, this study used high-amylose rice, which distracts from the main issue, as it will have a lower GI than low-amylose rice.

Milling increases the GI of rice (Boers et al., 2015; Panlasigui & Thompson, 2006; Trinidad et al., 2013). The influence of the degree of milling on GI is explained by the fact that the presence of fibre in brown rice acts as a barrier to digestive enzymes, and because white rice is more easily hydrated and gelatinized than brown rice, it is more easily digested, resulting in a greater glycaemic response when cooked under the same conditions (Chang et al., 2014). Naturally, the GI of brown rice is lower than that of milled rice; however, as it requires longer cooking time, this difference decreases as cooking time increases (Boers et al., 2015), and in some cases, the GI of brown rice is higher than that of its milled counterpart, as has been found for *Doongara* and Basmati varieties (Atkinson et al., 2021; Foster-Powell et al., 2002)

Parboiling is an industrial process that has sensory and functional effects on rice. During parboiling, raw rice grains are soaked in water and partially steamed before drying and milling, resulting in further migration of some vitamins into the grain (Manful et al., 2007). Several studies have reported that the GI of rice is reduced by this processing (Boers et al., 2015; Cheng et al., 2019; Gunaratne et al., 2013; Kataoka et al., 2013; Kongkachuichai et al., 2020). During processing, gelatinization followed by starch recrystallization increases the final gelatinization temperature of rice, thereby reducing its GI (Kumar, Lal, et al., 2022; Yin et al., 2023; Zavareze et al., 2010). The gelatinization temperature of rice increases proportionally with the severity of heat treatment (Islam et al., 2002; Larsen et al., 2000) and amylose content (Zavareze et al., 2010). Larsen et al. (2000) reported that more severe steaming conditions resulted in a reduction in GI of almost 30% compared to non-steamed rice. Parboiling reduces the viscosity of rice,

possibly allowing leached amylose to retrograde and/or to form inclusion complexes with seed surface lipids (Boers et al., 2015; FAO/WHO, 1998; Kataoka et al., 2013).

Non-thermal treatments, such as pulsed electric fields, have also been tried for this purpose, but without success (Bai et al., 2021), in contrast to the application of gamma radiation and radiofrequency, which have been shown to be useful in lowering the GI (khatun et al., 2021; Zhang et al., 2022).

Gamma radiation increases the amylose content of rice due to the vibrations of bonds (C-O and C-H) caused by radiation, which can induce molecular reorganization and cross-linking of irradiated rice starch chains (Bhat & Karim, 2009; khatun et al., 2021; Yassien & El-Bakary, 2019). In turn, radiofrequency treatment increased the resistant starch content of rice starch and reduced the rapidly digestible starch content, as this wave caused granule surface erosion and morphological changes (Zhang et al., 2022). Additionally, microwaves and electromagnetic waves with higher frequencies and energies were tested for their ability to reduce starch digestibility. Microwave treatment or pretreatment of rice also alters the starch structure via dehydration and/or molecular rearrangement of starch granules (Guo et al., 2019; Zhong et al., 2020).

→ Cooking and other cultural habits

After postharvest processing, domestic consumption of rice involves additional processes such as cooking, storage, and reheating. However, in some cultures, pre-cooking steps such as soaking, sprouting or fermentation are used before cooking rice. These practices can improve the nutritional value of rice and provide some sensory benefits. For example, when these practices are applied to brown rice, the texture and mineral content are improved. The increase in mineral content is due to a reduction in phytic acid content (Birla et al., 2017).

Soaking is part of several other domestic and industrial practices, such as parboiling, sprouting, and fermentation. It is one of the most critical steps in parboiling, as it changes the gross composition and distribution of nutrients in the grains (Dutta & Mahanta, 2012; Otegbayo et al., 2001). Soaking involves the diffusion of water into the rice grains, with 40% to 45% moisture considered optimal for starch gelatinization (Bhattacharya, 1985). The chemical composition, GI and starch characteristics of rice have been positively influenced by rice soaking (Hu et al., 2020; Kim et al., 2020; Lal et al., 2021; Yu et al., 2017; Yu et al., 2015), thereby improving the sensory and nutritional quality of cooked rice. Under certain temperature conditions, this practice decreases the amylose-to-amylopectin ratio, increases the crude fibre content, and decreases the GI (Kale et al., 2015). The decrease in GI with increasing immersion temperature can be attributed to

the formation of additional amylose-lipid complexes and partial gelatinization of starch (Kale et al., 2015; Mir & Bosco, 2013; Otegbayo et al., 2001; Sareepuang et al., 2008).

When subjected to sprouting, brown rice undergoes an improvement in protein components, phenolic acids, γ-oryzanol, and fibre, and induces the formation of new bioactive compounds, such as gamma-aminobutyric acid (GABA) (Cáceres et al., 2019; Cho & Lim, 2016; Patil & Khan, 2011; Roohinejad et al., 2010), which determines the name as it known (Gaba rice). Patil and Khan (2011) verified that the optimal conditions for obtaining the highest GABA content in germinated brown rice are soaking in water at 30°C for 3 h and sprouting for 21 h.

Studies have shown that replacing sprouted brown rice with white rice in individuals with impaired glucose tolerance or type 2 diabetes increases HDL cholesterol, decreases serum triglycerides and LDL cholesterol, and reduces the glycaemic response (Kongkachuichai et al., 2020; Na et al., 2023; Roohinejad et al., 2010). The hypocholesterolaemia effects of sprouted rice are mainly due to the formation of GABA (Roohinejad et al., 2010), which affects the gut microbiota (Ren et al., 2023). In addition, some studies have reported that consumption of germinated browns boosts the immune system, lowers blood pressure, inhibits the development of cancer cells, aids in the treatment of anxiety disorders, and has a calming effect (Hayat et al., 2015; He et al., 2019; Ito et al., 2005; Oh & Oh, 2004).

The culinary flexibility of rice, both in terms of preparation and combination, also allows an increase in the nutritional value of meals, and the addition or combination with suitable foods can reduce its GI (Kumar, Sahoo, Sahu, et al., 2018; Salis et al., 2021). Macronutrient composition and physicochemical reactions *in vivo* influence the postprandial GI response to mixed meals (Kim et al., 2019). In many cultures, intelligent combinations of ingredients are used to achieve better nutritional balance in rice (Juliano, 1993; Salis et al., 2021).

The consumption of rice meal with a mixture of brown rice, barley, pulses, fat, or vegetable oils results in a decrease in starch digestibility (Baggio et al., 2023; Jang et al., 2012; Jang et al., 2001; Kumar, Sahoo, Sahu, et al., 2018; Zhang et al., 2016). Mohan et al. (2014) verified that the addition of pulses to a brown rice meal significantly reduced glycaemic responses compared to white or brown rice diets consumed by overweight Indians without diabetes. Mixed brown rice, barley, and black bean meal were tested in Korean patients with coronary artery disease and were found to reduce fasting glucose, insulin, and lipid peroxidation levels (Jang et al., 2001).

Some of these beneficial mixed dishes or meals are typical recipes of certain gastronomic cultures and their preparation is not even intended to lower the GI of rice (Salis et al., 2021). For example, the co-ingestion of rice and beans, typical of South and Central America (Monge-Rojas et al., 2014; Passos et al., 2014; Thompson et al., 2012), the incorporation of seaweed in rice recipes in some Asian countries (Sugiyama et al., 2003), the addition of ghee (clarified butter) in India (Kumar, Sahoo, Sahu, et al., 2018; Salis et al., 2021), and the co-ingestion of rice and milk (Sun et al., 2017) used for breakfast in Nordic countries (rice porridge). Milk has the potential to reduce GI due to both lactose and milk proteins, which have insulinotropic effects (Nilsson et al., 2004).

In general, mixing rice with high-protein ingredients reduces the glycaemic response. This effect is thought to be due to the formation of a protective layer around the CHO molecule, which protects it from the action of glycolytic enzymes (Bornet et al., 1987). This may also be related to the Maillard reaction, in which starch forms insoluble complexes with proteins, making them unavailable for digestion and absorption, resulting in a reduction in the GI value (Foster-Powell et al., 2002). In the case of fat and vegetable oils, the reduction in the postprandial glycaemic response is explained by an increase in the viscosity of the intestinal contents and a decrease in the rate of gastric emptying (Diniz et al., 2008). In addition, fat can bind to amylose, making it less susceptible to its action (Siswoyo & Morita, 2001).

Organic acids are commonly used in Asian cuisine. For example, the CHO structure of rice in sushi can be modified by the addition of vinegar during preparation and refrigeration (Atkinson et al., 2021), and the addition of tamarind to *puliyodharai* (a typical Indian dish) has the same effect on the CHO structure (Sugiyama et al., 2003).

The continued recommendation to include traditional foods/dishes from each region in the GI analyses is precisely because of these pre-cooking, culinary practices and rice cooking methods that cause changes in the CHO structure and, consequently, in the GI of typical/traditional foods (Atkinson et al., 2021; FAO/WHO, 1998). For example, in Portugal and other southern European countries, where japonica rice is mainly cultivated, typical dishes are cooked in large amounts of water, resulting a more creamy and/or brothy rice, such as *Malandro* rice (from Portugal) and risotto (from Italy); when the starch is heated in the presence of excess water, the crystalline structure of the starch is broken by gelatinization, which promotes its susceptibility to amylolysis, thus resulting in cooked rice with a very low RS content, i.e. with a high GI (Miller et al., 1992).

The effect of food or meal sequence on glycaemic response is a household practice that cannot be overlooked. Studies have shown that consuming fruits, vegetables, oats, and

other sources of fibre, fructose, and glucose as a pre-load before meals contributes to lower blood glucose levels (Akhavan et al., 2014; Heacock et al., 2002; Steinert et al., 2016). Small amounts of macronutrients provided by these foods before meals may promote the release of gut peptides, such as gastric inhibitory peptide and glucagon-like peptide-1, to delay gastric emptying and insulin secretion before meals (Wu et al., 2011). Zhao et al. (2020) found that consuming dried apples before a rice meal significantly lowered the postprandial glycaemic response. It has been reported that when a low GI meal precedes a high GI meal, there may be an improvement in tolerance to CHO in the second meal, in addition to promoting lower food intake in the meal following the low GI (Haldar et al., 2020; Jenkins, Kendall, Augustin, Franceschi, et al., 2002).

→ Food processing

Studies have reported that rice consumption, in general, has decreased due to health and convenience issues; to counteract this decline, researchers have advanced the processing of rice products to provide consumers with healthier and more convenient rice (RTE-rice) that meets consumer expectations (Arribas et al., 2019; Cha et al., 2012b; Kwak et al., 2015; Yu et al., 2017; Yu et al., 2010).

The main strategy used in food processing to reduce the GI of rice is a starch modification by a variety of methods, as several starch characteristics, such as its digestibility, can be altered (Wee & Henry, 2020; Xu, Li, et al., 2021).

Sun et al. (2010) found that replacing 50 g/day of white rice with the same amount of brown rice was associated with a 16% lower risk of type 2 diabetes. However, brown rice is less commonly consumed because the presence of bran makes it difficult to absorb water, resulting in rice of poor quality for the consumer (Mohapatra & Bal, 2006; Yadav & Jindal, 2007). For this reason, ways have been developed to make it easier to consume, including the development of brown rice convenience products. New technologies to modify the texture of brown rice have also been tested. Li et al. (2022) tested combinations of enzymatic and ultrasound treatment in different ways to improve textural attributes of brown rice by optimizing bran cellulase hydrolysis.

Instant rice is produced by dehydrating cooked brown rice, so to make it more suitable for diabetics, (Ritudomphol & Luangsakul, 2019) evaluated different cooking conditions. They found that the GI decreased as the cooking temperature decreased and the water-to-rice ratio increased, suggesting that the optimal cooking conditions for producing lower GI instant rice are 82 °C with 1.9 times the water volume.

The domestic practices previously described have been experimented with by researchers/industries with the aim of developing a simple cost-effective method for preparing rice with a lower GI. Baggio et al. (2023), tested two formulations with rice for whole-wheat risotto and found that the incorporation of both chickpeas and lentils and beans resulted in a risotto with a GI of less than 50. The experiment also included post-purchase home cooking procedures, such as cooling and heating. These steps did not affect sensory acceptance or increase the RS content of meals.

The properties of sprouted rice are enhanced by fermentation; therefore, this processing has been used to obtain products with probiotic functions (Cáceres et al., 2019; Pino et al., 2022). Fermentation has been shown to be beneficial in reducing GI, even without the synergy of germination, due to the presence of resulting organic acids that reduce GI, both by reducing the gastric emptying rate and by reducing the starch digestion rate (Liljeberg et al., 1995; Mutlu et al., 2022).

Cooking methods involving the addition of acids, a traditional practice in Asia, were investigated to obtain RS-enriched cooked rice. Different types of rice were subjected to different cooking methods and food additives in soaking water, and it was found that soaking brown rice in water with citric acid or soybean oil cooked under pressure (15 psi) at 121°C for 30 min resulted in rice cooked with high RS content. This cooking method is known as retort cooking (Kim et al., 2020).

Polyphenols are considered functional ingredients due to their antioxidant, anti-tumour, and enzyme-inhibitory properties (Sun & Miao, 2020). Researchers have reported that polyphenols can reduce the rate of starch hydrolysis by inhibiting the activities of digestive enzymes or acting as physical barriers between enzymes and starch (Chen et al., 2020). Therefore, the addition of dietary phenolic extracts and pure polyphenols proved useful in the processing of low GI rice, as confirmed by Zheng, Tian, Kong, et al. (2021), who added Chinese berries and leaves (rich in polyphenols) to rice starch, suggesting it as a new method to produce functional starch with slower digestion. Another way to get the benefits of polyphenols was to cook rice with tea products. Polyphenols and caffeine in tea inactivated amylase and delayed starch hydrolysis (Fu et al., 2020).

The slow digestion of rice with polyphenols is due to the interaction between the hydroxyl groups that characterize polyphenols and starch, which form a phenol-starch complex through hydrophobic bonds (Zheng et al., 2020). The enzyme α-amylase therefore does not hydrolyse starch as it is physically inaccessible (He et al., 2021; Qadir & Wani, 2022). Factors such as the amount of phenolic compounds (He et al., 2021; Zheng et al., 2020;

Zheng, Tian, Ogawa, et al., 2021), the time of starch-polyphenol interaction and the type of starch and polyphenol used (Kan et al., 2020), the size of the compound molecule (D'Costa & Bordenave, 2021), and pH (Chou et al., 2020), directly influence the process of GI reduction GI.

Temperature changes during cooking and/or storage can lead to changes in starch structure. Increasing the cooking time of rice increases starch gelatinization, which in turn dramatically increases the availability of starch for digestion by amylases, thereby increasing the glycaemic response (Jung et al., 2009). Gelatinization refers to the irreversible loss of crystalline regions in starch granules after heating in the presence of water (FAO/WHO, 1998). To minimize the destruction of grain structure during cooking, which favours starch gelatinization, attention must be paid to the mechanical processes involved in cooking (Tamura et al., 2016).

Aware of the influence of heat treatment and cooling on starch structure, Yadav et al. (2009) tested the combined effects of these two factors. They proposed the use of multiple heating/cooling cycles to increase the RS content and reduce the GI of rice. The production of quick-cooked (pre-cooked) rice has also been reported to have a positive effect on GI because of the partial gelatinization of starch caused by immersion in heated water (Casiraghi et al., 1993; Ranawana et al., 2009).

While cooking time has a strong influence on gelatinization, retrogradation is influenced by refrigeration and storage conditions (Boers et al., 2015). Cooling cooked starch leads to starch retrogradation, which in turn increases the RS content (Sonia et al., 2015). Retrogradation – the recrystallization of amylose and amylopectin by cold storage and subsequent rearrangement of starch molecules - reduces the rate of starch digestibility and increases the content of resistant starch in cooked rice, thereby lowering the GI of rice (Amin et al., 2020; Jayawardena et al., 2017; Tian et al., 2021).

Chiu and Stewart (2013) evaluated the combined effect of the cooking method (baked oven, conventional stove, and pressure cooker), variety (jasmine, long grain, medium grain, and short grain), storage time and temperature of rice on the formation of RS. They quantified the RS content immediately after preparation and after three days of refrigeration at 4°C. They found that refrigerated rice had a higher resistant starch content and that the long-grain variety, cooked conventionally on a stove, had a higher RS content, while refrigerated short-grain rice cooked in a pressure cooker had the lowest RS content. The positive effect of the combination of low temperature and longer storage time on the formation of RS was also confirmed by Sonia et al. (2015), who also

observed a significant reduction in the glycaemic response when the individual ate cooled cooked white rice compared to the same freshly cooked rice.

Extrusion is a common food processing technology in which food undergoes mechanical shear at relatively low humidity and high temperatures. As a result of this process, food properties such as texture, microstructure, colour, and flavour are greatly altered (Camire et al., 1990). In terms of chemical composition, this processing reduces the crystalline structure of rice and delays its digestibility (Guha et al., 1997; Yang et al., 2020).

The combination of polyphenols and extrusion process generated positive synergies. Co-extrusion of rice with different concentrations of grape seed proanthocyanidins at low temperatures significantly decreased the rate of starch digestion (Zheng et al., 2020).

Glycaemic control strategies in domestic and industrial environments should reduce the amount of carbohydrates available for digestion (GL control), decrease the speed of food digestion, and decrease the speed of glucose absorption (GI control). In general, the following strategies have been followed to reduce the GI of rice and rice products: i) use of preprocessing/pre-cooking, resulting in bioactive compounds capable of influencing the glycaemic response; ii) optimization of cooking parameters (time, temperature, amount of water, and cooking method); iii) addition of functional ingredients or (co-ingestion) suitable meal components; and iv) meal sequencing. The latter is more closely related to the behaviour consumers should adopt.

2.7.5. Regulation and labelling of the GI

Current international dietary guidelines emphasize the importance of a diet rich in fruits and vegetables, pulses, and whole grain cereals (less processed foods) but differ in GI (Cámara et al., 2021; EFSA Panel on Dietetic Products & Allergies, 2010b; WHO, 1998). As early as 1998, the WHO and FAO recommended that GI be used as a useful indicator in choosing a healthy diet and advised that sources of CHO were preferably rich in non-starch polysaccharides and with a low GI (FAO/WHO, 1998). Over the years, more evidence of the association between high GI diets and a higher risk of developing non-communicable chronic diseases has been reported, leading some countries to place this issue on the health policy agenda (Barclay et al., 2021).

According to the International Diabetes Federation (IDF), there are currently 463 million people living with diabetes, and this number is expected to increase to 700 million by 2045 (IDF, 2021). This organization, which brings together over 230 national diabetes associations in more than 160 countries, has used this concept in patient education and

recommends a low-glycaemic diet for patients with type 2 diabetes to achieve optimal glycaemic levels.

Experts have reinforced the need for bodies issuing dietary recommendations to consider the classification of foods based on GI and GL in their healthy eating policies. For labelling, although the GL considers the amount of CHO present in the food, it is recommended to use the GI instead of the GL, as portion sizes vary according to the product and macronutrients are not adjusted for energy value (Salmerón et al., 1997). They also warned about the benefits of low GI foods for the European population, which have conditions that can significantly affect glucose metabolism, such as ageing, a sedentary lifestyle, and being overweight (Augustin et al., 2015). International Carbohydrate Quality Consortium (ICQC) stated the urgency of communicating information on GI and GL to the public and health professionals through channels, such as national dietary guidelines, food composition tables, and food labels (Augustin et al., 2015). Appealing, simple, and informative labelling can be an effective means to promote the consumption of healthy foods, because many consumers' decisions are made at the point of sale, considering external cues such as labels (Mayer et al., 1989; Reyes et al., 2019; Volkova & Ni Mhurchu, 2015).

Some regulatory authorities indicated that one of the constraints to the regulation of GI labelling is the difficulty for consumers to understand the GI concept (Aziz et al., 2013). Experts countered that regulation could prevent access to misleading information about GI, providing accurate guidance and information on the subject, thus helping consumers make healthier food choices (Aziz et al., 2013; Wolever, 2013). The benefits of regulating and popularizing this metric are evident for consumers in Australia and New Zealand, where this practice is well-established. Studies have shown that, since the introduction of GI claims on food labels, there has been a decrease in the average GI and GL of the population's diet (Kusnadi et al., 2017; Yeung et al., 2018).

Experts generally agree that consuming low GI foods and following a low GI diet can be advantageous for individuals with diabetes or impaired glucose metabolism. Nevertheless, the legalization and communication of low GI can vary across countries.

→ The European Union and the United Kingdom

Europe is moving towards a harmonized regulatory system for nutrition and health claims based on a permitted list of ingredients, additives, and others. Rules on nutrition and health claims have been established by Regulation (EC) No 1924/2006. This regulation covers all commercial communications, including product labelling, advertising, and the

presentation of food products sold to consumers (EFSA, 2006). However, there is no obligation to label the GI of food products has been established (Barclay et al., 2021).

The European Dietary Reference Values (DRVs) for Carbohydrates established by the European Food Safety Authority (EFSA) do not include specific recommendations on GI (EFSA Panel on Dietetic Products & Allergies, 2010a). However, when transposed into national guidelines, authorities and advisory bodies in some member countries made some considerations regarding GI. France and Germany have taken positions against GI labelling, citing "the level of evidence is insufficient to provide guidance on GI based on health benefits for the general population and have prohibited the use of GI labelling or derived measures" and "to date, there is only possible evidence of a risk-increasing effect of a high GI on some diet-related diseases" (Barclay et al., 2021; Hauner et al., 2012).

The DRVs of the Italian Society of Human Nutrition contain general qualitative indications of preference for foods with low GI content when carbohydrate intake approaches the upper intake limit (60% energy). It has also been established that foods with a low GI should be preferred unless the GI is reduced by the addition of fructose and/or fat (SINU, 2014). In 2017, the Italian Ministry of Health issued an interpretative letter to Regulation (EC) No. 1924/2006, stating that if a food obtains formal approval for a health claim on the reduction of postprandial glycaemic response, it is possible to use GI information on food packaging (Barclay et al., 2021).

The Nordic Nutrition Recommendations also state that there is insufficient evidence that choosing foods with low GI reduces the risk of chronic disease in the general population. However, they believe that there is suggestive evidence that classifying foods by GI may be useful for overweight and obese individuals (Overby et al., 2013).

The National Food Administration of Sweden is the only European authority to approve GI claims for food labelling. Authorized the endorsed labelling of foods with the claim, "for a healthy blood glucose control", based on their potential to slow glucose uptake.

The UK Scientific Advisory Committee on Nutrition has recognized that both lower GI and GL diets are associated with a lower risk of type 2 diabetes. However, in its comprehensive opinion on carbohydrates and health, published in 2015, the committee concluded that it is not possible to establish a causal relationship based on differences in diet GI or GL, as this depends on many factors other than carbohydrate content (Barclay et al., 2021).

Under articles 13 (Function Health Claims) and 14 (1a. Risk Reduction Claims; 1b. Claims to refer to children's development) of Regulation (EC) No. 1924/2006, health claims can be requested, accompanied by scientific evidence supporting such claims, as well as the intended wording; requests are evaluated on a case-by-case basis by EFSA's expert panels. Claim approval is given to the ingredients or nutrients, and not to the food carrying that ingredient/nutrient/compound.

EFSA has issued several favourable opinions for various ingredients/compounds such as resistant starch, pectin, beta-glucans from oats and barley, hydroxypropyl methylcellulose (HPMC), Alpha-cyclodextrin and Arabinoxylan produced from wheat endosperm on to reduction of the postprandial glucose response, allowing info their claim (EFSA Panel on Dietetic Products & Allergies, 2010c, 2010d, 2010e, 2011a, 2011b, 2012).

Recently, the ICQC (2019) sent a motion to the EU parliament asking the European Commission to adopt necessary measures to ensure the presence of a low GI symbol on the label of food products in Europe.

II. Consumer perception and preference

2.8. Theory of the Perceptual Process

Perception is the process by which sensations captured by sensory receptors (vision, nose, mouth, ears, fingers) are selected, organized, and interpreted (Solomon, 2019). Consumer perceptions can be affected by consumer experiences, interactions, beliefs, and values (Solomon et al., 2012).

Selection is provoked through the senses, mainly vision, which allows us to capture the first sensations. Perception increases when other senses are included in this process. In the organization stage, consumers access their memories by comparing existing knowledge (motivation, beliefs, experiences, salience, etc.) with the stimuli, allowing interpretation. The interpretation stage is the process of making meaning of the stimuli (Madichie, 2012).

In psychology, two more stages of the perception process are reported: memory and recall. Memory allows the user to store the experience of a stimulus. This stage will be responsible for repeating or not repeating the behaviour and will also store this

experience and make it available to participate in the organization in the next perceptual processes. The organization stage uses both internal information, including stored experience, and external information acquired during the process (Babutsidze, 2007). The stage of accessing memory to organize and interpret other stimuli is called the recall stage (Rookes & Willson, 2000). Figure 10 shows an outline of the extended perception process.

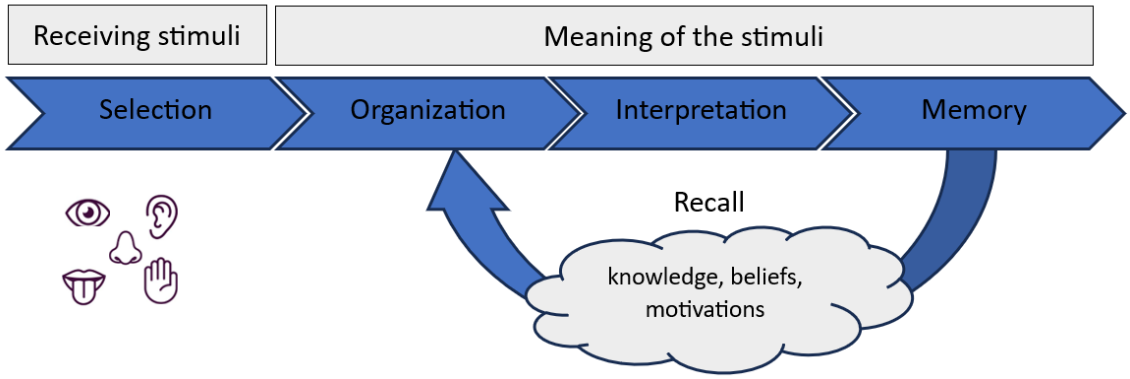

Figure 10 – Schematization of the perceptual process theory.

When confronted with the stimulus, the consumer does not use all the information captured in perceptual processing; that is, there is a selection of information referring to the stimulus. This selection occurs subconsciously and with the least effort on the part of the consumer (Cohen & Farley, 2008), and is determined according to the relevance, needs, interests, and expectations of each consumer (Solomon, 2019). That is, consumers evaluate different types of information and follow different strategies that minimize possible efforts and use heuristics that are consistent with their values and goals (Bettman et al., 1998; Sheth et al., 1991). This process is intuitive, fast, and spontaneous, as these decisions are guided by habit and trust, a plausible judgment that comes quickly into mind (Kahneman, 2003).

Bernard and Liu's study (2017) provides a good example of how individual traits (knowledge, beliefs, interests, and expectations) influence the formation of perceptions. These authors verified that information about the product being organic or local, in general, did not influence the taste perception of a certain group of consumers, apart from the consumers of health food stores in this group. These subjects assigned higher taste ratings to organic and locally labelled apples. These shoppers can be considered to have a different value system for these products and would likely be more interested in these sustainability issues; thus, their taste perceptions were shaped by label information.

In the perceptual process, it is important to differentiate sensations from perceptions. Sensation is experienced through the sensory receptors involved, which are transformed into a perception that influences consumption decisions and forms the basis of preferences (Niosi, 2021). In general, the investigation of perception focuses on a process that involves the addition of individual characteristics to the sensations captured to give meaning, which helps in making consumption decisions.

For the industry to produce products that meet consumer needs or competent bodies to establish correct health and nutrition policies, it is necessary to understand the factors that affect individual variation in perception.

2.8.1. Perception of consumption values

Consumers make choices based on their personal goals. In this context, Sheth et al. (1991) defined goals as seeking for satisfying multiple values. These values arise from Maslow's hierarchy of needs and personality models (Sheth et al., 1990).

Consumer choice is a function of multiple consumption values, and the greater or lesser influence of each value depends on the specific choice situation. Consumers structure their preferences based on their personal goals by combining these values or making a trade-off between them (Hirschman & Holbrook, 1982). he formation of personal goals is activated and structured unconsciously most of the time (van Osselaer et al., 2005); therefore, most consumers subconsciously form their preferences (Fitzsimons et al., 2002).

The emergence of the typology of consumption value research dates to the 1980s, and the 1990s and the 2000s were periods of clear growth and generation of important insights for marketing researchers (Zeithaml et al., 2020).

Holbrook and Hirschman (1982) pioneered research on the typology of values that structure consumption and considered the following values: experiential, hedonic, aesthetic, autotelic, and subjective consumption dimensions. Holt (1995) argued that these researchers and their followers tend to view consumption as a psychological phenomenon, emphasizing the emotional state that emerges with consumption. They considered completing the typology of consumption values with a more sociological view of consumption while also considering the integration of the social context in the formulation of values.

Consumption value is conceptualized as an individual’s assessment of a product’s utility based on what they have given and what they have received (Zeithaml, 1988); that is, it

is derived in terms of the product/service's ability to have an end in and of itself or to serve to a specific end (Holt, 1995; Lanseng, 2011).

According to Sheth et al. (1991) theory of consumption value defines the following values:

- Functional value: Perceived usefulness of physical and utilitarian functions.
- Social value: Perceived utility acquired from an alternative's association with one or more specific social groups.
- Emotional value: Perceived utility acquired from an alternative's capacity to arouse feelings of affective state.
- Epistemic value: Perceived utility acquired from an alternative's capacity to arouse curiosity, provide novelty, and/or satisfy a desire for knowledge.
- Conditional value: Perceived utility acquired by an alternative because of a specific situation or set of circumstances facing the choice-maker.

This typology has several researchers who have brought important reflections on the subject, resulting in valuable insights; however, there is a lack of standardization of terminology. There are different terms to define the same consumption value; some studies aggregate values into small subsets of values, decreasing the number of values, while others do the opposite. For example, hedonic value is described as experiential, functional value as utilitarian, and within symbolic value, there are other values that are separated in a certain study, such as social values. The same occurs with experiential value, which is sometimes divided into hedonic, emotional, and conditional values.

Over the years, researchers have adapted consumer perceived value, following different measurements and conceptual foundations, resulting in vast but disjointed literature (Zeithaml et al., 2020).

For food consumption, a shorter triadic approach has proven to be of interest (Charters, 2006; Son, Do, et al., 2014; Werle et al., 2013). Utilitarian values are determined as a function of a food's capacity to reach the final objective because of the specific characteristics of that food. Experiential values are related to sensory stimulation and affective and emotional reactions associated with consumption. The predominant psychological situations of consumers, such as feeling happy/unhappy, exert important influences on final choices; hence, experiential value predominates over utilitarian value (Adaval, 2001). Finally, symbolic values are determined from intangible concepts, such as cultural, ideological, or other concepts related to the belief itself (Holbrook & Hirschman, 1982). Symbolic benefits help, for example, communicate ideas about a person or the surrounding environment (Holt, 1995).

Some research has been conducted on the perceived values of consumption, where foods have been characterized according to their dominant values, showing that the relative importance of consumption values is culturally dependent (Letarte et al., 1997; Rintamäki et al., 2006; Rozin et al., 2002; Son, Do, et al., 2014; Werle et al., 2013). For example, the consumption of rice by Asian consumers is dominated by utilitarian values, whereas symbolic values are predominant for French consumers (Son, Do, et al., 2014)

2.9. Methodologies of food sensory analysis and consumer perception

Consumer perceptions are the main drivers of changes in food trends (Borra & Bouchoux, 2009). In marketing, visual perception is particularly prominent as it focuses on a variety of information (Gidlöf et al., 2017). However, in food science, taste receptors have a special emphasis, without detracting from the others, as together they contribute to the overall perception of the stimulus. Consumer perceptions of taste, safety, and naturalness are the most important quality attributes in food choice (Aprile et al., 2016; Bernard & Liu, 2017; Nguyen et al., 2015).

Both qualitative and quantitative methods have been used in consumer perception studies. Qualitative methods are suitable tools for uncovering how consumers view and perceive a new concept (Vespestad & Clancy, 2021). Examples include interviews, focus groups, observational methods, and free word association.

A consumer perception study aims to capture an intuitive and spontaneous response from the consumer, for which strategy and methodology must be used to trigger the use of heuristic approaches to decision-making (Jaeger, Hort, et al., 2017; Kahneman, 2003). The indirect measures allow users to capture intuitive responses from consumers (Jaeger, Hort, et al., 2017). Free word association and observational methods are indirect research methods. Direct measures such as self-report measures, scaled questionnaires, focus groups and interviews are useful from an analytical and controlled perspective but may introduce some bias due to people's tendency to provide socially desirable reasons for their food behaviours, which are often intuitive in nature (Nisbett & Wilson, 1977). As food choices are an unconscious process, consumers have difficulty expressing their food decisions (Donoghue, 2000). To complete the response task, consumers draw on past behaviours to respond to what is expected to be correct or socially satisfactory (Hofmann & Wilson, 2010).

To overcome the constraint of response bias that can occur with direct methods, researchers have advised the development and application of new methodological approaches to understanding these intuitive and automatic precepts (Jaeger, Fiszman, et al., 2017), or even the use or adaptation from other research areas of implicit (indirect) measures to complement, compare, and cross-validate the results of explicit (direct) measures (Ares & Varela, 2018; Köster, 2009).

Roininen et al. (2006) used two qualitative techniques – laddering and word association – to assess Norwegian consumers' perceptions of local food. They concluded that the methods were effective in assessing perceptions and positively highlighted the free association for its speed and effectiveness and the laddering interviews for their ability to provide information about the relationship between the perceived attributes and reasons for choice.

Direct measures approach to assess consumer perception include hedonic evaluation and sensory attributes, usually using a 9-point hedonic rating scale (Peryam & Pilgrim, 1957) and the various sensory analysis techniques available (Ares and Varela, 2018). The perception of a given stimulus can be self-reported on an intensity scale or recorded as the intensity of the brain response (Jaeger et al., 2017). Psychometric tools have also been used to quantify specific consumer perceptions of a particular concept or food. Examples of these tests include the Wellness Scale, which is used to capture the perception of well-being (Ares et al., 2016), perceived healthiness (Temmerman et al., 2021), and perceived naturalness (Michel and Siegrist, 2019) concerning a specific food, technology, or processing.

In addition to the intuitive processing of information that is desired in assessing perceptions, consumers can also rationally process information (Epstein et al., 1996). The use of questionnaires with self-reported or direct questions carries this risk; therefore, attention should be paid to the wording of questions and statements to elicit the most intuitive response possible (Jaeger, Hort, et al., 2017; van Herpen & Trijp, 2011).

Several researchers have used different methods (rational experience inventory, embedded figures test, and cognitive reflection test) to assess how individual differences in information processing (cognitive styles) affect consumer perceptions. For example, the cognitive reflection test has been used to study how individual differences in information processing affect consumers' perceptions of food labels and products (Ares, Mawad, et al., 2014; Kim et al., 2015; Mawad et al., 2015).

Perception studies of a specific food product are widely used, not only when a new product is being developed, but also when a new variant of the product is to be launched in the market. For example, to outline strategies for penetrating the European market for a new rice variety, researchers have conducted focus groups to understand the rice choice criteria of these consumers (Suwannaporn & Linnemann, 2008a). Supakornchuwong and Suwannaporn (2012) studied perceptions of rice in terms of taste, health aspects, price, calorie content, harmful substances, trustworthiness, digestibility, allergenicity, and perceived speciality food, comparing it with the main European side dishes (potatoes and pasta). They found that perceptions of rice were superior to those of potatoes and pasta in terms of healthfulness, price, calorie content, harmful substance content, trustworthiness, digestibility, and allergenicity. In conclusion, positive attitudes towards rice have increased significantly among consumers in the European target countries, and good taste, health benefits, low-calorie content, and speciality food status were key factors influencing consumers´ intention to buy more rice. Still to capture the difference in the perception of rice quality between Europeans and Asians, the perception of “good rice” and “rice” was assessed using the free word association method (Son, Do, et al., 2014).

Krutulyte et al. (2009) evaluated the perception of the quality of cereal products among consumers in Portugal, Denmark, and Lithuania. They found that the perception of quality varied between countries, with greater differences in the Portuguese group. Dimensions and cues such as taste and country of origin were most important for Lithuanians, while taste, label information, and price were the most important for Danes. and the perception of quality in Portugal varies with the product in question. Cues, such as type of shop for bread, brand for breakfast cereals and pasta, country of origin for vodka and price for biscuits, pasta, and vodka, were more likely to be considered relevant to purchase decision-making at the point of purchase. Consumers from the three countries showed that expected quality dimensions are much more important than extrinsic and intrinsic cues in almost all product categories (bread, biscuits, breakfast cereals, pasta, and vodka).

A person's perception of taste may be based on a system of values and beliefs (Bratanova et al., 2015), which are activated by cues that trigger expectations (Yeomans et al., 2008). As taste is the main attribute of food choice, studies have investigated the relationship between specific extrinsic cues and taste perception. Bernard and Liu (2017) examined whether taste beliefs about organic and local foods are sufficient for people to change their taste ratings of a product simply because it has an organic or local label.

They found that respondents with stronger and more positive beliefs about organic and local products attributed a higher taste rating to tasting food. They concluded that beliefs about the taste of organic and local foods may play a stronger role in taste perception than the actual taste for certain consumer segments. Similarly, Wiedmann et al. (2014) found that participants thought that conventional wine tasted better after being told that it was organic. Sörqvist et al. (2016) found that taste perceptions of raisins were influenced by eco- and GM labels in subjects from two universities. Tang et al. (2016) showed that tea with a fairtrade logo was rated as tasting better than the same tea without the logo, albeit with only a small sample of university students.

This work used direct and indirect methods such as interviews, FWA, hedonic evaluation, sensory analysis, psychometric scales, and conjoint analysis. The following sections describe each of these methods.

2.9.1. Interview

Interviews are a direct qualitative method (Lawless & Heymann, 2013) that can be used for a variety of purposes including needs assessment, program refinement, issue identification, and strategic planning. Some authors simply define an interview and completely as a “conversation with a purpose” (Burgess, 1984; Dexter, 1970; Kahn & Cannell, 1957). Qualitative research seeks to interpret phenomena in terms of the meanings that people give to them; that is, it is particularly interested in the perspective and point of view of the individual being studied (Denzin & Lincoln, 2003).

In-depth interviews are most appropriate in situations where a smaller sample size is sufficient, as they allow for more in-depth responses through open-ended questions, rather than the larger sample size required for quantitative surveys (Guion et al., 2011).

The interview needs to be consciously planned and organized using a semi-structured script with key questions, but the order of the questions is not rigid; it must be conversational and follow the interviewee´s spontaneous speech (Guion et al., 2011; Leonard, 2003). Open-ended questions need to be phrased in such a way that the interviewee elaborates on the topic, not just answers “yes” or “no.” Most questions need to begin with “why” or “how,” giving respondents the freedom to answer in their own language (Fontana & Frey, 2003).

In-depth interviews involve not only asking questions, but also thoroughly examining and preserving the answers for a more comprehensive understanding, which is achieved by systematically recording and documenting the responses during the task.

For many years, interviews were mainly face-to-face, but changes in living standards and the development of communication technologies have allowed for other procedures, such as telephone interviews and, more recently, video calls (online interviews) (Redlich-Amirav & Higginbottom, 2014). Several researchers have used this last procedure (Gruber et al., 2008; Redlich-Amirav & Higginbottom, 2014; Wilkerson et al., 2014), citing the main reasons as the limitation of research resources, the extension of the scope of the study, and the convenience of the participants.

Although online interviews can overcome some of the limitations mentioned above, the traditional method still has many advantages. For example, interviews need to capture not only what the interviewee says, but also how they say it and how they behave (Mason, 2002), since the object of the study is the interviewee´s communication of the interviewee. Non-face-to-face methods can withhold non-verbal communication, so it is advantageous to use the face-to-face method whenever possible.

In food consumer science, interviews are a great resource for exploring concepts, discovering processes of choice, perceiving emotions, and, above all, finding rational or intuitive reasons for the facts found.

Luomala et al. (2015) used interviews to understand the mental process of combining two features considered ambivalent in the choice process (taste and health) and concluded that this combination is possible and is the result of complex interaction and dynamics between consumer characteristics and product quality. Hoek et al. (2017), used it to explore consumers' perceptions, experiences, and attitudes towards healthy and environmentally friendly eating behaviours. Sajdakowska et al. (2018), studied the perception of the different technologies used in the production of cereals and cereal-based products to increase the nutritional value of food, to understand the level of acceptance of these food technologies among Polish samples. With the main objective of orienting rice cultivation priorities towards the development of targeted and market-oriented rice varieties, Custodio et al. (2016) conducted in-depth interviews with Bangladeshi farmers.

Carrete and Arroyo (2014) used interviews to gain a deeper understanding of consumers' motivations and attitudes towards changing their behaviour from unhealthy to healthy. In the context of healthy eating, researchers conducted interviews to gain a deeper understanding of how certain thought patterns can trigger eating behaviours that lead to weight gain (Wehling & Lusher, 2019).

2.9.2. Free word association

Free word association (FWA) is a projective technique used to access associative memory and has become increasingly popular in food consumption research (Rojas-Rivas et al., 2022). This method encourages participants to share their underlying motivations, beliefs, attitudes, and/or feelings regarding a particular food (Lawless & Heymann, 2013; Smith & Albaum, 2010). FWA can uncover unconscious thoughts that capture consumers' intuitive and automatic behaviours better (Donoghue, 2000; Köster, 2009).

In word association tasks, a participant is presented with a series of words and asked to respond immediately by saying the first words that come to mind. Stimuli can be a word or list of words that consumers hear or read, a food item (real, picture, or reported), an aroma, or any other stimulus (Roininen et al., 2006). This task is easy to use, provides valuable insights, and assesses knowledge, familiarity, and interest in the topic under study. According to expectancy-value theories, the most salient beliefs, and associations that consumers hold about a particular object or stimulus are the most reliable predictors of their attitudes and behaviours towards it. Consequently, the associations that first come to a respondent's mind tend to be the most relevant in determining their choice of consumer goods and products (Ajzen & Fishbein, 1980; Roininen et al., 2006). FWA can serve as a quick and convenient tool for exploring consumer perceptions of new and undefined concepts (Roininen et al., 2006).

Some researchers have made modifications to the free word association procedure to increase its operability or to capture as much information as possible. For example, Benthin et al. (1995), Roininen et al. (2006) and Slovic et al. (1991) asked their respondents not only to make associations but also to rate their responses on a 5-point scale as follows:1, very negative/very bad; 2, somewhat negative; 3, neutral; 4, somewhat positive; and 5, very positive/very good. Hässig et al. (2023) followed the same procedure but used a different scale to examine the feelings associated with responses to "food processed by the food industry". They asked participants to rate their feelings on an 11-point Likert scale ranging from −5 (extremely negative) to +5 (extremely positive). These approaches allowed assessments to be made both from a qualitative perspective of understanding the beliefs and attitudes behind the concepts and from a quantitative estimate of the valence of these attitudes (positive/negative). However, most studies do not make this classification by adding a quantitative component through the correlations between the FWA categories and certain characteristics of the respondents.

FWA has been used to translate consumer perceptions towards different foods, aspects of foods, or concepts. For example, consumers´ perception of rice (Son, Do, et al., 2014), dairy products (Ares et al., 2010; Oliveira et al., 2016), meat products (de Andrade et al., 2016), fruits and vegetables (Krumreich et al., 2019), packaging (Ares & Deliza, 2010a) and herbal infusions (Rocha et al., 2020). It has been used to interpret broad concepts in food-related contexts, such as wellbeing (Ares et al., 2015; Ares, De Saldamando, et al., 2014) and the concept of “feeling good” (Sulmont-Rossé et al., 2019). Food categories such as local foods (Roininen et al., 2006), traditional foods (Guerrero et al., 2010), and functional food labelling (Oliveira et al., 2016) have been extensively studied using this technique.

2.9.3. Consumer hedonic evaluation

The hedonic scale, also known as an affective test, aims to evaluate consumer acceptability for a target product. The hedonic scale assumes that participants' preferences exist on a continuum and that their responses can be categorized into like and dislike (Lawless & Heymann, 2013). The results obtained allow the industry to develop new products, improve or maintain food products, and explore a product's market potential before it is launched (Stone et al., 2020).

There are several types of hedonic scales, but the most used is the 9-point hedonic scale. This is a nine-point scale used to assess liking, and each response is converted to a corresponding value. It is a direct affective magnitude scale that directly assesses one’s hedonic experience in response to a stimulus and then assigns the magnitude of that experience to one of the nine points or categorized points that represent different semantic magnitudes along the affective dimension (Cardello & Jaeger, 2010).

The 9-point hedonic scale (Peryam & Girardot, 1952; Peryam & Pilgrim, 1957) was developed at the Quartermaster Food and Container Institute of the US Armed Forces to measure the food preferences of US soldiers (Heymann & Ebeler, 2017). If the product being evaluated has a mean liking score of 7 or more on a 9-point scale, it generally indicates a highly acceptable sensory quality and can be used with confidence as a good indicator of quality (Everitt, 2009).

The 9-point hedonic scale is widely used to assess acceptability despite recognized shortcomings, such as the lack of linearity of the adjectives (Peryam & Pilgrim, 1957), under-use of end categories (Stevens & Galanter, 1957), the internal validity (accurate and precise results of consumer liking) rather than external validity (more important for

the market (Van Trijp & Schifferstein, 1995), and the use of parametric analysis which assumes normality of the data despite being an ordinal measure (Lim, 2011; Peryam, 1960; Wichchukit & O'Mahony, 2015). The extremes of the scale have also been shown to be problematic for comprehension when translated into Latin American Spanish (Curia et al., 2001) or other Asian languages (Yeh et al., 1998).

Several researchers have proposed alternative hedonic measures and compared their performance with a nine-point hedonic scale. For example, the labelled affective magnitude scale (Schutz & Cardello, 2001), the best/worst method (Marley & Louviere, 2005), the semantically labelled hedonic scale (Lim et al., 2009), and the general labelled magnitude scale hedonic scale (Kalva et al., 2014). However, in almost all cases, the results of the comparison studies showed that the 9-point hedonic scale performed equally well (Kalva et al., 2014; Lawless et al., 2010; Lim, 2011; Lusk et al., 2015). However, Lusk et al. (2015) found that in an evoked context, samples were discriminated by the best-worst scaling and not the 9-point scale.

They have also compared 9-point hedonic scales with just-about-right (JAR) scales, but no general superiority of the JAR scale has been demonstrated (Song et al., 2021). The JAR scale incorporates both intensity and hedonic judgments and assumes that consumers have a common understanding of the attributes being measured (Stone et al., 2020). Stone et al. (2020) recommend that these scales should not be used in liking tests outside the realm of optimization.

The linear hedonic scale (also known as the unstructured visual analogue scale) is a continuous scale represented by a line anchored at its extremes with the minimum (extremely disliked) and maximum degree (extremely liked) of liking (Wichchukit & O'Mahony, 2022). This scale has the advantage of giving assessors with more flexibility to express their liking, minimize contextual effects, and enable more accurate acceptability evaluations, as any point on the scale can be marked. However, it may be more challenging to understand, which could potentially slow the sensory evaluation process (Pimentel et al., 2016).

Recently Wichchukit and O'Mahony (2022) compared the 9-point hedonic scale with the unstructured hedonic scale in terms of effectiveness in analysing the preference probability (R-index) and verified that the R-index analysis has clear advantages over 9-point hedonic scale for measuring and analysing preferences because it uses preference effect sizes rather than liking effect sizes. However, they do not discourage the use of traditional methods. They advise that an approximate method may be

sufficient if the user is aware that it is inferring approximate likings from a set of "like" effect sizes that are appropriate for the purpose.

Despite the weaknesses, the 9-point hedonic scale continues to be widely used due to its ease of understanding and use by consumers from different segments as well as acceptable levels of accuracy and precision in discrimination (Heymann & Ebeler, 2017; Lim, 2011; Meullenet, 2004), demonstrating that it is a suitable measure for measuring hedonic differences or predicting product acceptability.

2.9.4. Sensory profiling analysis

Quantitative Descriptive Analysis (QDA) is the most widely used classical sensory methodology for sensory descriptive analysis. This methodology provides a quantitative sensory map of the products, delineating all the characteristics, and allows different products to be tested and compared (Stone et al., 2012). This test is traditionally carried out by trained evaluators, who are selected according to their sensory acuity and ability to discriminate between products (Stone & Sidel, 2004). Prior to the task, these evaluators go through several phases, such as familiarization with the test procedures and several training sessions, to reliably recognize, describe or quantify the sensory characteristics of the products to be evaluated (Lawless & Heymann, 2013).

Despite the clear advantages of this method, its limitations are evident in the execution of a quick and less costly job, as expected in a very dynamic market. Given the high demand for this method in terms of panel training and task time, there has been a natural transition towards the adoption of faster and more flexible analytical techniques. The main advantages of the rapid methods for characterizing the sensory profile of products include the use of panels with different levels of training (untrained or semi-trained), the consideration of consumer perceptions and the use of holistic approaches, which are closer to reality (Varela & Ares, 2012).

Researchers are breaking the classical paradigm and defending the use of consumers to generate sensory profiles in product development (Ares & Varela, 2017; Valentin et al., 2012; Varela & Ares, 2012). In recent years, most sensory research has used the so-called rapid techniques as a method of sensory analysis due to their numerous advantages (Ares & Jaeger, 2023; Bruzzone et al., 2012; dos Santos Garruti et al., 2012) (Jaeger, Fiszman, et al., 2017; Neves et al., 2023; Rocha et al., 2021). Several studies have compared the results of QDA with those of rapid analysis techniques, confirming the validity of the latter and the similarity of the results (Albert et al., 2011; Delarue &

Sieffermann, 2004; He & Chung, 2019; Heo et al., 2023; Moussaoui & Varela, 2010; Oliver et al., 2018). Studies have compared the performance of these two types of panels and found significant agreement between trained assessors and consumers (Ares & Varela, 2017; Barton et al., 2020; Chollet & Valentin, 2001; Souza Gonzaga et al., 2020; Worch et al., 2010).

Ares & Varela (2017) argued that it is often more advantageous to use consumer panels because their assessments are closer to reality, as the differences found by experts are often not perceived by consumers. Therefore, it becomes relevant to use consumer panels to determine when sensory differences perceived by trained assessors effectively translate into sensory or hedonic differences for naive consumers.

Regarding hedonic tests, there is a consensus that trained assessors cannot perform hedonic tests because they are trained to evaluate products according to specific criteria and not to show their personal preferences (Ares & Varela, 2017). Therefore, the results are not representative of naive consumers, and therefore cannot be considered as a measure of the potential performance of a product in the market (Lawless & Heymann, 2013; O'Mahony, 1979). The use of a panel of consumers in the sensory analysis allowed for a holistic sensory evaluation (analytical and affective evaluation), as the hedonic response results from the evaluation of the product as a whole and is determined by the synthesis process of the relative importance that the assessor attributes to each sensory characteristic of the product (Jaeger et al., 2000).

Currently, these questions regarding the accuracy and feasibility of rapid methods are already outdated, and new questions have arisen. For example, the need to consider the evolution of sensations (perception of sensory attributes) throughout the sensory test (temporal methods) (Meyners, 2016), of the need to perform the analysis in a realistic environment (Colla et al., 2023; Jaeger, Hort, et al., 2017) and the involvement of geneticists and neuroscientists in the assessment of individual differences in sensory perception (Jaeger, Hort, et al., 2017).

Meiselman et al. (2022) presented some of the current and future relevant issues that are ongoing in sensory and consumer science. Efforts should be made to replace the convenience sample with a representative sample of the population and to consider its segmentation (product users) when the research aims to measure consumer response to a product. They also identify ethical issues as important in sensory research, considering cultural differences and differing opinions on what is preferred versus what is essential.

→ Check-All-That-Apply (CATA)

The Check-All-That-Apply (CATA) method has become the most popular approach to sensory product characterization with consumers because it is easy for consumers to understand and perform, the results are reproducible, and it is reliable for sensory characterization of a wide range of products (Ares & Jaeger, 2023).

CATA is an analytical method consisting of a ballot with a list of words or phrases describing sensory attributes, in which assessors must select all the words they consider appropriate to describe the product under study (Adams et al., 2007; Ares et al., 2011). This list of sensory terms/phrases is usually generated by the researcher using an exploratory method such as a focus group, free word association, or free listing (Vidal et al., 2015). Other ways to obtain sensory terms are through descriptive analysis by a trained panel, or through another rapid method where consumers are asked to choose the words that describe the product during the test, as in the Free Choice Profile (dos Santos Garruti et al., 2012).

The task is intuitive and requires little cognitive effort from consumers, even compared to other rapid analysis methods that are based on the identification of product attributes, such as free-choice profile, flash profile, and projective mapping, where the terms characterizing the attributes are generated by the assessors (Ares et al., 2011). Compared with intensity or Just-about-Right (JAR) questions, the CATA question is easier for consumers to understand (Adams et al., 2007).

As it is a method that synthesizes the evaluation of consumers, it has been suggested that the ideal number of participants for sensory characterization would be between 50 and 100 (Ares et al., 2010; Dooley et al., 2010); however, as this method is most often combined with a hedonic test, one should consider between 100 and 120 assessors should be considered (Hough et al., 2006; Moskowitz, 1997). This method is not recommended for evaluating products with very similar attributes, as the nature of the responses obtained by this technique may lead to the selection of the same terms and attributes (Varela & Ares, 2012).

In CATA, the intensities are not assigned to attributes and the data are generated by the number of consumers identifying each sensory term for each sample. Jaeger, Chheang, et al. (2020) directly compared CATA questions with intensity ratings obtained on 10 cm unstructured linear scales. They verified that the responses obtained by the two methods

are linearly related, meaning that it is possible to infer that significant differences between samples for a given CATA term as represent differences in perceived intensity, corroborating the other work that verified that the intensity of attributes is proportional to the frequency of use of the term (Jaeger, Beresford, et al., 2020). It was concluded that although CATA responses are not measures of intensity, the average citation frequency reflects the perceived intensity. They added that in a group of consumers there is no loss of information in terms of rating scales.

The data were analysed using multivariate statistical techniques such as Correspondence Analysis or Multiple Factor Analysis, which generates a sensory space like principal component analysis. Cochran's Q test can be used to evaluate significant differences between the terms of the samples, and correspondence analysis to determine the sample and terms configuration (Ares & Jaeger, 2023).

When CATA questions are used in conjunction with hedonic scales, they can be used to study the impact of each attribute on overall liking. This test is known as penalty analysis (Plaehn, 2012) and allows liking to be mapped by correlating hedonic assessment with sensory attributes. The combination of CATA with the hedonic test leads to a multidimensional approach to the data, in which two types of sensory maps are generated: the internal liking map, which is a multidimensional representation of the stimuli based only on the acceptability data, and the external liking map, which relates product acceptability to a multidimensional representation of stimuli derived from descriptive analysis or instrumental data (Greenhoff & MacFie, 1994).

During the development of new products, one of the important tasks of sensory analysis is to provide useful information on changes to the product formulation. The ideal product concept is often used as a benchmark for comparison. This problem has allowed a new approach to CATA beyond penalty analysis. Multidimensional Alignment (MDA) has been proposed as an effective method for investigating the relationships between products and attributes. MDA allows for a full-dimensional correspondence analysis approach, providing complete information about the relationship between products and attributes and identifying both the positive and negative drivers of the tastes of the product samples under evaluation (Meyners et al., 2013).

2.9.5. Psychometric evaluation

According to the American Psychological Association (APA), the field of psychometrics deals with the theory and technique of psychological measurement that quantifies

knowledge, skills, attitudes, and personality traits (Maddocks, 2019). A psychometric tool must be objective, simple, clear, relevant, precise, diverse, modal, typical and reliable. It must adhere to four fundamental principles by which the quality of a psychometric assessment is judged: reliability, validity, standardization, and freedom from bias (Cunha et al., 2016; Pasquali, 2009).

Psychometric measures began to be used in consumption science research in the mid-20th century, allowing researchers to explore the psychological factors underlying consumer behaviour and preferences using a more systematic, quantitative, and standardized approach (Cunha et al., 2016). Psychometric measures have continued to evolve and be integrated into different areas of consumption science research, including market segmentation, brand perception, and product evaluation. Researchers have begun to use well-established psychological theories and methods to create and validate multidimensional scales to understand consumer behaviour and decision-making (Malter et al., 2020).

For example, Byrne et al. (1963) developed Food Attitude Scales to measure individuals´ feelings, beliefs and behaviours related to food consumption. The Food Neophobia Scale (Pliner & Hobden, 1992) has been used to identify factors influencing food acceptance and rejection. Steptoe et al. (1995) developed the Food Choice Questionnaire (FCQ), which categorizes food choice motives into several dimensions such as health, sensory appeal, convenience, natural content, weight control, price, familiarity, mood, and ethical concerns. Health and taste attitude questionnaires have been developed to assess consumer orientations towards healthy and hedonic food characteristics (Roininen et al., 1999).

Following the development of more general scales, these have been adapted for use in more specific contexts, such as the Food Technology Neophobia Scale (FTNS), which was developed to quickly identify segments of a market that might be likely to avoid foods produced using novel technologies (Cox & Evans, 2008). Scales have emerged to measure more contemporary issues, such as assessing perceptions of well-being in the context of food (Ares et al., 2016; King et al., 2015; Meiselman, 2016), the influence of emotions on food choices (King et al., 2010), the importance of naturalness (Michel & Siegrist, 2019), sustainability and ethical issues in food choices (Verain et al., 2021), and the trend towards convenience food choices (Buckley et al., 2007).

Scales are usually made up of several constructs (dimensions), which usually reflect concepts. Each concept is measured by rating several items. Each item is usually presented as a statement or a question (Moura, 2020).

The most used rating scale to measure construct items is the Likert scale, coined with the name of its creator (Likert, 1932). Likert scales can have different amplitudes, but the most used are 5 and 7 points, and it is recommended to use the odd scale anchored at the extremes, as it allows the balance between both sides of a neutral option, creating a less biased measurement (Cunha et al., 2018). This is particularly important when measuring consumer perceptions as consumers do not necessarily have to agree (have a positive rating) or disagree (have a negative rating); they may simply have no opinion or be indifferent, as naturally happens.

In this doctoral research project, psychometric tools, such as the Well-being Scale, New Naturalness Scale (NNS), and Convenience Food Lifestyle (CFLS), were used to evaluate consumers' attitudes and perceptions. The following topics describe each of these tools.

→ Well-being Scale

Wellbeing is a broad and multidimensional concept (Diener et al., 2003; Dodge et al., 2012; McGillivray & Clarke, 2006) related to subjective assessments of life (Diener & Ryan, 2009).

Bublitz et al. (2013) and Block et al. (2011) defined food well-being as the positive physical, psychological, emotional, and social outcomes that individuals may experience because of adequate food consumption. However, other authors have studied perceptions of food well-being as a determinant of choice, defining it as an influencer of choice rather than a consequence of consumption (Apaolaza et al., 2018; Ares et al., 2015; Ares et al., 2016).

Well-being has been assessed in various ways. Some authors have used direct questions to the consumer to self-assess the wellbeing index (Reeves et al., 2013; W.H.O., 1998), while others have used indirect tools, such as multidimensional scales, as in the case of (Boelsma et al., 2010), who used scales to assess objective (physiological) and subjective aspects (satisfaction, pleasure, relaxation, physical energy, alertness, and drowsiness) in consumers' perceptions of well-being towards specific meal consumption. Some researchers constructed multidimensional questionnaires to assess differences in perceptions of wellbeing between different foods or food concepts (Ares et al., 2015; Ares et al., 2016; Dye & Blundell, 2002).

Ares et al. (2016) proposed a multidimensional scale to assess well-being, consisting of 31 items (questions) divided into the following dimensions: General, Physical, Intellectual, Emotional, Social, and Spiritual. When wellbeing is assessed in the food

context, its multidimensionality depends on the type of food assessed, as each type of food has a different impact on physical health, which in turn has a different impact on behaviours and cognitive functioning (Ares et al., 2016; Dye & Blundell, 2002).

Perceptions of well-being in relation to food also vary across cultures. Ares et al. (2015) evaluated perceptions of well-being in five countries in Europe and South America. They found differences in how countries view food and well-being as well as the contribution of specific foods to well-being. France and Spain give more weight to the characteristics of foods, including flavour, whereas Brazil and Portugal give more weight to specific foods, such as fruits and vegetables. Conversely, European countries such as France, Spain, and Portugal are less likely than Brazil and Uruguay to rate specific foods as good for well-being.

This scale is shown in Table 4 with the corresponding translation into Portuguese made by Moura and Cunha in the context of this cross-cultural study (Ares et al., 2015).

The perception of well-being, together with sensory and extrinsic cues, can be a predictor of food choice, providing useful information for both the development of new products and implementation of health policies related to healthy eating. For example, Oliveira et al. (2017) studied the influence of sensory attributes and packaging on the perception of the well-being of probiotic dairy products. To support the adoption of a healthy diet, Mora et al. (2020) investigated the perception of wellbeing of a gastronomically enhanced healthy menu. Reis et al. (2017) investigated the effect of sugar reduction information and sweetener use on consumers´ hedonic, sensory, and well-being perceptions using orange/pomegranate.

Table 4 - Wellbeing dimension and items and their translation into Portuguese (Ares et al., 2015).

Dimension (EN)	Item (EN)	*Dimensão* (PT)	*Item* (PT)
General	It is good for wellbeing	*Geral*	*É bom para o bem-estar*
	It makes me feel good		*Faz-me sentir bem*
Physical	It is good for my health	*Física*	*É bom para a minha saúde*
	It is nutritious		*É nutritivo*
	It makes me feel satiated		*Faz-me sentir saciado(a)*
	It helps me control my weight		*Ajuda-me a controlar o peso*
	It keeps me fit		*Mantém-me em forma*
	It keeps me healthy		*Mantém-me saudável*
	It gives me energy		*Dá-me energia*
Intellectual	It keeps me alert	*Intelectual*	*Mantém-me alerta*
	It improves my mental performance		*Melhora o meu desempenho mental*
	It improves my memory		*Melhora a minha memória*
	It helps me concentrate		*Ajuda-me a concentrar*

Dimension (EN)	Item (EN)	*Dimensão* (PT)	*Item* (PT)
	It makes me think clearly		*Faz-me pensar claramente*
Emotional	It makes me feel calm and relaxed	*Emocional*	*Faz-me sentir calmo(a) e relaxado(a)*
	It makes me feel guilty		*Faz-me sentir culpado(a)*
	It gives me pleasure		*Dá-me prazer*
	It makes me feel excited		*Faz-me sentir excitado(a)*
	It makes me feel satisfied		*Faz-me sentir satisfeito(a)*
	It makes me feel sad		*Faz-me sentir triste*
	It makes me feel happy		*Faz-me sentir feliz*
Social	It is good for sharing with family	*Social*	*É bom para partilhar com a família*
	It makes me feel connected to others		*Faz-me sentir ligado com outros*
	It improves what others think of me		*Melhora o que os outros pensam de mim*
	It makes me feel supported by others		*Faz-me sentir apoiado por outros*
	It is good for sharing with friends		*É bom para partilhar com amigos*
Spiritual	It makes my life closer to my ideal	*Espiritual*	*Torna a minha vida mais próxima do meu ideal*
	It makes me feel closer to nature		*Faz-me sentir mais próximo da natureza*
	It gives me a sense of gratitude		*Dá-me um sentido de gratidão*
	It gives me inner peace		*Dá-me paz interior*
	It is good for my soul		*É bom para a minha alma*

→ Food Naturalness assessment

Consumers perceive “natural” foods in different ways. For many years, natural meant perishable, or unprocessed food (Stanziani, 2008). Consumers have gained more trust in the “natural”, associating it with a sense of trust and transparency (Moscato & Machin, 2018), recognising it as healthy, and environmentally friendly (Rozin, 2005), and associating natural with organic production, OGM-free foods and of artificial ingredients (Berry et al., 2017; Dominick et al., 2018), as well as ethical agricultural production issues (Nawaz & Satterfield, 2022).

Consumers are increasingly showing interest in natural foods, which arises concomitantly with an interest in nutrition, health, animal welfare, and the environment (McFadden & Huffman, 2017). According to the Nielsen Global Health and Wellness Survey Report (Nielsen, 2015b), naturalness, freshness, and minimal processing are among the most desirable food attributes. This trend can also be seen in the increasing sales of products advertised as natural (Cao & Yan, 2016). In general, naturalness is considered a positive food attribute (Chrysochou & Grunert, 2014; Petty, 2015; Rozin et al., 2012). The importance of naturalness is positively correlated with the choice of organic foods (Hasselbach & Roosen, 2015; Lockie et al., 2004), and conversely is

associated with negative perceptions of highly processed foods (Evans et al., 2010; Rozin et al., 2012) and new food technologies (Siegrist et al., 2018).

Several scales have been proposed to assess the importance of naturalness to consumers. These scales differ in the number of items and the scope of the constructs (different aspects of naturalness). The “natural content” dimension of the FCQ assesses only three items related to the absence of artificial ingredients and additives in food (Steptoe et al., 1995). Pula et al. (2014) added items to the “natural content” of the FCQ that evaluate processing and residues from agricultural production. The measure of consumer attitudes towards the health and hedonic characteristics of food (Roininen et al., 1999) includes items on processed foods and organically grown foods in the “natural product interest” construct, in addition to items on foods with artificial additives and flavourings. The Eating Motivation Survey (Renner et al., 2012) addressed concerns about harmful substances and organic food production.

In general, measures of naturalness include concepts (constructs) such as the degree of processing (natural vs. transformed food), conventional and unconventional beliefs (natural, genetically modified, absence of pesticides/chemicals), and the outcome of naturalness in the product (healthy, ethical, freshness, taste, preservation). However, these constructs are not added to a single scale, resulting in numerous measures to assess naturalness.

Michel and Siegrist (2019) proposed a new scale that evaluates how the food is produced, considering the ingredients and the production process, but not the form of cultivation or the perceived properties of the final product. The NNS measure of the importance of naturalness is unidimensional and consists of nine items addressing the following naturalness issues: artificial ingredients, preservatives, additives, artificial colours and flavours, chemicals, hormones and pesticides, GMOs, presence of natural ingredients and production process (minimally processed, traditional, and homemade production). Table 5 shows the original items and the translation carried out in this study using a back-translation procedure (Brislin, 1970).

Table 5 - Items of the New Naturalness Scale (Michel & Siegrist, 2019) translated into Portuguese.

Item no.	*DE-CH (Michel & Siegrist, 2019)*	EN-US (Michel & Siegrist, 2019)	*PT-PT*
1	*Ich achte darauf, Produkte zu kaufen, die möglichst frei von künstlichen Inhaltstoffen sind.*	I make sure to buy products that are preferably free from artificial ingredients.	*Certifico-me de comprar preferencialmente produtos que sejam livres de ingredientes artificiais*
2	*Ich meide Lebensmittel, die Konservierungsmittel enthalten.*	I avoid food that contains preservatives.	*Evito alimentos que contenham conservantes*
3	*Ich meide Lebensmittel, die Zusatzstoffe einhalten.*	I avoid food that contains additives.	*Evito alimentos que contenham aditivos*
4	*Ich meide Lebensmittel, die künstliche Farb- und Aromastoffe enthalten.*	I avoid food that contains artificial colours and flavours.	*Evito alimentos que contenham corantes e sabores artificiais*
5	*Ich bin besorgt über die Rückstände von Chemikalien in Lebensmitteln.*	I am worried about residues from chemicals in food.	*Sou preocupado (a) com os resíduos de produtos químicos nos alimentos*
6	*Ich meide Lebensmittel, welche mit genetisch veränderten Pflanzen hergestellt wurden.*	I avoid food that is made from genetically modified plants.	*Evito alimentos feitos com plantas geneticamente modificadas*
7	*Mir ist es wichtig, dass Lebensmittel so viele natürliche Zutaten wie möglich enthalten.*	It is important to me that foods contain as many natural ingredients as possible.	*É importante para mim que os alimentos contenham tantos ingredientes naturais quanto possível*
8	*Ich meide stark verarbeitete Lebensmittel.*	I avoid highly processed foods.	*Evito alimentos muito processados*
9	*Ich bevorzuge unverarbeitete Lebensmittel gegenüber verarbeiteten Lebensmitteln.*	I prefer unprocessed foods over processed foods.	*Prefiro alimentos não processados a alimentos processados.*

→ Food Convenience

Convenience is associated with a reduction in the effort expected from customers in shopping for food, preparing meals, cooking, or cleaning up after a meal (Brown & McEnally, 1992; Buckley et al., 2007), i.e. ease and comfort in food acquisition and consumption.

The current food consumption scenario shows an increasing orientation towards convenience foods (Jabs & Devine, 2006). Due to the time pressure in which we live, energy is no longer spent on food preparation and, as a result, the population has even lost the necessary skills to prepare meals from scratch (Lang & Caraher, 2001; Worsley et al., 2015), leaving aside healthy foods such as vegetables, fruits, legumes, and whole grains due to the effort required to prepare them (Reipurth et al., 2019). Together, these factors can result in unhealthy diets that can lead to chronic non-communicable diseases, such as obesity, hypertension, diabetes, and coronary heart disease (NCCDPHP, 2022).

To overcome these issues, industry and researchers have made efforts to combine convenience and health, two attributes that have been considered incompatible for many

years due to the harmful effects of ultra-processed convenience foods (Lavelle et al., 2016; Peura-Kapanen et al., 2017; Rogus, 2018). Therefore, convenience has been reinforced as a tool to support healthy eating habits by promoting formulations and processing that result in more nutritionally balanced convenience products (Nakano & Washizu, 2020).

For staple foods, convenient and healthy products must be available to support daily life without compromising consumer health. Studies have identified a lack of convenience as a barrier to rice consumption, and RTE-rice formulations have been proposed (Cha et al., 2012a; Kwak et al., 2015; Yu et al., 2017). Methods to obtain convenient and healthy rice products have also been investigated (Arribas et al., 2019; Beck et al., 2018; Dalbhagat et al., 2019) (see Section 2.7.4.).

Several studies have examined the importance of convenience in food choice (Brunner et al., 2010; de Boer et al., 2004; Nakano & Washizu, 2020), while others have focused on specific populations (Alexy et al., 2011; Beshara et al., 2010; Horning et al., 2017; Peura-Kapanen et al., 2017). An exploratory study aimed to assess the acceptance of and barriers to the use of convenience foods among older people in Finland found that individuals valued the healthiness of food, freedom of choice, and the right to self-determination in eating and that the acceptability of convenience foods depended on taste preferences. This demonstrates the importance of combining the attributes of taste, health, and convenience. Brunner et al. (2010) found that factors strongly related to health, such as concern for naturalness and nutritional knowledge, were strong predictors of convenience food choice in a representative German sample. Motivational orientations related to health and convenience food consumption are emerging issues that have been explored in several studies (Brunner et al., 2010; Costa et al., 2007; Geeroms et al., 2008; Jabs & Devine, 2006).

The Convenience food lifestyle (CFLs) (Buckley et al., 2007) is a scale developed with a sample of the British population to assess attitudes and behaviours towards convenience food lifestyles (CFLs). They used lifestyle variables to segment consumers based on their attitudes and behaviours towards convenience foods and identified 20 dimensions/segments from a total of 70 items. The original scale is presented in Table 6.

Table 6 - Convenience food lifestyle (CFLs) dimensions and items.

Factor	Item
Convenience food choice	We use a lot of ready-to-eat foods in our household
	One of the reasons I use convenience foods is to reduce the amount of washing up
	I choose easy, quick-to-prepare food for weekend evening meals
	Foods that do not require clearing up following a meal are an important part of my shopping list
	I choose easy, quick-to-prepare food for weekday evening meals
	Convenience foods allow me to have something that I wouldn't normally know how to cook
	I choose foods that don't create much, if any, washing up
Convenience in meal preparation and cooking	I don't like spending too much time on cooking
	I like to have ample time in the kitchen for cooking/preparing meals
	Cooking is a task that is best over and done with
	I love spending time in the kitchen preparing food
	Preparing meals gives me a lot of satisfaction
	I enjoy preparing meals from scratch
Neophilia	I look for ways to prepare unusual meals
	I love to try recipes from foreign countries
	Recipes and articles on food from other cooking traditions make me experiment in the kitchen
	I like to try new foods that I have never tasted before
	I like to try out new recipes
Fresh versus convenient	I prefer fresh products to canned or frozen products
	It is important to me that food products are fresh
	Frozen foods account for a large part of the food products I use in our household
	I prefer to buy meat and vegetables fresh rather than frozen/canned
Convenience in shopping	Shopping for food does not interest me at all
	I just love shopping for food
	I try to do my food shopping as quickly as possible
	I do not like spending much time shopping for food
	Food shopping takes up too much of my time
Time pressures	I am always looking to save time
	I am often rushing to get everything done
	I am always in a rush
Individualism	There is at least one person in my family who often needs a separately prepared meal
	Certain members of my family have different tastes in food to the rest of the family
	Certain members of my family are choosy/picky in what they eat
Price check	I compare prices between product variants (i.e. various brands of same product) in order to get the best value for money
	I look for ads in the newspaper for store specials and plan to take advantage of them when I go shopping
	I always check prices, even on small items
Shopping list	Before I go shopping for food, I make a list of everything I need
	I make a shopping list to guide my food purchases
Disposal of waste ingredients	I find that I often have to throw away ingredients when cooking a meal from scratch
	Throwing out leftover ingredients is all too common in this household

Factor	Item
	I often find that I buy ingredients, use them once, then leave them in the cupboard and never use them again
Information check	I compare product information labels to decide which brand to buy
	I like buying food products in speciality stores where I can get expert advice
	I do not see any reason to shop in speciality food stores
	I like to know what I am buying, so I often ask questions in stores where I shop for food
Eating out	Dining with friends is an important part of my social life
	Going out for dinner is a regular part of our eating habits
	I enjoy going to restaurants with my family and friends
Whole family	The kids or other members of the family always help in the kitchen e.g. they peel the potatoes and cut the veg
	My family helps with other mealtime chores, such as setting the table and doing the dishes
	When I do not really feel like cooking, I can get one of the other members of my family to do it
Woman's task	It is the woman's responsibility to keep the family healthy by serving a nutritious diet
	Nowadays the responsibility for shopping and cooking ought to lie just as much with the husband as with the wife
	I consider the kitchen to be the woman's domain
Stress levels	In the last month, difficulties were piling up so high that I could not overcome them
	Recently I have been unable to control the important things in my life
	Lately, things have been going my way
Propensity towards convenience processes	I regularly use the microwave to cook my evening meal during the week
	I regularly use the microwave to cook my evening meal during the weekend
Planning	I always plan what we are going to eat a couple of days in advance
	What we are going to have for supper is very often a last-minute decision
	Cooking needs to be planned in advance
Breakdown of mealtimes	We often like to watch TV while eating meals
	In my house family members often have their meals at separate times
	It is difficult for us to have a family meal together
Snacking	I eat before I get hungry which means I am never hungry at mealtimes
	I eat whenever I feel the slightest bit hungry
	I snack a lot when I am at home on my own
Eating alone	I don’t usually prepare a proper meal when there's just me
	I don’t enjoy cooking just for myself

2.9.6. Conjoint analysis

Conjoint Analysis (CA) is a widely used marketing research technique that helps to understand how consumers make decisions. The roots of CA can be traced back to the fields of psychology and economics, with early developments in the mid-20th century and significant advances since then (Green, 1975; Green & Srinivasan, 1990).

The formal development of CA as we know it today was introduced in the 1970s and has evolved over the years with significant advances (Rao, 2010). It is mainly used in the development of new products, in predicting the market price or the perception of price sensitivity (market value) and in discovering and identifying competitive advantages over similar products in the market. This technique has the advantage of simulating real-world purchase situations where respondents are asked to make trade-offs for product attributes (Green & Srinivasan, 1978).

CA starts with the consumer´s global judgment of a set of attributes. It then calculates the value of the contribution of each level and attributes for consumers´ evaluations (Meyerding & Merz, 2018). This approach examines the contribution of each attribute to the construction of consumer preferences by evaluating different configurations of the same product (Alriksson & Oberg, 2008; García-Torres et al., 2016). The overall preference for a given product is obtained by combining all contributions of the individual levels of each attribute considered. These contributions are referred to as part worths or utility values, and the value of each attribute is referred to as the relative importance (Green & Srinivasan, 1978; Heide & Olsen, 2017; Moskowitz et al., 2004; Sckokai & Soregaroli, 2008). Because of the decompositional approach of this method (Green & Srinivasan, 1978), one of its main advantages is to evaluate the importance and preference of each attribute/component of the product/service, which can serve as inputs for the development or improvement of a product or service.

This approach allows the exploration of both the intrinsic (e.g., flavour, ingredients, nutrition) and extrinsic components of a product in shaping consumer preferences and choices (Asioli et al., 2017; Enneking et al., 2007). This preference is based on the expected quality resulting from intrinsic and extrinsic food cues. Extrinsic cues can communicate experience and credibility attributes, and intrinsic cues, in turn, are important for predicting experiential attributes. Extrinsic components include attributes such as price, brand, packaging, point of sale, country of origin, and product-related information, which serve as value signals and actively influence the weighting of benefits and costs (Enneking et al., 2007; Northen, 2000).

One of the major advantages of this approach is that it allows the researcher to select the attributes that most influence consumers by creating hypothetical attributes according to their objectives (Alriksson & Oberg, 2008). In addition, this method allows for dealing with complex decision situations where more than one attribute has an important influence on the decision (Rolfe et al., 2000). However, it is important to consider that many combinations can lead to consumer fatigue; therefore, researchers

need to understand which attributes are interesting to integrate into the study and which are far from the consumer's interests and should be excluded from the study (Alriksson & Oberg, 2008). On the other hand, one of the limitations of this method is that it cannot distinguish whether an attribute is not considered because it is not valued by the consumer or because it was simply not seen (Vidal et al., 2013). Researchers have pointed to the integration of eye tracking into AC as a potential method to overcome this limitation (Meyerding & Merz, 2018; Vidal et al., 2013).

CA is widely used in food science to understand consumer preferences and food decision-making. Donadini and Porretta (2017) studied consumer preference patterns for craft beer and found that the main driver for Italian craft beer consumers was the type of packaging and technological processing, with a preference for microfiltered beer and beer bottled in glass bottles with crown caps. The sensitivity of wine consumers to brand, region, price, and awards in wine selection was investigated and it was concluded that premiums and brand had a greater impact on consumers with low involvement in wine than on those with high involvement, while a well-known region of origin had a greater impact than a well-known brand (Lockshin et al., 2006). Similar results were found for the region of origin of spelt wheat, adding that the narrower and more precise the geographical area of origin, the higher the quality expectations of consumers who perceive the region of origin as an indication of product quality (Stefani et al., 2006).

This methodology has been used to determine which innovations and food processing techniques are most attractive to consumers (Asioli et al., 2019; Dixon et al., 2020; Donadini & Porretta, 2017; Pérez et al., 2022). Asioli et al. (2019) investigated consumer preferences for dried organic strawberries based on attributes such as origin, price, nutritional value, and drying method (traditional or microwave drying). The main finding was that customers reject technology and prefer domestic goods at low prices. The authors advised producers to focus on promoting the benefits of this technology if they decide to use the new drying technology. Different rice varieties and cooking methods were tested to obtain thermally processed shelf-stable rice that is sensorially appealing to consumers. Mind Genomics was involved in this task, which involves understanding specific messages, ideas, and messages of interest to consumers. Using this technique, it was possible to segment consumers according to their reasons for and barriers to choosing RTE-rice. Segments were characterized as those who used traditional methods of cooking rice, those who were driven by simple meals, or those who were driven by packaging rather than the rice product (Dixon et al., 2020).

Another advantage of using CA independent of research topics in the field of food consumption is the possibility of identifying consumer segments based on their preferences for food attributes, which allows for targeted marketing strategies (Green & Krieger, 1991; Moskowitz, 1996; Velázquez et al., 2021). It has been used to create a large database based on consumers´ perceptions of safety and interest in foods they consider important (Saulo & Moskowitz, 2011). One study evaluated women's perceptions of functional foods through messages found on the internet and segmented them according to their interest in functional foods (Moskowitz et al., 2004).

CA provides valuable insights to support product improvement or development, marketing strategies, and specific food policy initiatives. It is possible to consider the different levels of attributes, both intrinsic and extrinsic, to find the perfect combination that meets consumer expectations in a single product, thus increasing the chances of product success in the marketplace.

→ Attributes and sensory cues

As sensory appeal is one of the main motivators for food choice, CA has been used to investigate the role of sensory attributes (e.g., taste, texture, and aroma) in shaping consumer preferences. Endrizzi et al. (2015) studied whether the intensity of intrinsic sensory attributes and different information about fibre and antioxidant content (extrinsic attributes) provided before tasting could affect the acceptability of four apples. They found that the overall liking was positively influenced by high levels of crunchiness and sweetness. Kiss et al. (2022) to understand Hungarian consumers' preferences for chocolate bars, included in that experiment brand (manufacturer and private label), type (milk, dark, and white), health claim (sugar-free), and price. They found that the respondents showed a clear preference for manufacturer brands: milk chocolate, followed by dark and white chocolate. Sugar-free claims and an increase in product price had a negative impact on consumers' perceived utility.

Sensory attributes are also referred to as experiential attributes, as consumers must taste the food to evaluate it (Asioli et al., 2017). Therefore, several studies have gone beyond hypothetical profiles, including tasting products, to evaluate the impact of both extrinsic and intrinsic attributes (De Pelsmaeker et al., 2017 {García-Torres, 2016 #635; Sipple et al., 2022; Solheim, 1992; Stefani et al., 2006), which provides more complete and realistic information about consumer behaviour on real-life purchase situations (Grunert, 2015). (Sipple et al., 2022) evaluated whether pre-tasting information about ingredients and nutritional composition influenced product acceptability and improved the nutritional quality of ice cream and frozen dairy desserts. They found that claims

about the type of sweetener (naturally sweetened, reduced sugar, no added sugar), together with an “all-natural” claim and a short list of ingredients, were the main attributes that contributed to the perception of a frozen dairy dessert as “healthier” They concluded that the taste of healthier frozen desserts remains more important than the perception of healthiness (Sipple et al., 2022). Using CA, (Zhou et al., 2022) provided input for the design of a diet quality improvement strategy based on perceptions of healthiness and familiarity with dishes suitable for older consumers.

De Pelsmaeker et al. (2017), also integrated tasting into the experimental design to investigate the effects of sweetener type (sweetener, with sugar and stevia content), brand and package size on chocolate preference and purchase probability. They concluded that tasting led to greater consistency in respondents' responses and influenced the importance ratings and utilities of the overall population sample.

Sensory and hedonic cues were used in the form of messages on the packaging or elicited at the time of evaluation. Marquis et al. (2023) used “tasty” as a palatability claim to investigate how specific claims combined with attractive visual elements can influence young consumers´ emotions, perceptions, and acceptance. Luomala et al. (2015) also used “tasty” claims to assess how ambivalent hints of health and taste shape perceptions of the inclusiveness and exclusivity of these attributes. Heide and Olsen (2017) found that when choosing cod, the “freshness” information on the packaging was much more important than the visual aspects of the packaging. Other taste cues may include the origin or production method (Kos Skubic et al., 2018; Lusk et al., 2008; Stefani et al., 2006). For example, Lusk et al. (2008) evaluated preferences for beef from cattle fed on pasture compared to beef from animals not fed on pasture, and consumers perceived beef from cattle fed on pasture as tasting more.

→ Packaging design and information

Several studies have used a conjoint approach to understand how packaging design elements (e.g., colours, graphics, information layout) influence consumer perceptions and preferences (Ares & Deliza, 2010b; Gadioli et al., 2013; Gelici-Zeko et al., 2013; Pentus et al., 2014; Rocha, 2020; Romeo-Arroyo et al., 2023). Ares and Deliza (2010b) used word association and conjoint analysis to study the influence of package shape and colour on consumer expectations of milk desserts. The results showed that packaging colour influenced both taste and willingness to pay. Another study investigated the visual design of product packaging to create positive emotions in consumers (Pentus et al., 2014). (Gadioli et al., 2013) evaluated the relevant packaging attributes of orange juice on purchase intention and found that the relevance of the attributes depended on the

consumer segment. The cluster with the highest percentage of young people preferred the lowest prices, the cluster with a higher presence of older people preferred homemade juice, and the last cluster with more interest in general health consisted mainly of people with a higher level of education. A recent study assessed packaging features such as curvature, symmetry and marking (black vs. no-fill) on consumers' perceptions of premiums in four different food product categories (chocolate, coffee, jam, and ice cream). They found a significant positive effect of symmetry on the perception of premium quality in all product categories, while the effect of other visual attributes depended on the product (Romeo-Arroyo et al., 2023).

In addition to these packaging layout aspects, other unobservable aspects are exposed in the form of information on the label or front-of-package to inform consumers about the properties and attributes of the food product (Ballco & Gracia, 2022; Biondi & Camanzi, 2020; Carneiro et al., 2005; Carrillo et al., 2014; Hubbard et al., 2016; Poelmans & Rousseau, 2016). Aspects such as nutritional claims (NCs), health claims (HCs), organic claims, ethical claims, and sustainability claims have been emerged as one of the main research topics in the mapping of food preferences through CA in recent years (Ballco & De Magistris, 2019; Ballco et al., 2020; Banovic et al., 2019; Grasso & Asioli, 2020; Poelmans & Rousseau, 2016; Stojanović et al., 2017; Tórtora et al., 2019; Viscecchia et al., 2019; Weinrich & Elshiewy, 2019).

When assessing consumer interest in specific claims, studies have shown that consumers are very price-sensitive and are not willing to pay more because of HC or NC (Biondi & Camanzi, 2020; Steinhauser et al., 2019). On the other hand, another study evaluating HC in frozen hamburgers and dairy desserts revealed that the attribute “claim” is more relevant than “price” in both products and that the level of the claim “source of fibre” in hamburgers is rejected by consumers; while in dairy desserts, consumers reject the level of the claim “antioxidants” and positively evaluate the claim “fibre” (Viana et al., 2021), which shows that the type of HC is in some way favourable or unfavourable depending on the general perception of the product being evaluated. For example, in biscuits, the fibre claim does not evaluate the product, whereas the saturated fat reduction claim has a stronger influence on choice (Ballco et al., 2020).

According to the cognitive-experiential self-theory, human behaviour is determined by the interaction of two information processing systems: rational and intuitive (Epstein, 1994). Therefore, the impact of information on purchase decisions depends on the consumers’ thinking style (Epstein et al., 1996). Ares, Mawad, et al. (2014) evaluated the influence of both thinking styles on consumer choice and information processing when

evaluating yoghurt labels and concluded that consumers who predominantly relied on analytical-rational thinking engaged in more information search. Typically, consumers rely on effortless and intuitive thinking as they have a limited ability to digest all the information presented when making dietary decisions (Epstein, 2003).

→ Pricing

Assessing consumer perceptions of a product is the central question in food economics. Most predictive models of consumer purchase behaviour consider perceived quality and price as the main purchase determinants (Grunert, 2005).

Despite the increasing role of non-price factors in the marketing process, price remains an important element of the marketing mix (Kotler et al., 2010). For food products, the price can be a decisive factor in the acceptance or rejection of a product (Moskowitz, 1995), because the customer´s perception of value represents a relationship between the quality the perceived benefits and the perceived sacrifices in paying for the product (Zeithaml, 1988).

In the development of new products, when similar products are available in the market, the price of the product is often determined by the desired positioning concerning existing products. In the case of innovation, however, pricing is more challenging. There are two strategies to choose from: market skimming pricing and market penetration pricing (Kotler et al., 2010). Skimming pricing is a strategy in which a relatively high initial price is set for the product and the price is reduced over time. This strategy allows the company to quickly recover its costs before competitors reduce their market prices. The strategy of setting a low price is used when one wants to achieve a large volume of business and a fast and deep integration of the new product in the market (Spann et al., 2015). The market favours the second strategy because, on the one hand, consumers are very price-sensitive, so low prices lead to greater market additions; on the other hand, production and distribution costs decrease as sales volumes increase (Kotler et al., 2010).

It is considered more advantageous to set prices in the early stages of product development (Jariri & Zegordi, 2008) to decide on which attribute levels should be added to the product. For example, if a user is willing to pay a high price for a product, more expensive features can be added; otherwise, features can be added so that they can be sold at a lower price (Moskowitz et al., 2006).

To determine the price, contingent valuation can be applied (Boccaletti & Nardella, 2000; Maruyama & Kikuchi, 2004), where willingness-to-pay, questions are used to predict the

price. The acceptance of predicted and actual prices may differ because the true range of an acceptable price may change at the time of purchase due to, for example, budget constraints, experimental gains, similar products at the time of purchase, the perception of fair value, and other situational factors, such as time pressure at the time of purchase (Moskowitz et al., 2008; Zeithaml, 1988).

Price is one of the most important attributes influencing product preference and one of the most evaluated product features in CA (Ballco & De Magistris, 2019; Banovic et al., 2019; Krystallis & Chrysochou, 2012; Stojanović et al., 2017). CA allows for different approaches to pricing. In one approach, price is considered as an attribute of a concept and the effect of price on the acceptance or rejection of the concept is analysed. In another approach, price is considered as a rating scale, and respondents rank concepts in terms of the appropriate product price. The second approach is to use price as the dependent variable instead of accepting a price among the concepts presented. The rating scale can be labelled with a price at each point or anchored at the price ends (Moskowitz et al., 2008).

Price as an element of a product concept can be studied in terms of utility. Price is related to utility value, usually for food products; as price increases, utility value decreases (Moskowitz et al., 2008). Price can also be determined by the sum of the utilities of the different elements of the concept in the following way: create the concept without price, and if the sum of the utilities of the attributes of the concept is high, it means that there is room to add a high price to the concept. If the utility without price as an element is low, the way to increase the overall utility is to have a low price or even below the fair price as perceived by the consumer (Moskowitz et al., 2008).

Given the increasing role of non-price factors in the marketing process, some studies have not included price as an attribute of this concept (Ares & Deliza, 2010b; Solheim, 1992; Velázquez et al., 2021; Vidal et al., 2013). Price is one of the most salient attributes, especially in countries with weaker economies, overshadowing other attributes that may need to be analysed. For this reason, researchers must assess whether to include it as an attribute, depending on their objectives, considering the spontaneous behaviour of the consumers being studied.

Chapter 3 – Results

3.1. Paper I - Conceptualization of Rice with Low Glycaemic Index: Perspectives from the Major European Consumers.

Diva Cabral, Susana Caldas Fonseca, Ana Pinto Moura, Jorge C. Oliveira and Luís Miguel Cunha

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Article

Conceptualization of Rice with Low Glycaemic Index: Perspectives from the Major European Consumers

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Abstract: Rice and cereal consumption has become a concern for consumers due to usually high glycaemic indexes (GI), which is a critical issue for a balanced and healthy diet. Therefore, the development of new products with low GI is an important target of the industry, particularly in countries with high consumption. This study assesses consumers' perceptions about "rice" and "rice with low GI" and evaluates the effect of consumers' rice consumption profiles through the application of a free word association technique in a structured self-administered electronic questionnaire with 256 Portuguese consumers (the European market with the highest per capita consumption of rice by far). The frequency of rice consumption was evaluated, and the consumption profile was determined through a hierarchical cluster analysis, with 9% identified as daily consumers. The response words were categorized by the triangulation technique, and the association between the word categories and dimensions, sociodemographic characteristics, and consumption profile were determined. Respondents most frequently associated "rice" with rice dishes, its sensory attributes, and nutrition, highlighting the satisfaction of nutritional and hedonic needs. Consumers revealed positive expectations in relation to the functionality of "rice with low GI". The consumers' rice consumption profiles, sex, age, and educational levels influenced their perception towards "rice" and "rice with low GI". This study provides important insights for the industry to develop a consumer-oriented, low GI rice product.

Keywords: consumers' perceptions; consumption; free word association; glycaemic index; Portugal; rice

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1. Introduction

Rice (*Oryza sativa* L.) is the staple food of most of humankind, with a world per capita consumption of about 80.6 kg/year. The European average value of consumption is more modest, at just 6.7 kg/capita/year, registered between 2015 and 2019 [1]. Within this region, Portugal has the highest consumption, with an average of about 16.1 kg/year. Rice plays a relevant role in Portuguese cuisine, being used as a main course, as a side dish, and even as a dessert [2]. It accounts for 5.2% of the total energy intake, higher than its most direct carbohydrate competitors, namely, potato and pasta, which contribute to 4.6% and 3.0%, respectively [3]. In Portugal, there are two main commercial rice types, namely, *Carolino*, which is a long grain Japonica variety with milled kernels over 6mm in length, a length/width ratio between 2 to 3, and an amylose content below 22% (expressed in dry matter); and *Agulha*, which is a long grain Indica variety with milled kernels also over 6 mm length, but with a length/width ratio ≥ 3 and an amylose content above 25%, according to the Portuguese legislation DL 157/2017. *Carolino* rice is produced from different cultivars,

Ariete being the most common, and is traditionally used to make rice dishes with a creamy texture. It is often cooked in a traditional way that uses abundant water, and the high amylopectin content results in the rice absorbing the broth it is cooked with to obtain rich flavours, derived from the ingredients being cooked together, such as tomato, vegetables, pulses, meat, fish, or shellfish. As it absorbs much more water than other types of cooking, it seems to "produce more food" by just using water, and therefore this way of cooking is traditionally known as "*Malandro*", which means "cheater".

Rice may be served as a side dish or as a main course, depending on the major ingredient added to the rice. Although *Agulha* and *Carolino* are the most consumed types of rice, other white rice types such as *Arborio* and *Carnaroli* (the Japonica varieties used for *Risotto*), and the aromatics Basmati and Jasmine are also becoming increasingly popular [4]. Rice can be consumed just de-husked, still with its bran layer, which is most typically brown rice, although other bran colours can be found, namely red, black, and purple. This is becoming more common due to the health benefits of bran. However, the vast majority of the consumption of traditional cuisine is with milled rice, all of it white once the bran is removed (by abrasion,) and thus white rice and milled rice are synonymous.

Several nutritional studies have shown that the excessive consumption of white rice is associated with an increased risk of non-communicable diseases (NCDs), namely diabetes, hypertension, obesity, and cardiovascular diseases [5–10]. The amount and nature of its refined carbohydrates (CHO) turns white rice into a food with a high glycaemic index (GI) [11]. The GI is an indicator of the health quality of the carbohydrates (CHO) present in foods based on how quickly blood glucose levels rise following digestion.

Based on the GI (considering glucose as a standard food), foods are considered as presenting high GI ($GI \geq 70$), intermediate GI ($55 < GI < 70$), or low GI ($GI \leq 55$) [12]. Foods with high GI release glucose rapidly into the blood, and foods with a low GI tend to release glucose slowly and steadily. Thus, foods with a low GI are likely to improve blood glucose and lipid control as well as promote insulin sensitivity and thus are beneficial dietary treatments for diabetic patients [13]. The GI of cooked rice ranges from 37 to 151, depending on variety, processing, and recipe factors [14–17]. Among milled (white) rice, the rice with the lowest GI are Basmati, *Doogara*, and some hybrid rice [18,19]. Rice from the Japonica subspecies (local rice) has the highest GI, with Portuguese varieties *Ronaldo* and *Ariete* having GIs of 89 and 151, respectively [16]. Brown (whole grain) rice and parboiled rice (rice pre-treated with steam prior to milling) tend to have the lowest GI compared to their polished forms [18,20].

This is particularly relevant, as NCDs are one of the most serious public health concerns in Portugal [21]. In 2015, cardiovascular diseases represented 29.7% of total deaths [22], with diabetes affecting approximately 10% of the Portuguese population, and the prevalence of high blood pressure being approximately 36% [23]. Obesity affects more than 20% of Portuguese adults, together with overweightness, which affects more than 50% of the population [3]. Prevalence of childhood overweightness (including obesity) is also high, estimated at 29.6% in 2019 [24]. In the same way, over the last decade, consumers consider in general that CHO negatively affects health, namely, as a cause of weight gain [25]. This is particularly relevant for consumers, as studies conducted in Western societies have shown that health is operating as an important individual food choice criterion [26]. In fact, more and more consumers believe that foods contribute directly to their health, and eating healthy products may prevent nutrition-related diseases and improve physical and mental wellbeing [27].

It is therefore very important for the rice industry to understand better how consumers perceive the connection between diet-related health and the consumption of rice. To evaluate consumer perceptions, researchers recur to direct methods, such as questionnaires, focus groups, or interviews, and to indirect methods such as free word association or observational research [28], the latter methodology having the advantage of being better able to grasp consumer intuitive and automatic behaviours [29].

Free word association (FWA) is a projective technique used to achieve associative memory and has gaining popularity in food consumption research, as it encourages respondents to project their underlying motivations, beliefs, attitudes, and/or feelings regarding a specific food [30–32]. It consists of presenting a series of words (stimuli words or target words) to a respondent, encouraging an immediate response by associating them with the first words that come to mind. Word association tasks are simple and easy to use and offer powerful insights into the concepts being tested [32]. This cognitive task, which involves the conceptualization of the stimulus, allows for the assessment of the knowledge, the degree of familiarity, and interest in relation to the topic under study. The first ideas to come to mind or the most recurrent might be the most relevant, for example, for purchasing decisions [33].

The FWA technique was also used to explore consumers' perceptions concerning wellbeing in a food-related context [27] to investigate default attitudes toward food [34] and to assess the perceived cross-cultural values of consumption in a triadic approach [35]. The typology of consumption values is derived in terms of the product's/service's ability to have an end in and of itself or to serve as a means to a specific end, which includes utilitarian, symbolic, experiential, and aesthetic values [36]. For food consumption, a shorter triadic approach without aesthetic value proved to be interesting [35,37,38]. Within these, the utilitarian values are determined as a function of the food's capacity to reach the final objective due to a specific characteristic of that food; the symbolic values are determined from intangible concepts, such as cultural and ideological, or other concepts related to the belief itself [39]. The achievement of an end is also latent to these values; however, it is not dependent on the physical attributes of the product. Finally, the experiential values are related to sensory stimulation and affective and emotional reactions associated with consumption. Some research has been done on the perceived values of consumption, where foods have been characterized according to their dominant values as well, showing that the relative importance of consumption values is culturally dependent [34,35,38,40,41]. For example, the consumption of rice by Asian consumers is dominated by utilitarian values, while symbolic values predominate for French consumers [35].

The aim of this study is to evaluate how rice with low GI is perceived and understood by Portuguese consumers compared to the more common white rice with high GI values. This is particularly relevant for the food industry, which intends to develop new products or improve existing products to meet consumers' demands.

2. Materials and Methods

2.1. Participants

Over 250 participants living in the Great Oporto area were recruited considering the following inclusion criteria: (i) consuming rice at least once a month; (ii) above 18 years old, and (iii) willing to participate in the study. Despite being a convenience sample, it focused on a specific target group (rice consumers), and as such it may be considered as a reliable sample, commonly used in qualitative research [42].

The respondents were recruited by a sensory analysis and market research company from the North of Portugal named Sense Test. The company ensures the protection and confidentiality of data through the authorization 2063/2009 of the National Data Protection Commission and following EU Regulation 2016/679, as well as a longstanding internal code of conduct. The recruitment and scheduling of the inquiry were performed following a telephone-based invitation where only general information about the survey was provided.

All participants followed an informed consent procedure before answering the questionnaire.

2.2. Data Collection

In order to obtain consumers' intuitive and spontaneous ideas, an FWA approach was applied. Each participant was asked to write the first three words that came to mind when they read the stimulus word "rice" (*arroz*, in Portuguese) on the screen, showing three

blanks reserved for filling in, followed with the same question to the stimulus "rice with low glycaemic index" (*arroz com baixo índice glicémico,* in Portuguese). At the time of the questionnaire application, each respondent was taken to a quiet room and filled out the questionnaire that was presented on a computer screen. Data collection was done through a structured self-reported electronic questionnaire, using Lime Survey, and further included the evaluation of rice consumption patterns. The frequency of consumption of overall rice and of each different type of rice was asked, using close-ended questions, following a typical food frequency questionnaire [43]: (1) 1 to 3 times per month; (2) once a week; (3) 2 to 4 times a week; (4) 5 to 6 times a week; (5) once a day; and (6) 2 or more times per day. All types of rice in the Portuguese market were included in the questionnaire options, namely, Arborio (*Risotto*), *Agulha*, Basmati, *Carolino*, brown, wild, Jasmine (Thai Jasmin), and parboiled. Although wild rice (*Zizania aquatica* and *Z. palustris*) is not the same species as the others (*Oryza sativa* L.), it was included in the study as both are marketed as rice with no clear distinction between species. Additionally, sociodemographic data were also collected. The questionnaire also included the collection of age, sex, education level, and monthly household income. Data were collected over a two-month period, from February to March 2018.

2.3. Data Analysis

Data analysis of the FWA results was initiated with a spell check and correction of all response words. Next, the categorization of the response words was done by three experienced researchers using the triangulation technique [44]. This technique is widely used in content analysis to reduce the subjectivity related to this type of analysis [45]. The researchers, both individually and independently, grouped the words into exclusive categories and then into dimensions that were more comprehensive, considering the semantic and lexical relations according to the Portuguese language dictionary. The following assessment criteria were taken to each response word: (i) did not include words that elicited multiple interpretations in the context of the stimulus word (ambiguous words); (ii) maintained the same form for words that allow plural or singular and female or male; and (iii) did not include words that had no type of connection to the stimulus word, or made no sense; however, when the ambiguous or presumptively out-of-context words were in sounding numbers, they were grouped for later analysis and joint decision-making.

After the individual categorization of the response words by each researcher, a consensus categorization was achieved. This analysis was done in the native Portuguese language and only after was it translated into English using the rules established by Anderson and Brislin [46].

The frequency of each category and dimension was determined by word, counting the number of response words, and summing those in the same category and dimension; and by participant, counting the number of respondents that mentioned those categories or dimensions. The word frequencies were counted without considering if the words were evoked by the same respondent or not [47–49]. To avoid losing valuable information about the perception of cognitive associations of smaller groups, all the categories referred by at least 5% of the participants were considered for analysis.

In addition to grouping the words according to their semantic meaning, words were also grouped according to the perceived value into utilitarian, experiential, and symbolic. There are a variety of definitions and conceptualizations of value that depend on both the context of the study and the methodology and measurement techniques, as well as the theoretical background of the study (such as economic theory and cognitive psychology or consumer behaviour psychology) [40,50–53]. This has followed the classification consolidated by Lanseng [36] resulting from the analysis of the relevant literature that reflects on this topic.

To draw a rice consumption profile, a hierarchical cluster analysis was applied over the consumption frequency data for the different rice types using the Ward method for agglomeration and the square Euclidean distance as the similarity measure. The nonpara-

metric Kruskal–Wallis test followed by pairwise comparison was also used to compare the frequency of consumption by type of rice between clusters.

A chi-square test of independence was used to evaluate if there is a significant relationship between FWA dimensions, rice consumption profile, and the sociodemographic variables (age group, sex, and education level), following a 95% confidence level. A chi-square test per cell was used to identify the source of the global chi-square variation through the adjusted standardized value [54–56]. To compare the consumption values associated with each stimulus word, the same analysis procedure was followed.

Statistical data analysis was processed with XL-STAT®, v. 2020.5.1 (Addinsoft, New York, NY, USA).

3. Results

3.1. Characterization of Participants

The questionnaire was applied to 256 Portuguese respondents aged between 18 and 73 years. Table 1 shows the sociodemographic characteristics of the participants in terms of age, sex, education level, and monthly household income.

Table 1. Sociodemographic characteristics of the participants (n = 256).

Variable		Absolute Frequency	Relative Frequency
Age group (mean ± SD: 40 ± 13 years)			
	[18; 35[	90	35.2%
	[35; 55[	124	48.4%
	55+	42	16.4%
Sex			
	Female	164	64.1%
	Male	92	35.9%
Education level			
	No higher education	164	64.1%
	Higher education	92	35.9%
Net monthly per capita household income			
	≤250 €	65	25.4%
	[250–400[€	66	25.8%
	[400–550[€	62	24.2%
	>550 €	63	24.6%

3.2. Conceptualization of the "Rice" and "Rice with Low Glycaemic Index" Stimuli

A total of 1498 different terms was generated after consumers were invited to write the first three words that came to mind when thinking about "rice" and "rice with low GI". Figure 1 shows the frequency of the 20 most evoked words in the FWA task for the stimulus (a) "rice", and (b) "rice with low GI". While 'white' and 'tasty' were the most frequent words for the "rice" stimulus, they were 'brown rice' and 'healthy' for the "rice with low GI" stimulus (Figure 1).

3.2.1. "Rice" Stimulus

The FWA technique applied to the "rice" stimulus gave rise to 768 written words (all the respondents evoked the three words) that corresponded to 188 different response words. The four most recurrent response words were 'white' (30.9%), 'tasty' (15.2%), 'loose' (11.3%), and 'side dish' (10.2%) (Figure 1a).

The response words were grouped into 18 categories and 10 dimensions. Figure 2 presents the frequency of respondents according to each dimension for the "rice" stimulus, and Table 2 shows the frequencies of words and respondents according to each category with examples of the elicited words. The category 'distribution and price' (e.g., words: price, hypermarket, cheap, affordable, packaging, brand) was mentioned below the established cut-off point, and therefore was not considered for further analysis.

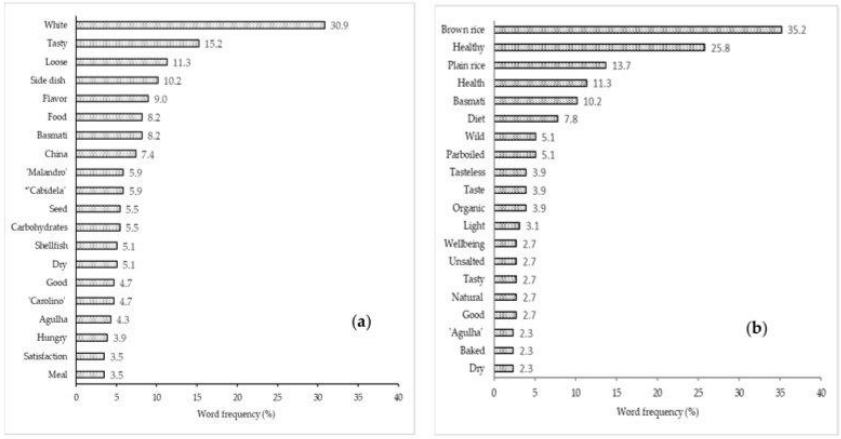

Figure 1. Word frequency of the twenty most evoked words for the stimulus: (**a**) "rice" and (**b**) "rice with low glycaemic index". * *Cabidela* rice is a traditional *Malandro* rice dish of the gastronomy of the Northern region of Portugal made with *Carolino* rice, poultry, and chicken blood with vinegar, where the offal is also incorporated, resulting in a creamy/saucy rice with meat served as a main course.

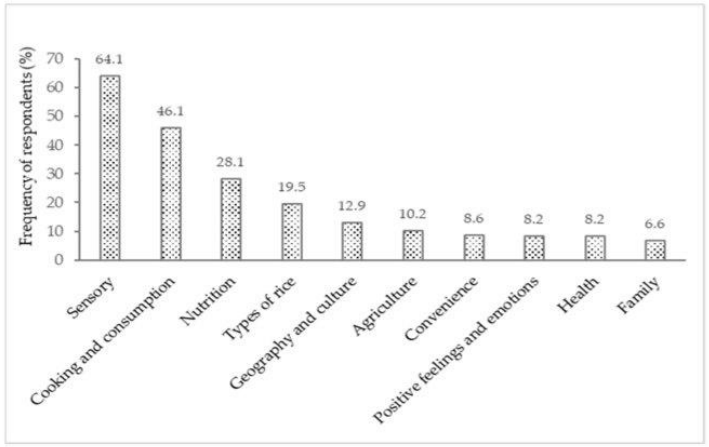

Figure 2. Frequency of respondents (%) describing words according to the dimensions for the "rice" stimulus.

Table 2. Frequencies of words and respondents (%) according to each dimension and category for the "rice" stimulus. The predominant consumption value associated with the words within each dimension is also referred.

Dimension	Category	Examples of Elicited Words	Word (%)	Respondent (%) [1]	Predominant Consumption Value
Sensory	Appearance	appearance, colour, white, large grain, loose, size, small grain	16.3	38.3	Experiential
	Flavour	aroma, savour, smell, sweet, taste	9.8	26.2	
	Texture	*al dente*, brothy, creamy, crunchy, dry, grainy, hard, moist, parched, smooth, soft, wet, texture	4.2	10.9	
	Positive hedonics	appetizing, favourite, good, 'I love it', pleasant, wonderful	3.9	10.9	

Table 2. *Cont.*

Dimension	Category	Examples of Elicited Words	Word (%)	Respondent (%) [1]	Predominant Consumption Value
Cooking and consumption	Specific foods	bacon, beans, cabbage, carrot, chicken, herbs, meat, red beans, shrimp, onion, peas, tomatoes, tuna, vegetables	8	15.6	Utilitarian
	Rice side dish	bean rice, cabbage rice, carrot rice, *Malandro* rice, side dish, spring rice, tomato rice, plain rice	7.6	21.9	
	Rice main course	*Cabidela* rice, chicken rice, codfish rice, duck rice, seafood rice, octopus rice, sweet rice (dessert), Valencian rice	5.8	14.1	
	Culinary practice	bake, braise, *estrugido*, grill, hot, oven, porridge, roast, soggy, stir-fry	2.9	7.8	
Nutrition	Staple/sustenance	basic, eating, essential, food, meal, staple, sustenance	6.8	18.4	Utilitarian
	Nutritional aspect	balanced, calories, carbohydrates, energy, good nutrition, nutritious, natural, nutritious, protein	4.3	12.5	
Types of rice *		Basmati, *Carolino*, *Agulha*, *Risotto*, brown rice, parboiled, wild, Jasmine, waxy	8.5	19.5	Utilitarian
Geography and culture		Africa, Asia, China, national, East, Thailand, exotic, chopsticks	4.8	12.9	Symbolic
Agriculture		agriculture, countryside, farming, environment, paddy field, plantation, seeds	4.1	10.2	Symbolic
Convenience		easy, fast, practical, variety, versatile	3	8.6	Utilitarian
Positive feelings and emotions		comfort, enjoyment, fun, joy, passion, pleasure, spectacular, success	3.4	8.2	Experiential
Health		health, healthy	3	8.2	Utilitarian
Family		childhood, holidays, home, family, mother, grandmother, son	2.5	5.9	Symbolic

[1] Respondent percentages for each category. * Types of rice utilizes the nomenclature freely used by consumers, as explained in the text.

More than half of the respondents (64.1%) mentioned the 'sensory' dimension, corresponding to 34.2% of words, in which the main components of the rice quality assessment were elicited, related to shape, colour, integrity, results, cooking, and grain processing. 'Appearance' (16.3% of words) was the largest category of the "rice" stimulus, and the main sensory attribute cited far more often than the other attributes such as 'flavour' (9.8% of words) and 'texture' (4.2% of words).

The second most expressive dimension was 'cooking and consumption' with 24.3% of words and 46.1% of respondents, which refers to methods of preparing and ways of consuming rice. This dimension was comprised by 'specific foods' (shellfish, tuna, beans, tomato, bacon, chicken, duck, etc.) that are commonly used as ingredients in culinary preparation (8.0% of words), 'rice side dish' (7.6% of words), and 'rice main course' (5.8% of words), as well as 'culinary practices' (2.9% of words). In the category 'culinary practices', some cooking methods were evoked, such as 'braise' and '*estrugido*', which are common ways of cooking rice. '*Estrugido*' (Portuguese word) is a specific term for braising rice, which is frying garlic and onion in olive oil (may include other condiments) and gaining colour without burning, where other ingredients of the dish to be cooked are later added.

The 'nutrition' dimension contained the 'staple/sustenance' and 'nutritional aspects' categories, revealing the functional dimension of rice. Due to the importance of rice in the Portuguese eating habits, associations with the basic nutritional characteristics ('staple/sustenance' category) were already expected. In this category, words such as 'basic', 'essential', 'food', 'eating', 'to eat', and 'staple' were mentioned. The 'types of rice' dimension was mentioned by 19.5% of respondents who mentioned various types of rice such as Basmati, *Carolino*, *Agulha*, *Risotto*, brown, parboiled, wild, and Jasmine. It is noted

that consumers will freely describe as 'types of rice' a mix of actual names of varieties, commercial names, and forms of cooking. For instance, *risotto* is an Italian way of cooking rice, not a variety or type of rice. Actually, Portuguese restaurants have been known to cook *risottos* using *Carolino* rice; there is nothing wrong with that because Portuguese consumers do not actually appreciate the *al dente* texture that would require varieties like Arborio or Carnaroli to be used. This mix-and-match of names is what consumers read in the packages that they buy, and thus these loose designations were maintained in the text.

'Positive feelings and emotions' include terms such as 'comfort', 'enjoyment', 'fun', 'joy', 'passion', 'pleasure', 'spectacular', and 'success' (3.4% of words and 8.2% of respondents), which are words that express positive feelings and affective aspects of consumption.

The 'geography and culture' dimension brought together names of countries and terms related to specific culture and habits. 'Agriculture', 'convenience', 'health', and 'family' were the last dimensions associated with rice. 'Convenience' was positively referred to, associating words such as 'easy', 'fast', 'practical', and 'versatile'. The versatility and practicality are related to the wide culinary applicability of rice, as well as the existing varieties.

3.2.2. "Rice with Low Glycaemic Index" Stimulus

This stimulus had a total of 730 written words, with 265 different response words, with 'brown rice' (35.2%) and 'healthy/health' (25.8% + 11.3%) being the most evoked words (Figure 1b). Thirty-nine missing values (non-responses) were obtained, corresponding to 8.6% of respondents. Among the twenty most frequent, other words were also evoked, such as 'plain rice' (13.7%), 'Basmati' (10.2%), 'diet' (7.8%), 'organic' (3.9%), 'natural' (2.7%), as well as some sensory descriptors, namely, 'flavour', 'tasteless', and 'dry'.

The "rice with low GI" stimulus gave rise to 19 categories; of these, the following ones were not considered due the low reference frequencies (cut-off point: minimum 5% of respondents): 'other types of rice' (*Agulha*, *Carolino*, Jasmine), 'appearance', and 'texture', decreasing to a total of 16 categories. These categories were grouped into nine dimensions presented in Figure 3. Table 3 shows the frequency of words and respondents according to each category with examples of the elicited words.

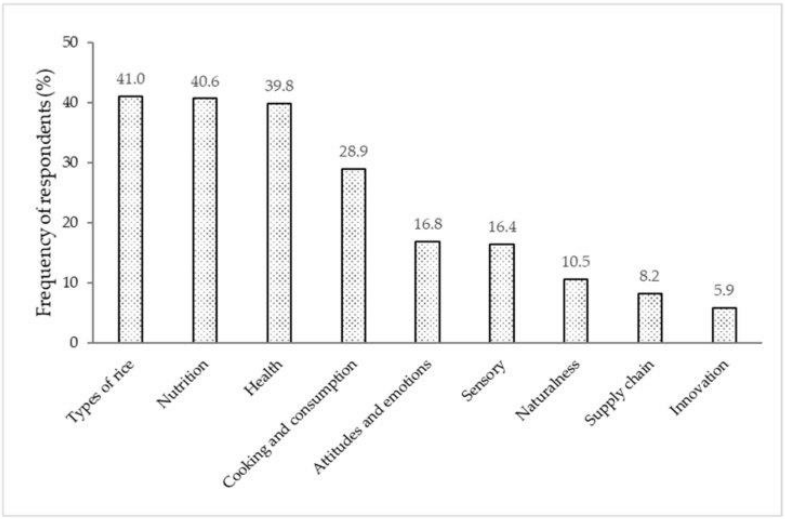

Figure 3. Frequency of respondents (%) describing words according to the dimensions for the "rice with low glycaemic index" stimulus.

Table 3. Frequencies of words and respondents (%) according to each dimension and category for the "rice with low glycaemic index" stimulus. The predominant consumption value associated with the words within each dimension is also referred.

Dimension	Category	Examples of Elicited Words	Word (%)	Respondent [1] (%)	Predominant Consumption Values
Types of rice		brown, Basmati, wild, parboiled	19.4	41.0	Utilitarian
Nutrition	Nutritional aspects	low sugar, low carbohydrates, calories, energy, fat, fibre, nutrients, nutritive, nutrition, protein	7.0	20.3	Utilitarian
	Diet patterns	balanced regime, diet, eat small amounts, few, less, moderation	5.7	15.2	
	Low GI disconnects	gluten free, with vitamins, more vitamins, more phosphorus, without salt, fat free, high in carbohydrates, non-fat rice	4.3	11.7	
Health	Physiological	blood glucose, diabetic, health, healthy, hunger, slow absorption	18.0	38.0	Utilitarian
	Health benefits	cleanse organism, slimming, treatment, good for health, prevent, longevity, strengthening the organism, healthy life, quality of life, good disposition	2.5	6.6	
Cooking and consumption	Rice dishes	plain rice, vegetable rice, *Malandro* rice, rice soup, raisin rice	6.3	16.4	Utilitarian
	Specific foods	bean, chia, chicken, coconut water, fish, mushrooms, oat, quinoa, rice, seeds, spices, vegetables, yogurts	4.8	11.3	
	Culinary practices	boiling, confectioning, cooking, grilling, steaming, stewing	1.7	5.1	
Attitudes and emotions	Positive attitudes and emotions	advisable, alternative, appropriate, better, essential, good mood, happiness, ideal, interesting, joy, quality, recommendable, safe, satisfaction, special, suitable, wanting	4.7	12.9	Experiential
	Negative feelings and emotions	dissatisfied, doubt, expendable, misinformation, uncertainty, unfamiliarity	2.0	4.3	
Sensory	Positive	delicious, loose, multicolour, taste, tasty	3.6	10.9	Experiential
	Negative	bitter, little taste, insipid, less appealing, no-taste, tasteless, unpleasant	2.5	5.9	
Naturalness		additive-free, natural, organic, preservative-free, pure, unprocessed	4.0	10.5	Utilitarian
Supply chain		brand, chain, cost, customer, dehydrated, expensive, health and wellbeing section, instant rice, rice drink, price, tufted rice	3.0	8.2	Utilitarian
Innovation		created, develop, development experiment, innovation, laboratory, produce	2.5	5.9	Symbolic

[1] Respondent percentages for each category.

The most referred dimension was 'types of rice' (19.4% of words and 41.0% of respondents). The 'nutrition' dimension (17.0% of words and 40.6% of respondents) was composed of 'nutritional aspects', where the terms related to the nutritional characterization of the stimulus and main nutrients of rice were grouped, while the category 'diet patterns' consisted of terms related to the usual food intake and terms relating to food restriction or reduction. This dimension also included the 'low GI disconnects' category, which gathered incoherent nutritional aspects in the context of this stimulus, such as 'gluten free', 'more vitamins', 'with more vitamins', and 'more phosphorus'. There was also the association of this stimulus to 'unsalted' and 'non-fat', where about 11.7% of respondents made this kind of association.

The 'health' dimension (20.5% of words and 39.8% of respondents) was composed of the categories 'physiological' and 'health benefits'. The 'physiological' category grouped terms related to the organic functions or vital processes of the human organism. The 'health

benefits' category includes terms associated with achievements driven by healthy eating and some specifically by consumption of low GI foods.

The 'rice dishes', 'specific foods', and 'culinary practices' categories made up the 'cooking and consumption' dimension. In 'culinary practices', healthier cooking methods were mentioned, such as 'grilling', 'boiling', and 'steaming'. In the 'naturalness' dimension, the concern was with both production and processing, mentioning terms such as 'organic', 'additive-free', 'preservative-free', and 'unprocessed'.

In the 'sensory' dimension, some limiting attributes of liking were evoked, such as 'bitter', 'tasteless', 'little taste', 'insipid', and 'no-taste'. However, there was also mention of attributes indicating positive attitudes and feelings such as 'satisfaction', 'happiness', 'joy', and 'good mood' grouped in the 'attitudes and emotions' dimension. Related to this dimension, terms associated with negative feeling (e.g., 'doubt', 'dissatisfied', 'uncertainty', 'unfamiliarity') also appeared. The 'positive attitudes and emotions' category highlighted a positive perception of rice with low GI, evoking words such 'suitable', 'interesting', 'advisable', 'ideal', 'better', 'essential', and 'special'.

The last dimensions were 'supply chain', which cited some rice products (rice drink, tufted rice, rice flour, instant rice, dehydrated rice), and 'innovation', which made perfect sense for this concept, since the stimulus incited something new for the respondents. These terms allude to innovation and rice products that can be clues to the intended low GI products. These least frequent dimensions ('supply chain', 'innovation') also referred to the way of accessing "rice with a low glycaemic index".

3.2.3. Consumption Values for "Rice" and "Rice with Low Glycaemic Index" Stimuli

When addressing the consumption values associated with each of the elicited words, in accordance with the stimuli concepts "rice" and "rice with low glycaemic index", clear differences emerged, both based on the frequencies of words and participants. These results are shown in Figure 4.

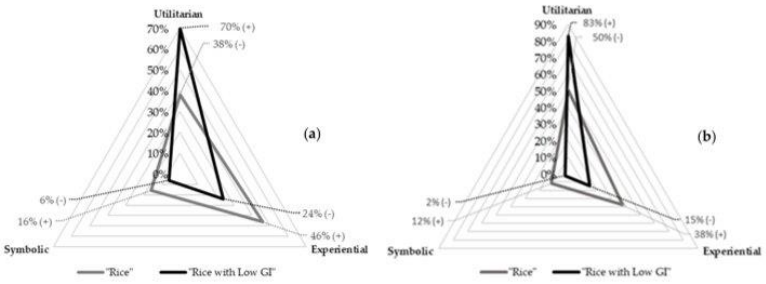

Figure 4. Frequency of (**a**) respondents and (**b**) words associated with each consumption values (utilitarian, experiential, symbolic) and stimuli ("rice" and "rice with low GI"). Effect of the chi-square per cell: (+) or (−) indicate that the observed value is significantly ($p < 0.001$ for all comparisons) higher or lower than the expected theoretical value.

The response words evoked by the respondents from the "rice" stimulus were mostly of an experiential nature (46%), followed by utilitarian (38%), and finally the symbolic values, with 16% of respondents. The most evoked dimension (sensory) carried experiential value, but most dimensions followed predominantly utilitarian values.

In the association task with "rice with low GI", most response words represented utilitarian consumption values (70% of respondents), demonstrating the functionality of rice with low GI. There were 24% of respondents who expressed words with experiential values. These words were grouped in the 'attitudes and emotions' and 'sensory' dimensions. Symbolic values were the least mentioned with only 6% of respondents.

Through the chi-square test, it was verified that there were significantly more associations of experiential and symbolic values to the stimulus "rice", while for the stimulus "rice with low GI", the respondents made significantly more utilitarian associations.

3.3. Rice Consumption Profiles

To better understand the respondents' rice consumption profiles, a hierarchical cluster analysis was performed based on the consumption frequency of each type of rice. Four clusters were obtained and labelled as follows (Table 4):

- Specialities Cluster—consumers which stood out for their specialty rice types (Basmati, Jasmine, Risotto, brown, parboiled) consumption and with the lowest frequency of rice consumption in general (overall rice consumption: 3.6 times/week);
- Local Cluster—most frequent consumers of Carolino rice (a Portuguese rice type) and Agulha rice (the most consumed rice type), and those who consume fewer specialty rice types (overall rice consumption: 4.2 times/week);
- Daily Cluster—group with highest weekly consumption for all types of rice, depicting a daily consumption of rice (overall rice consumption: 6.8 times/week);
- Agulha Cluster—most frequent consumers of Agulha rice (overall rice consumption: 4.5 times/week).

Table 4. Self-reported frequency of consumption of different types of rice (meals/week) by consumption profile.

		Rice Consumption Profile (n = 256)			
Types of Rice	**Overall(n = 256)**	**Specialities (n = 58)**	**Local (n = 108)**	**Daily (n = 24)**	***Agulha* (n = 66)**
Rice *	4.4 (0.12)	3.6 (0.27) ^{b}	4.2 (0.20) ^{b}	6.8 (0.73) ^{a}	4.5 (0.33) ^{b}
Agulha	2.6 (0.08)	0.5 (0.53) ^{c}	2.8 (0.15) ^{b}	4.1 (0.61) ^{a}	3.6 (0.31) ^{a}
Carolino	1.9 (0.08)	1.3 (0.10) ^{b}	2.8 (0.10) ^{a}	4.3 (0.43) ^{a}	0.3 (0.03) ^{c}
Basmati	1.0 (0.05)	1.7 (0.16) ^{b}	0.5 (0.04) ^{c}	2.7 (0.26) ^{a}	0.9 (0.09) ^{c}
Parboiled	0.8 (0.05)	1.3 (0.13) ^{b}	0.6 (0.07) ^{c}	2.2 (0.22) ^{a}	0.4 (0.57) ^{c}
Brown	0.5 (0.04)	0.7 (0.07) ^{b}	0.3 (0.04) ^{c}	2.1 (0.24) ^{a}	0.3 (0.04) ^{c}
Jasmine	0.3 (0.03)	0.5 (0.06) ^{b}	0.2 (0.11) ^{c}	1.7 (0.23) ^{a}	0.2 (0.02) ^{c}
Risotto	0.2 (0.04)	0.4 (0.04) ^{b}	0.2 (0.01) ^{c}	0.7 (0.07) ^{a}	0.2 (0.02) ^{c}

$^{a, b, c}$ Homogeneous group according to the nonparametric test of Kruskal–Wallis with 5% significance level and the pairwise comparison post hoc test. * Global rice consumption frequency as directly reported by participants. Mean (standard error).

Table 5 shows the relationship between the rice consumption profiles (four clusters) and the respondents' sociodemographic characterization variables (age group, sex, education level, and monthly household income). There were significantly more male respondents in the Local cluster (consumption of the most common rice types and lower consumption of specialities) than female, while for the Specialities and Daily clusters, the opposite was verified. There were significantly more respondents with higher education in the Specialities cluster, and more respondents without higher education in the Local cluster.

Table 5. Sociodemographic characterization of the rice consumption profiles according to age group, sex, education level, and monthly household income.

	Rice Consumption Profile (n = 256)			
Sociodemographic Variables	**Specialities (n = 58)**	**Local (n = 108)**	**High Frequency (n = 24)**	***Agulha* (n = 66)**
Age group (mean ± SD: 40 ± 13)				
[18; 35[	18.1	43.0	12.2	26.7
[35; 55[	25.8	41.9	8.1	24.2
55+	22.2	43.7	4.8	29.3

Table 5. *Cont.*

Sociodemographic Variables		Rice Consumption Profile (n = 256)			
		Specialities (n = 58)	Local (n = 108)	High Frequency (n = 24)	*Agulha* (n = 66)
Sex					
	Female	25.7 (+) ***	35.4 (−) ***	11.5 (+) ***	27.5
	Male	16.8 (−) ***	55.7 (+) ***	4.4 (−) ***	23.1
Education level					
	No higher education	19.5 (−) **	46.0 (+) **	8.4	26.1
	Higher education	28.1 (+) **	36.3 (–) **	10	25.6
Monthly household income (estimated per capita)					
	≤250 €	21.5	44.6	12.3	21.6
	[250–400[€	18.7	45.0	12.1	24.2
	[400–550[€	19.4	43.0	6.5	31.1
	>550 €	30.7 (+) **	37.6	4.7 (−) **	27.0

(+) or (−) indicate that the observed value is greater or less than, respectively, the expected theoretical value. ** $p < 0.01$; *** $p < 0.001$ chi-square effect per cell.

3.4. Evaluation of the Relationship between the Free Word Association Categories, Dimensions, and Values, the Rice Consumption Profiles, and the Sociodemographic Variables

To perceive the relationships between variables emerging from free association (categories, dimensions, and values), consumption profile, and sociodemographic variables (age group, sex, educational level, and monthly household income), the chi-square independence test was performed for both stimuli with a 0.05 significance level.

3.4.1. "Rice" Stimulus

Table 6 presents the results of the associations considering the rice stimulus. Results showed that male respondents made significantly more associations to the 'specific foods' (which are normally ingredients for the preparation of rice dishes or to complement the rice meal) and 'geography and culture', while female respondents mentioned significantly more 'types of rice', 'sensory', and 'family'. The oldest respondents made significantly more associations to 'nutrition', 'positive feelings and emotions', 'agriculture', 'convenience', and 'health', and the younger, in turn, made significantly more associations with 'appearance'. The middle age group associated more positively with 'specific foods'.

Respondents with higher education seemed much more often to consider the 'rice as side dish' and 'type of rice' categories in their associations than individuals without higher education. Those without higher education more frequently associated the "rice" stimulus to 'flavour', 'positive feelings and emotions', 'convenience', and 'health'.

As for the rice consumption profile, it was found that the Specialities cluster mentioned significantly more 'types of rice' and 'agriculture'. The high frequency rice consumption cluster made significantly more associations to the 'convenience' category. The cluster with the highest *Agulha* rice consumption was the one that made most mention of the words related to mood ('positive feelings and emotions'), which were significantly less mentioned by the Local cluster.

The female respondents and *Agulha* clusters mentioned significantly more response words of experiential value. Symbolic values, which were the least associated with the concept (16%, Figure 4), were significantly more often mentioned by the Specialities cluster.

Table 6. Frequency (%) of elicited words according to dimensions, categories, and values in the free word association task using the "rice" stimulus according to sex, age group, education level, and rice consumption profile.

Dimension	Sex		Age Group (years)			Education Level		Rice Consumption Profile			
Category	**Male**	**Female**	**[18; 35[**	**[35; 55[**	**55+**	**No Higher Education**	**Higher Education**	**Specialities**	**Local**	**Daily**	***Agulha***
Sensory	30 (−) **	70 (+) **	39	46	15	68	32	16 (−) *	45	11	28
Appearance	33	67	43 (+) ***	43	14	63	37	14 (−) **	44	10	32
Flavour	32	68	30	53	17	75 (+) ***	25 (−) ***	19	49	11	21
Texture	22	78	47	41	12	63	37	16	40	16	28
Positive hedonics	20 (−) **	80 (+) **	33	53	14	77	23	20	43	14	23
Cooking and consumption	45 (+) **	55 (−) **	34	55 (+) ***	11 (−) ***	57 (−) ***	43 (+) ***	22	48	8	22
Specific foods	52 (+) **	48 (−) **	31	67 (+) ***	2 (−) ***	62	38	16	52	16	16
Rice side dish	43	57	33	47	20	50 (−) ***	50 (+) ***	26	45	7	22
Rice main course	45	55	36	50	14	61	39	30	42	5	23
Culinary practice	32	68	41	55	4	50	50	19	49	11	21
Nutrition	34	66	34	42	24 (+) ***	67	33	26	42	10	22
Staple/sustenance	27	73	29	46	25	67	33	29	36	8	27
Nutritional aspect	45	55	43	36	21	67	33	21	52	12	15
Types of rice	25 (−) **	75 (+) **	45	53	2 (−) ***	44 (−) ***	56 (+) ***	34 (+) *	31 (−) *	7	28
Positive feelings and emotions	31	69	8 (−) ***	57	35 (+) ***	85 (+) ***	15 (−) ***	15	19 (−) **	4	62 (+) **
Geography and culture	53 (+) **	47 (−) **	36	56	8	67	33	19	47	12	22
Agriculture	45	55	32	32	36 (+) ***	65	35	42 (+) *	29	32	26
Convenience	30	70	39	30	31 (+) ***	87 (+) ***	13 (−) ***	22	39	26 (+) *	13
Health	35	65	13 (−) ***	35	52 (+) ***	96 (+) ***	4 (−) ***	22	43	5	30
Family	18 (−) **	82 (+) **	23	64	13	64	36	36	32	5	27
Consumption values											
Utilitarian	39	61	36	48	16	61	39	25	43	9	23
Experiential	29 (−) *	71 (+) *	35	48	16	69	31	16 (−) *	43	11	30 (+) *
Symbolic	42	58	32	48	20	66	34	32 (+) *	38	7	23

Effect of the chi-square per cell. (+) or (−) indicate that the observed value is higher or lower than the expected theoretical value: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

3.4.2. "Rice with Low Glycaemic Index" Stimulus

The associations considering the "rice with low GI" stimulus are presented in Table 7. 'Types of rice' was mentioned significantly more by female and higher education respondents. In the nutritional dimension, the youngest cited more terms related to the 'nutritional aspect'. 'Low GI disconnects' was evoked significantly more by respondents without higher education. 'Cooking and consumption' was evoked significantly more by the middle-aged group ([35; 55[) and by respondents without higher education. In the dimension 'attitudes and emotions', male respondents were the ones who most evoked 'negative feelings and emotions', while 'positive attitudes' was significantly more often mentioned by the older ones. Older respondents also evoked significantly fewer sensory terms and evoked significantly more terms from the 'naturalness' dimension. The terms related to 'innovation' were significantly more often mentioned by male, younger, and higher education individuals.

Rice dishes were mentioned more by Local consumers, while the Specialities consumers mentioned significantly more 'types of rice' and significantly less 'health' and 'sensory' dimensions.

For consumption values, significant differences were found between Specialities and Local consumers. It was found that the Specialities consumers mentioned significantly more response words with utilitarian values, while the Local cluster mentioned significantly more experiential values.

Table 7. Frequency (%) of elicited words according to dimensions, categories, and consumption values in the free word association task using the "rice with low glycaemic index" stimulus according to sex, age group, education level, and rice consumption profile.

Dimension	Sex		Age Group (Years)			Education		Rice Consumption Profile			
Category	**Male**	**Female**	**[18; 35[**	**[35; 55[**	**55+**	**No Higher Education**	**Higher Education**	**Specialities**	**Local**	**Daily**	***Agulha***
Type of rice	19 (−) ***	81 (+) ***	40	49	11 (−) ***	54 (−) **	46 (+) **	34 (+) *	34 (−) *	8	24
Nutrition	33	67	34	48	18	90	42	24	41	10	25
Nutritional aspect	35	65	50 (+) ***	43	7 (−) ***	56	44	28	35	9	28
Diet patterns	33	47	30	48	22	70	30	18	48	11	23
Low GI disconnects	30	70	15 (−) ***	58	27	88 (+) **	12 (−) **	27	39	9	24
Health	41	59	33	50	17	66	34	16 (−) *	45	12	27
Physiological	40	60	32	52	16	65	35	16	45	10	29
Health benefits	11	10	37	42	21	74	26	16	47	21	16
Cooking and consumption	39	61	21 (−) ***	68 (+) ***	9	76 (+) *	24 (−) *	26	50	7	17 (−) *
Rice dishes	31	69	27	58	15	79 (+) **	21 (−) **	21	56 (+) *	6	17
Specific foods	46	54	16 (−) ***	81 (+) ***	3	76	24	30	43	8	19
Culinary practices	46	54	15	70	15	62	38	31	46	8	15
Attitudes and emotions	50 (+) ***	50 (−) ***	24	42	34 (+) ***	68	32	18	46	6	30
Positive attitudes	44	56	22	33 (−) ***	45 (+) ***	75	25	19	39	8	33
Negative feelings and emotions	69 (+) ***	31 (−) ***	31	56	13	56	44	13	63 (+) *	6	19
Sensory	40	60	42	51	7 (−) *	60	40	7 (−) *	49	12	33
Positive	39	61	32	57	11	61	39	16 (−) *	45	10	29
Negative	40	60	60 (+) ***	33	7 (−) ***	60	40	7	53	20	20
Naturalness	35	65	32	39	29 (+) ***	65	35	16	42	3	39
Supply chain	26	74	35	39	26	65	35	22	43	13	22
Innovation	68 (+) ***	32 (−) ***	74 (+) ***	21 (−) ***	5	32 (−) **	68 (+) **	11	42	16	32
Consumption values											
Utilitarian	33	67	35	50	15	64	36	24 (+) *	41 (−) *	10	25
Experiential	42	58	33	46	21	65	35	13 (−) *	50 (+) *	7	30
Symbolic	44	56	43	44	13	56	44	6	50	19	25

Effect of the chi-square per cell. (+) or (–) indicate that the observed value is higher or lower, respectively, than the expected theoretical value: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

4. Discussion

The findings of this research emphasize the long experience of Portuguese consumers in the context of rice in their meals. In the FWA task, all respondents filled in the three reserved spaces for the "rice" stimulus. For the "rice with low GI" stimulus, 10% of the respondents left at least one blank, and the level of response divergence was greater, resulting in a greater number of different words, indicating that our respondents were less familiar with this concept, as the familiarity of the participants with the stimulus determines how they will process information to answer questions [57,58].

For the "rice" stimulus, the most frequent words evoked by our participants were 'white', 'taste', and 'loose'. This revels that the 'sensory' dimension represents the main rice consumer association, as the higher the frequency of elicitations the greater the salience of the association or concept in the consumers' minds [59]. Additionally, only positive hedonic words, such as 'appetizing', 'favourite', 'good', 'I love it', 'pleasant', and 'wonderful', were evoked by our participants. Not surprisingly, this reinforces that the Portuguese consumer focuses on sensorial attributes of the product, which is in tune with findings that sensory appeal is one of the main determinants of food choice by Portuguese consumers [26]. 'Appearance' was by far the largest category of the "rice" stimulus and the main sensory attribute, followed by 'flavour' and 'texture'. This means that Portuguese consumers can rely on extrinsic rice attributes (e.g., visual appearance) to assess intrinsic product attributes (e.g., texture). These findings reveal similarities between Portuguese and Asian consumers who describe a "good rice" based on the appearance attribute [35], and contrast with other consumers, namely European consumers [60], for whom the texture is a decisive attribute of quality rice [61–63]. This could be explained by the fact that Asian and Portuguese consumers have a vast experience in eating and cooking, enabling them to use different intrinsic and extrinsic cues when evaluating the quality of rice [64]. This similarity of behaviours of one European country and Asia is likely the result of the fusion of experiences brought about by the maritime expansion of Portugal towards South and Eastern Asia for over 500 years from the 15th century.

In fact, the second most frequent dimension for the "rice" stimulus was 'cooking and consumption', a dimension that aggregates categories related to the methods of preparation and ways of consuming rice. This salience could be explained by the fact that rice is part of the Portuguese cuisine, as it was considered by our participants as an everyday food (a 'staple' food) and an ingredient served as side dish (e.g., 'plain rice', 'bean rice', 'cabbage rice', 'carrot rice', '*Malandro* rice', 'spring rice', 'tomato rice') or as a main course (e.g., '*Cabidela* rice', 'chicken rice', 'codfish rice', 'duck rice', 'seafood rice', 'octopus rice', 'sweet rice'—dessert, 'Valencian rice'). Additionally, participants also spontaneously evoked words related to the methods of preparing and consuming rice (e.g., 'bake', 'braise', '*estrugido*' (with pre-stir fried onions in olive oil), 'grill', 'hot'), revealing familiarity with these culinary practices. Some of our participants seemed to be so familiar with rice's culinary practices, that they perceived this food as 'easy', 'fast', 'practical', 'variety', and 'versatile' to cook ('convenience' dimension).

Although our participants evoked some words such as 'carbohydrates' and 'calories' (grouped in the category 'nutritional aspects'), presumably reflecting some concern about its caloric content, other words were also found, evoking positive associations with rice's nutritional properties, such as 'balanced', 'good nutrition', and 'nutritious'. This shows that rice consumption is also positively related with a healthy diet, in accordance with French, Spanish, Greek, and Dutch consumers [65], as well as US consumers [66–68].

Even though the hedonic value dominates for the "rice" stimulus, as our participants appreciated the sensory properties of rice as it offers pleasure and evokes feelings of pleasure (experiential view) [39], the value of rice was also determined by how well it performs, namely, considering its use as a side dish or main dish, or as a source of nutritional properties or as a means to prepare a conventional meal. As a result, for our participants, the two dimensions of rice's benefits, hedonic and utilitarian, are not mutually exclusive [69], and do not compete with each other [70], thus promoting rice consumption.

Additionally, words carrying cultural or personal meaning, such as 'childhood', 'family', 'grandmother', and 'party' were also referred to by our participants. These words have already been reported in studies of traditional food conceptualization [48,71], and this symbolic view of consumption has been closely associated with ethnic and traditional food consumption [48,72,73], reinforcing the cultural/traditional identity associated with rice consumption in Portugal. By contrary, French consumers consider rice as a food from other cultures [35], emphasizing the European food cultural heterogeneity despite the geographical proximity between countries [48,74].

Considering the "rice with low GI", consumers made significantly more associations with utilitarian values and significantly less with experiential and symbolic values. In fact, for this stimulus, the most frequent words mentioned by our consumers were 'brown rice', 'healthy/health', and 'plain rice', resulting in three dimensions related to the rice's functional attributes: 'types of rice', 'health', and 'cooking and consumption'. One may infer that eating "rice with low GI" promotes health benefits (e.g., 'cleanse organism', 'slimming', 'good for health', 'good disposition') due to their nutritional properties, as "rice with low GI" contains 'proteins', 'low sugar', 'low carbohydrates', or 'fibre'. For our participants, these functional properties are essentially found in 'brown', 'Basmati', or 'parboiled' rice, corresponding to the rice types with the lowest GI [17,19]. Nevertheless, they also evoked 'plain rice' (a popular side dish usually made with white rice cooked only with water and salt and some other condiments), which may demonstrate a health concern but also a lack of knowledge because they believe that simple-cooking rice may be healthier. Additionally, in order to lose weight or for health and wellbeing reasons, participants evoked words that are related to the moderation and restriction of food consumption (e.g., 'balanced regime', 'eat small amounts', 'few', 'moderation').

Although our participants evaluated "rice with low GI" in a favourable way, in the sense that it was considered as 'recommendable', 'appropriate', 'special', and 'suitable', some also evoked negative feelings and emotions, such as 'misinformation', 'uncertainty', and 'unfamiliarity', and negative sensory terms, such as 'bitter', 'little taste', 'insipid', 'less appealing', 'no-taste', 'tasteless', and 'unpleasant'. This could be a barrier to promoting consumption of "rice with low GI", as consumers hardly compromise taste for health [72]. Similar results were obtained for functional foods, as their health/wellbeing benefits acceptance has become more conditional, particularly with respect to bad taste [75–77]. In the same way, "rice with low GI" may evoke contradicting perceptions, as this product is perceived to be innovative ('development experiment', 'innovation') or natural ('additive-free', 'natural', 'organic', 'unprocessed'). Previous studies have shown that a product perceived to be natural is thought to be minimally processed and/or produced by traditional methods, and it also seems that naturalness is associated with desirable sensory attributes [78].

Regarding the rice consumption profile, it was found that the most frequent rice consumers (Daily cluster) were those who reported consuming all types of rice available on the market significantly more often, demonstrating that the variety of types of rice allows or facilitates such daily consumption. This contrasts with the Specialities cluster, which are the respondents with the lowest frequency of rice consumption. This cluster seems to be more selective in the type of rice, choosing the types considered exotic, which are usually more expensive. Moreover, there were significantly more respondents with higher education (28.1%) and with higher income (30.7%) in the Specialities cluster, thus confirming that the prices of this type of rice are important in the purchase decision. The importance of this factor is reinforced by the fact that Daily consumers have significantly fewer respondents with the highest income, showing in a way that rice (in general) is an affordable food. This same consumer cluster associated symbolic values to "rice" significantly more, demonstrating a certain projection of the lifestyle and cultures, and this was shown by words such as 'brand', 'family', 'exotic', 'party', 'modernity', and 'sushi', which formed this value group.

In the "rice" stimulus, the older respondents did significantly fewer associations to the 'types of rice' than the younger groups. This may be the result of the presence of new types

of rice in the national market to which younger people are more familiar or perhaps more open to new experiences. On the other hand, for "rice with low GI", the older age group and respondents without higher education evoked significantly more terms related to 'low GI disconnects'. This is aligned with the findings that reveal that the level of education has significant effects on nutritional knowledge [79,80] and on healthy food perception [81].

The younger respondents referred significantly more to 'innovation'; however, it was the older ones who showed greater interest, referring significantly more to 'positive attitudes'. These positive associations such as 'appropriate', 'suitable', 'safe', 'ideal', and 'recommendable' showed that interest in the potential product is more significant for the older age group. These findings contrast with results from the United Kingdom and France, where it was found that the perception of rice differs between age groups, where rice is seen as a new food by older consumers and as a staple food by young ones [82]. The older respondents also evoked significantly more terms related to 'naturalness' and 'attitudes and emotions', which have a stronger experiential dimension. However, as the affective dimension is something acquired (experiential), the association of these categories to a hypothetical low GI product (stimulus) highlights the importance of these dimensions in food choice, especially in this age group, corroborating studies that predict a greater focus on affective and emotional issues in older consumers [81,83].

The "rice dishes" dimensions from the "rice with low GI" stimulus were significantly more often mentioned by Local consumers, which is justified by the fact that the mentioned dishes were mostly typical Portuguese dishes made with the *Carolino* rice type, the locally produced one. In this cluster there were significantly more male respondents (55.7%), while in the Specialities cluster there were significantly more female respondents (25.7%), confirming that males are less prone to new experiences and more neophobic than female consumers [84,85]. This aversion to the unknown, or low propensity for new foods shown by male respondents, can also be reinforced by the 'negative feelings and emotions' category of the stimulus "rice with low GI", where they mentioned significantly more words from this group. The word "rice" evoked more associations with experiential values and the 'sensory' dimension for female respondents. This result suggests that women in relation to men give more importance to hedonic consumption, as found in other studies [86–88].

5. Conclusions

The FWA task showed differences between "rice" and "rice with low GI", exploring the constructs that can shape attitudes and preferences in relation to such concepts and capturing the consumers' perceptions and expectations in relation to the product concept.

For Portuguese consumers, rice is an everyday food and a major ingredient served as a side dish or as a main course, as they appreciate their sensory properties, offering pleasure and evoking feelings of pleasure. On the other hand, the utilitarian value dominates the consumption values of the "rice with low GI".

"Rice with low GI" incites something new and positive for health, as normally, health benefits are connected to uncertainties regarding future health status. However, to accept this product innovation, consumers must perceive and be persuaded that health and nutritional benefits compensate for negative sensorial properties.

The relationship between values, dimensions, and categories with socio-demographic characteristics and consumption profiles allowed us to explore differences among consumers, clearly identifying four clusters of consumers: Specialities, Local, Daily, and *Agulha*. For these groups, the differences in the rice consumption patterns were clearly associated with different attitudes and perceptions towards "rice" and "rice with low GI".

The results provide general information for the development of a consumer-oriented low GI rice product. However, future research may be oriented towards a more specific assessment of the intrinsic and extrinsic expectations of consumers in relation to this type of product.

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Informed Consent Statement: All participants involved in the study followed an informed consent procedure before answering the questionnaire.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

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3.2. Paper II – Exploring rice consumption habits and determinants of choice, aiming for the development and promotion of rice products with low glycaemic index.

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Exploring Rice Consumption Habits and Determinants of Choice, Aiming for the Development and Promotion of Rice Products with a Low Glycaemic Index

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Abstract: Current consumption drivers, particularly those related to health and wellbeing, have been influencing trends for the lower consumption of cereals, particularly rice, due to their typical high glycaemic index (GIs) and consequent impacts on obesity. To satisfy this consumer concern, more food innovations that promote healthy eating habits are required. Such innovations must be consumer-oriented to succeed, understanding the dynamics of consumer habits and responding to consumer expectations. This study explored these habits, from acquisition to consumption practices, and the expectations of the European market from the perspective of the major European consumer, Portugal, to obtain insights that support the development of low glycaemic index (GI) rice products. A mixed-methods approach was applied. For the first quantitative questionnaire, 256 Portuguese rice consumers aged 18–73 years were recruited. Twenty-four individuals were selected according to their gender and rice consumption profiles for in-depth interviews. The results confirmed that rice was the main side dish for the participants and was mainly consumed at home, cooked from raw milled rice. The drivers of consumption differ according to the provisioning process stage. In the acquisition stage, participants reported benefits from the rice's dynamic market by comparing products on price, brand, and rice types. In the preparation stage, participants reported the adequacy of the recipe and occasion, while in the consumption stage, participants enhanced their sensory preferences, depending on the rice dish. Although the GI concept was unknown to half of the participants, it was perceived as interesting and positive for healthy eating. Consumers showed concern about the taste and naturalness of the product, preferring it to be as close to a homemade dish as possible. The negative perceptions we verified were interpreted to be due to a lack of knowledge about the GI concept. Therefore, awareness actions and informative campaigns are recommended to promote low-GI rice products.

Keywords: rice consumption; consumption drivers; glycaemic index; mixed methods; thematic analysis; rice provisioning process; rice types; healthy rice promotion

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1. Introduction

Rice (*Oryza sativa* L.) is a grain widely consumed worldwide. It is the staple food of most Asian and African countries, so its overall world per capita consumption reaches 78.9 kg/year [1]. Portugal has the highest European per capita consumption, with an average of 19.3 kg/year in 2020 compared with an average consumption in Europe of 7.2 kg/year [1]. The fact that Portugal is the fourth largest rice producer in Europe [2] facilitates the availability of this staple food in the market, even though Portugal imports far more than it exports [3].

Cereals were the largest contributor to Portugal's per capita daily food availability (30.2%), with rice contributing 17.8% of the daily per capita availability of cereals, second only to wheat, a staple food across Europe [4]. Rice accounts for 5.2% of the total energy intake, which is higher than that of its most direct carbohydrate competitors, potato and pasta, contributing 4.6% and 3.0%, respectively [5].

There are two main commercial rice types in Portugal: Carolino, a long-grain Japonica subspecies with kernels over 6 mm in length, a length-to-width ratio of 2–3, and amylose below 22%, and Agulha, a long-grain Indica subspecies with kernels also over 6 mm in length, but with a length-to-width ratio of at least three and amylose above 25%, according to Portuguese legislation DL 157/2017. Other white rice types, such as Arborio and Carnaroli (the Japonica varieties used for Risotto) and the aromatic Basmati and Jasmine, are also becoming increasingly popular [6]. Furthermore, in Portugal, 88% of rice is consumed as white rice, and only 12% is consumed as brown rice [6], like global rice consumption patterns [7,8].

Brown rice results from simply de-husking and sorting the dried paddy rice, thus retaining the bran. It is nutritionally healthier due to the nutritional components primarily contained in the bran, such as lipids, proteins, dietary fibre, γ-oryzanol, and phytochemical components [9]. Consequently, it has been associated with a reduction in the risk of several chronic diseases, including various types of cancer [10,11], the reduction of blood cholesterol levels [12,13], and the ability to decrease the risk of type II diabetes [14,15]. However, brown rice is less accepted than milled rice (which results from the removal of the bran and germ by abrasion and subsequent polishing, and is also known as white rice) in terms of texture (brown rice is harder and chewier than white rice) [16] and flavour (due to lipid oxidation that leads to the development of off-flavours) [17]. The milling process improves these sensory properties by removing the bran and germ, leaving only the endosperm, which is mostly carbohydrates (CHO). As the most nutritious parts of the grain are removed, milled rice is left with very few essential nutrients other than starch, but it is better accepted by consumers due to its colour, texture, and flavour, especially for aromatic rice varieties, such as Basmati and Jasmine [16–18]. Furthermore, it is considered more convenient to use as it cooks in less than half the time required to cook brown rice. However, due to the amount and nature of its refined CHO, milled rice has a high glycaemic index (GI) [19,20].

The GI indicates the health quality of the CHO present in foods, based on how quickly blood glucose levels rise following digestion. Based on the GI, considering glucose as a standard food, foods are considered as presenting low GIs (GI $\leq$ 55), intermediate GIs (56–69), or high GIs (GI $\geq$ 70) [21,22]. Foods with high GIs potentiate a rapid rise in blood glucose; low-GI foods tend to release glucose more slowly and steadily. Thus, low-GI foods are considered healthier, improving blood glucose and lipid control, and promoting insulin sensitivity, and are therefore beneficial dietary treatments for diabetic patients [23–25].

Based on the international GI table of Atkinson et al. [21], the GI of cooked rice ranged from 19 to 116. In this compilation, no entry of Portuguese rice was found; however, there were indications of several milled rice of the japonica subspecies, which presented values between 76 and 89. This subspecies, the most locally produced rice in Europe and Portugal, had the highest GI. Portuguese japonica varieties *Ronaldo* and *Ariete* have GI values of 89 and 151, respectively [26]. GI depends on various factors such as variety, processing, and recipe ingredients [27–30].

According to the International Diabetes Federation, an estimated 463 million people globally live with diabetes, and this number is projected to escalate to 700 million by the year 2045 [31]. Portugal is the second country in the European Union with the highest prevalence of diabetes (13.6% of the population aged between 20 and 79) [32]. Several nutritional studies have shown that the excessive consumption of white rice is associated with an increased risk of non-communicable diseases, namely diabetes, hypertension, obesity, and cardiovascular diseases [33–39]. Many studies have discussed GI and its importance in controlling diabetes and related diseases and demonstrated the importance of a food-centred

approach [29,40–45]. Methods to reduce the GI of rice have been investigated, and products with a lower GI have been obtained by controlling the processing parameters [46–50] using selected rice varieties and adding ingredients [51–54]. These trends have pressured the food industry to develop low-GI rice products in Western societies, where health has functioned as an important criterion for individual food choices [55]. Given the scientific evidence of the usefulness of GI in controlling the metabolic syndrome and the different methods of obtaining products with a lower GI, it is important to investigate this topic from a consumer-centred perspective. This will support a better promotion of healthier habits of rice consumption, particularly in countries with high rice consumption. Such steps involve the understanding of consumers' perceptions, behaviours, and attitudes, as well as the development of rice-based food products that meet the consumers' expectations.

This study aimed to explore and understand the rice-provisioning process of Portuguese consumers, from acquisition to consumption practices, and their associations and consumption drivers regarding low-GI products. The approach was to gather insights to support the development of new consumer-oriented low-GI rice products and healthier forms of rice consumption while focusing on the European market with the highest per-capita consumption.

2. Materials and Methods

A mixed methodology [56] was applied, combining the evaluation of consumers' behaviour, assessed through self-reported measures questionnaires, and in-depth interviews. The combined use of these procedures in consumer research allows for an apprehension of the phenomenon and the object of study from different perspectives [56], thus intervalidating the findings. All participants followed an informed consent procedure before participating, previously approved by the Ethical Committee of the Faculty of Sciences of the University of Porto, with reference number 50/2023. All participants received a small financial compensation for their participation.

2.1. Questionnaire

A structured self-reported electronic questionnaire was applied using the Lime Survey software v.2.50. The questionnaire (Supplementary Materials) combined indirect and direct methods, respectively: (i) free word association (FWA) towards low-GI foods, (ii) rice preparation and consumption practices, and (iii) sociodemographic characteristics. In the FWA task, participants were invited to write down the first three words that came to mind when thinking about "low glycaemic index foods" (*alimentos com baixo índice glicémico*, in Portuguese). To avoid biases from previous questions, the FWA task was the first to appear in the questionnaire flow. In the second part of the questionnaire, the frequency of rice consumption, the place of consumption, the rice dishes consumed, rice substitutes, and rice purchase formats were evaluated through a checklist-type multiple-choice questionnaire. Seven response options were considered (in general and by rice type) for consumption frequency evaluation: (i) less than once a month; (ii) 1 to 3 times per month; (iii) once a week; (iv) 2 to 4 times a week; (v) 5 to 6 times a week; (vi) daily; and (vii) 2 or more times per day. The types of rice present in the Portuguese market were included in the questionnaire options under their trade names: *Agulha* (long grain Indica variety), Basmati, brown rice, *Carolino* (long grain Japonica variety), Jasmine, parboiled, and Risotto (although Risotto is not a type of rice but a form of cooking, it is known by consumers as "Risotto rice" short for "rice for Risotto", with very few consumers being able to relate to the varieties widely used for Risotto cooking (Arborio or Carnaroli). Both dishes served as a side (accompanying some protein source on the side) or as a main course (mixed with the protein source) were considered in the evaluation of the frequency of consumption, such as plain rice, rice with duck, rice with seafood, rice with carrot, rice with tomato, rice with fish, rice with beans, rice with peas, rice with chicken, rice with cabbage, rice with meat, and rice with chicken blood. The latter, designated as *Cabidela*, is a traditional dish of the gastronomy of the northern region of Portugal, made with *Carolino* rice, chicken and its blood, and

vinegar, where the meat and offal are also incorporated, resulting in a stew served as a main course [57]. These rice dishes were chosen due to their popularity in Portuguese cuisine, based on a multitude of blogs, cooking magazines, and videos of chefs and home cooks, among other varied sources of popular knowledge related to traditional Portuguese cuisine, and providing a much wider variety of rice dishes than what exists anywhere else in Europe. Some dishes involve a very loose grain and dry dish (e.g., a typical Basmati), others a very creamy one (e.g., a typical Risotto). The questionnaire was finalised, asking for age, gender, educational level, household size, and monthly household income (all other details remained anonymous). The questionnaire was completed in person using a computer at the premises of the recruiting company. Data were collected over a two-month period, from February to March 2018.

2.1.1. Participants

Participants were recruited from the sensory evaluation company Sense Test's consumer database (Vila Nova de Gaia, Portugal). They were mainly residents of the Porto metropolitan area, in the North of Portugal, which has the country's highest per capita rice consumption.

A convenience sample of over 250 consumers was recruited from the database, with the following inclusion criteria: (i) being Portuguese, (ii) consuming rice at least once a month, and (iii) being responsible or sharing responsibility for grocery shopping and preparing meals.

2.1.2. Data Analysis

In the FWA task, response words were classified into categories, which were then classified into dimensions, considering internal homogeneity and external heterogeneity, using the triangulation technique [58]; it followed the same analytical procedure described in a study by Cabral et al. [57]. After the individual categorisation of the response words done by experienced researchers, the agreement between categorisations was verified and a label was assigned to each category and dimension. The frequencies of each category/dimension were determined by counting the participants who mentioned that category/dimension, without considering whether the same respondent evoked the words of the same category/dimension or not; so, the sum of the frequencies may have been greater than 100%. The cut-off point of 5% of participants, by category, was considered as inclusion criteria for further analysis. To assess the relationship between the participants' characteristics and the type of perception in relation to low-GI foods, an independence χ^2 test was performed. When significant differences were found (significant level of 0.05), a χ^2 test per cell was used to identify the source of the global χ^2 variation [59]. The words/categories/dimensions gathered from the categorisation of the FWA task were translated into English using a back-translation procedure [60].

To assess the frequency of the consumption and purchasing of rice, the response options were converted to obtain the weekly frequency using the following conversion factors: 0 (less than once a month), 0.5 (1 to 3 times per month), 1 (once a week), 3 (2 to 4 times a week), 5.5 (5 to 6 times a week), 7 (once a day) and 14 (2 or more times per day). Descriptive statistical analysis was performed to determine self-reported consumption frequencies, means, standard deviations (SDs) and standard errors (SEs). Statistical data analysis was processed with XL-STAT®, v. 2020.5.1 (Addinsoft, New York, NY, USA).

2.2. Interviews

A face-to-face individual interview was conducted to provide a more detailed understanding of consumers' experiences and opinions about rice choice, preparation, and consumption practices, and a better understanding of the associations and consumption drivers regarding low-GI products [61]. For this, a semi-structured interview guide of open-ended questions (Supplementary Material) was developed considering the following dimensions: (i) rice choice criteria and consumption habits; (ii) rice sensory criteria

valorisation; (iii) knowledge about foods with low GI and drivers of choice of rice with low GI; and (iv) expectations regarding new rice products, to promote low-GI alternatives. After probing participants about the GI concept, they were presented with the FAO/WHO definition [62], in the following simpler version: "The glycaemic index is defined as the increase in blood glucose after eating a certain food", and some examples were given to the participants. Examples of high-GI foods include white wheat bread, potatoes, and sugary desserts [21]; while low-GI foods include fresh fruits and vegetables, such as apples, pears, and beans [21]. The first two authors conducted the interviews during September 2019.

2.2.1. Participants

Twenty-four participants who responded to the initial questionnaire were chosen for a semi-structure face-to-face interview based on their willingness to participate and on their reported rice consumption profiles: (i) daily rice consumers (eight participants who consume rice at least once a day), (ii) light rice consumers (eight participants who consume rice less than three meals per week), and (iii) brown rice consumers (eight participants who consume at least three brown rice meals per week). According to Cabral et al. [61], the rice consumption profile influences perceptions regarding "rice" and "rice with low GI". An attempt was made to have male and female participants in each of the three groups, participants with and without higher education, and participants from different age groups, to minimise the eventual impact of major variations in such demographics. The interviews were conducted in a separate room with a see-through mirror window for observations at the consumer studies company Sense Test, Lda. All interviews began with a greeting and initial introduction as an icebreaker, followed by a report on their two meals (lunch and dinner) during the past week. The interviews were audio and videotaped with the stated consent of the participants. The interviews had an average duration of 32 $\pm$ 10 min (maximum duration: 61 min; minimum duration: 17 min).

2.2.2. Data Analysis

The transcripts of the interviews were explored with a qualitative data analysis software, QSR NVivo2020 (Copyright® QSR International Pty Ltd., Melbourne, Australia). Interviews were analysed using a thematic analysis procedure that involves a progression from description to interpretation data [63]. A comprehensive data-coding process and identification of dimensions, consistencies, and discrepancies across dimensions, was applied to provide an in-depth understanding of the texts [64]. To illustrate the analysis, consumer direct quotes were transcribed, describing the topic explored.

3. Results

3.1. Questionnaire

3.1.1. Participants' Characterisation

Appendix A (Table A1) shows that the 256 participants responded to the full questionnaire. The participants were mainly female (64%), with a mean age of 40 $\pm$ 12.8 years old (ranging between 18 and 73 years old), spread across three age groups, with 64% of participants being without a higher educational level.

3.1.2. Questionnaire on Rice Preparation and Consumption Practices

Tables 1–3 provide information about participants' self-reports on their preparation and consumption of rice. Participants regularly consume rice every week with an average rice consumption of 4.4 times/week. Most of the participants (53.9%) consumed rice one to four times/week, 39.8% consumed five or more times/week, and only 1.2% consumed less than one time/week (Table 1).

Table 1. Overall self-reported rice consumption and according to rice type.

Rice Consumption	Rice *	*Agulha*	*Carolino*	Basmati	Parboiled	Brown	Jasmine	Risotto
<One time/week	1.2%	20.3%	36.8%	62.9%	74.6%	84.4%	87.9%	93.4%
One to four times/week	59.0%	64.5%	54.3%	36.6%	20.7%	14.1%	10.9%	6.7%
Five or more times/week	39.8%	15.3%	9.0%	3.6%	4.7%	1.6%	1.2%	0.0%
Average (±SE) ***	4.4 ± 0.16	2.6 ± 0.14	1.9 ± 0.14	1.1 ± 0.10	0.8 ± 0.09	0.5 ± 0.07	0.4 ± 0.05	0.3 ± 0.02

*** Average (± SE) weekly rice consumption in general and by rice type. * Overall, all types included. Sample size = 256.

Table 2. Frequency of participants (%) who self-reported rice consumption according to the place of consumption.

Rice Consumption	Home (n = 256)	Restaurant (n = 186)	Canteen (n = 62)	Other * (n = 57)
<One time/week	0.8%	57.0%	24.2%	35.1%
One to four times/week	64.9%	37.1%	61.2%	47.4%
Five or more times/week	34.3%	5.9%	14.5%	17.6%
Average weekly consumption (±SE)	4.1 ± 0.14	1.0 ± 0.13	0.9 ± 0.35	0.9 ± 0.44

* Relatives and friends' homes. Sample size = 256.

Table 3. Frequency of participants (%) who self-reported purchasing different commercial formats of rice products.

Rice Purchase	Raw	Takeaway	Dehydrated	Pre-Cooked	Frozen	Refrigerated
<One time/week	42.3%	77.3%	93.4%	93.7%	98.0%	96.9%
One to four times/week	40.6%	21.5%	6.6%	6.3%	1.6%	1.9%
Five or more times/week	17.1%	1.2%	0.0%	0.0%	0.4%	1.2%

Sample size = 256.

The most-consumed type of rice by the panel was *Agulha* (long grain Indica, 2.6 times/week), followed by *Carolino* (long grain Japonica, 1.9 times/week) (Table 1). Basmati rice was consumed on average 1.1 times/week, closer to parboiled rice (0.8 times/week). Participants self-reported that they consume less brown rice (0.5 times/week), Jasmine rice (0.4 times/week), and Risotto rice (0.3 times/week).

On average, rice was mostly consumed at home (4.1 times/week) rather than out of the home: 1.0 times/week at restaurants and 0.8 times/week at canteens/refectories (Table 2). Approximately 65% of the participants consumed rice at home one to four times/week, and 34% consumed rice at home five or more times/week. Of the 186 subjects who answered that they chose rice in restaurants, 57% reported doing so less than one time/week. Regarding canteens, only 52 respondents chose rice when they ate in them, and of these, the majority (61%) did so one to four times per week.

Plain white rice was reported as the most frequently consumed rice dish, both at home and out of home (see Figure 1). All rice dishes being analysed were consumed more frequently at home than out of home, except for rice with duck.

Table 3 shows the purchase frequency of the various rice commercial formats consumed at home by the panel. Raw rice was bought by 42.3% of respondents less than one time/week to cook at home, and 77.3% of respondents bought ready-to-eat rice at the same frequency. Most participants indicated that they had never bought rice in dehydrated (86.3%), pre-cooked (82.8%), frozen (90.6%), or refrigerated (88.7%) formats, demonstrating the low popularity of ready-to-eat or processed rice among participants.

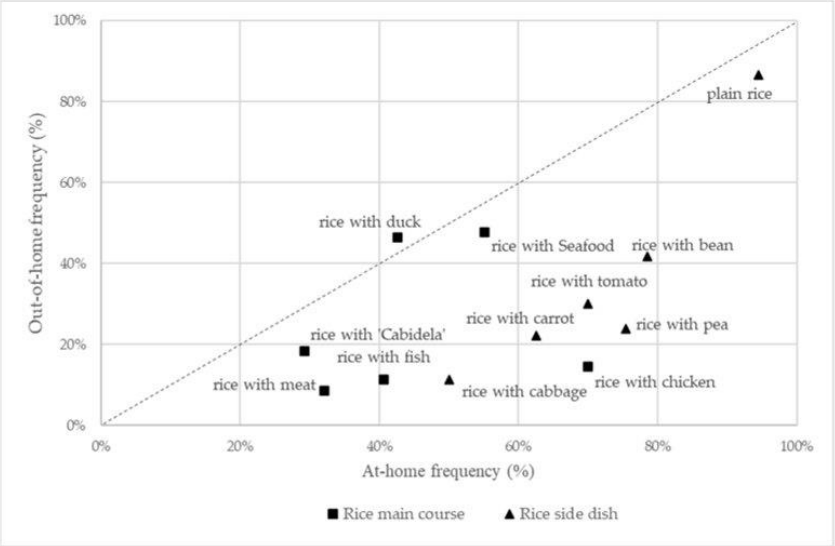

Figure 1. Frequency of participants (%) that self-reported rice consumption at home and out of the home, according to rice dishes. Sample size = 256.

3.1.3. Questionnaire on Free Word Association with "Low Glycaemic Index Foods" Stimulus

The free word association generated 719 words, of which 260 were different response words, with 49 participants (17.2% of the total) not responding. Figure 2 presents the ten words most frequently associated with "Low GI foods". Among the most frequently mentioned words were foods that indeed generally have a low GI, such as "vegetables", "fruits", "brown rice", "fish", "oat", and "water". "Healthy" and "health" were also the main perceptions concerning this stimulus.

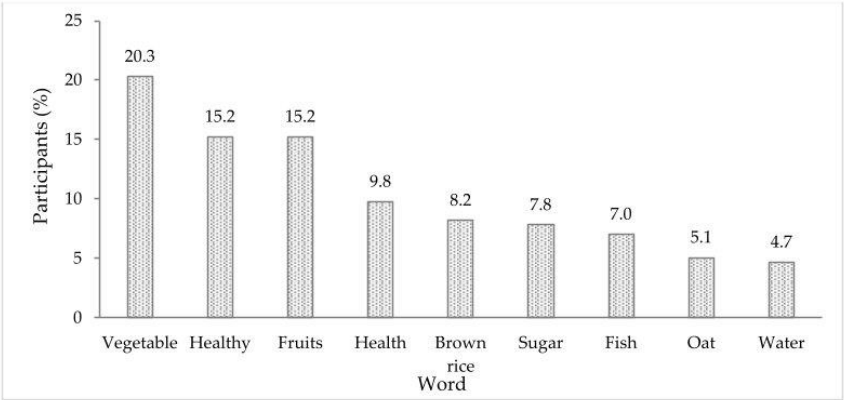

Figure 2. Frequency of participants (%) citing the ten most evoked words for the stimulus "Low glycaemic index foods". Sample size = 256.

The words were grouped into nineteen categories, four of which did not meet the minimum answer criteria—5% of participants—to be included in the analysis: sweetener, price, negative emotions, and family. These were then merged into eleven dimensions

(Table 4). The dimensions that were most mentioned were "Fruits and vegetables" (40.2% of participants), "Nutrition" (38.7% of participants), "Health" (32% of participants), and "Whole grains" (21.5% of participants).

Table 4. Frequency of words (%) and participants (%) according to the dimension and category of the "Low GI foods" stimulus.

Dimension	Category	Examples of Elicited Words	Word (%)	Respondent (%)
Fruits and vegetables	Vegetables	broccoli, carrots, greens, lettuce, spinach, sweet potatoes, vegetables, and watercress.	13.9	32.8
	Fruits	apple, fruit, lemon, pear, watermelon.	7.4	21.1
Nutrition	Nutritional aspect	balanced diet, dietary, carbohydrates, correct diet, diet, eat tiny amounts, energy, healthier eating, nutrition, restriction, routine, water	10.7	26.6
	Sugar reduction	eat little sugar, little sugar, low in sugar, low carbohydrates, low consumption of sweets, no sugar, sugar-free	3.9	10.5
	Low GI disconnects	healthy for the intestines, light, low-fat, low fibre, moderate salt, no salt, vitaminic, without fat, with iron	3.3	8.2
Health	Health	health, healthy	8.6	23.0
	Physiological	age, blood glucose, diabetes, slow absorption, hunger	5.9	14.5
Whole grains	-	brown rice, oat, whole grains	7.7	21.5
Positive attitudes and emotions	-	advisable, balance, beneficial, comfort, decisive, determining, desire, good mood, happy, happiness, ideal, living better, necessary, satisfaction, quality, quality of life, positive, wellbeing, vitality	6.9	15.2
Sugar	-	fructose, glucose, sugar	4.0	9.8
Dairy products	-	cheese, dairy products, milk, yoghurt	3.6	10.5
Bread and pasta	-	bread, pasta	3.4	9.4
Fish and white meat	-	chicken breast, fish, white meat	3.3	8.2
Pulses and seeds	-	almonds, beans, chickpeas, lentils, peanuts, pulses, seeds, soybeans, walnuts	3.5	8.6
Sensory	-	bitter, flavour, sour, taste, tasteless, white	2.9	7.4

Simple size = 256.

In the "Sugar reduction" and "Nutritional aspect" categories ("Nutrition" dimension), participants defined their understanding of low-GI food or a low-GI diet. Expressions such as "eat little sugar", "little sugar", "low consumption of sweets", "no sugar", "no glucose", and "low carbohydrates" were referred to. Although these categories have reflected some knowledge about the low-GI concept, there were some incorrect associations, which were grouped into the category "Low GI disconnects", where 8.2% of participants associated ideas related to fat and salt reduction, the addition of vitamins and iron, into their understanding of a low-GI food.

The "Health" dimension clearly reflects the idea of low-GI foods, which has been assigned a function of control and maintenance of good health. In its "Physiological" category, terms associated with biological functions related to sugar ingestion, digestion, and the effect of blood glucose on the body were gathered. In the "Positive attitudes and emotions" dimension, ideas of acceptance and positive emotional state were expressed beyond the terms that generally qualify the stimulus in a positive way, such as the words

"necessary", "ideal", "positive", and "decisive". However, in the "Sensory" dimension, the associations were not very positive in relation to flavour, associating words such as "tasteless", "bitter" and "sour", which are attributes that are not normally appreciated by consumers.

The categories resulting from associations with the stimulus "Low GI foods" were significantly dependent on gender (χ^2 = 22.157, DF = 11, $p < 0.05$), age group (χ^2 = 37.802, DF = 22, $p < 0.05$), and educational level (χ^2 = 16.205, DF = 11, $p < 0.05$). Table 5 shows the result of the χ^2 test per cell. Women associated "Fruits and vegetables" with "Low GI foods" significantly more than men.

Table 5. Respondents' absolute frequency in the free word association task using the "Low GI foods" stimulus, according to the elicited categories and gender, age group and educational level.

Dimension	Gender		Age Group (Years)			Educational Level	
Category	**Male**	**Female**	**[18; 34]**	**[35; 54]**	**55+**	**No Higher Education**	**Higher Education**
Fruits and vegetables	45 (−)	116 (+)	62	81	18 (−)	97	64
Vegetables	30	75	41	52	12	60	45
Fruits	15	41	21	29	6	37	19
Nutrition	58 (+)	77 (−)	55	57	23	87	48
Nutritional aspect	38 (+)	44 (−)	37 (+)	33	12	50	32
Sugar reduction	13	16	14	11	4	17	12
Low GI disconnects	7	17	4 (−)	13	7	20 (+)	4 (−)
Health	45	66	34	55	22	76	35
Health	27	39	21	30	15	46	20
Physiological	18	27	13	25	7	30	15
Whole grains	16	43	25	27	7	30 (−)	29 (+)
Positive attitudes and feelings	22	30	7 (−)	28	17 (+)	33	19
Sugar	14	16	7	17	6	17	13
Dairy products	14	14	14	12	2	18	10
Pulses and seeds	13	13	9	12	5	18	8
Bread and pasta	7	19	8	13	5	5 (+)	**21 (−)**
Fish and white meat	8	17	6	14	5	17	8
Sensory	7	15	13 (+)	7	2 (−)	10	12

(+) or (−) indicate that the observed value is significantly higher or lower than the expected value (χ^2 test per cell with a significance level of 0.05). Sample size = 256.

Older participants expressed more "Positive attitudes and emotions" than younger participants, which in turn mentioned significantly more "Sensory" and "Nutritional aspects". In the "Sensory" dimension, the descriptors elicited were negative, which shows that while young people have a less positive perception of "Low GI foods", the older ones have the opposite perception, attributing significantly more words referring to "Positive attitudes and emotions", showing more awareness of the health benefits that low-GI foods can bring to the consumer.

As for the level of education, participants with higher education made significantly more associations with "Whole grains", while those with no higher education made significantly more associations with "Bread and pasta" and "Low GI disconnects".

3.2. Interviews

The interviews evaluated two main broad dimensions: the domestic rice provisioning process and the perception towards GI concepts and low-GI foods. Six major levels of analysis were identified: (i) acquisition (the rice choice criteria), (ii) cooking (including aspects of preliminary preparation and cooking), (iii) eating, (iv) GI concept, (v) the drivers and barriers of choice for low-GI rice, and (vi) new low-GI rice alternatives. This approach follows the sequence of stages in which the consumer goes through domestic rice provision-

ing, from the initial rice purchase decision to the eating stage, rather than simply focusing on eating in the narrowest sense of consumption [65].

3.2.1. Participants' Characterisation

A total of twenty-four consumers, eight from each of the rice consumption profiles, as previously described, were recruited for the interview task, as shown in Appendix A (Table A2). Once relevant information regarding the phenomenon under investigation was obtained, and the data saturation was achieved, the sample size was deemed adequate [66].

3.2.2. Acquisition

Various factors influenced the choice of raw rice, ranging from practical reasons (price, brand, rice variety) to physical appearance and personal concerns (health, nutrition).

The participants benefit from rice's dynamic market by comparing products on price, brand preferences, and packaging, and according to the rice varieties. Consumers can only choose foods which are available and that they can afford to pay for. Participants also mentioned that they changed their traditional variety of rice choices by replacing the traditional Carolino with *Agulha* and other exotic rice, such as Basmati and Jasmine, due to their appealing taste, texture, appearance, and speed of cooking: '*. . . much more Agulha rice and Basmati* (. . .) *I always choose Agulha or Basmati because I don't like Carolino very much*', P1; '*. . . more recently it is Basmati rice, but before that, it was Agulha rice*', P16. However, those who frequently consumed brown rice (Group 3) complained that there are not as many brands for this type of rice and that the product is not well displayed on supermarket shelves, hidden among other dietetic products: '*. . . within the brown rice I don't find great varieties of brands*', P21. This suggests that brown rice would be purchased more often if brown rice were in the same place as milled rice. Furthermore, the price was reported by most participants as a decisive element in rice purchase ('*Price is always first*', P10), and some of them tried to join the desired attributes with the affordable price ('*The quality and the price, I try to reconcile these two things*', P18), by benefitting from sales promotions, particularly price reductions. They reported buying the manufacturer's brands on promotion or trying new types of rice ('*It was only when promotional campaigns began to appear that I started to consume and try new types of rice. I also didn't know about parboiled until one day I saw it on promotion, and it caught my attention*', P2; '*If the parboiled from X* [manufacturer's brand] *is not on promotion, I won't buy it. I can even buy the Agulha*', P9) or increase rice quantity ('*When I get a promotion, I buy the X* [manufacturer's brand]. *I buy about three or four kg to have at home*', P14; '*If it's on the promotion of the brand I like, I bring more quantity*', P5).

The promotional campaigns stimulated purchases not only due to lower prices but also because the products are strategically displayed in the store to increase consumer interest: '*There is always something yellow there [commonly used promotional tags] that catches our attention* (. . .) *in the middle of all the shelves it is often very difficult to find the rice we are looking for. We often go for the packaging, for the colour of the packaging, but if there's a promotion, it's yellow or whatever and that one stands out*', P21. This allows consumers to become less loyal and more price sensitive, switching from brand to brand and type of rice depending on the benefits offered: '*I use several brands and qualities of rice*', P5; '*. . .if there is a big difference in price, I buy the cheapest one* [manufacturer brand] *or the own-label one. . . and if* [own label] *is cheaper than the cheapest brand, I always buy it*', P16.

Participants also reported that when they buy rice, they particularly focus on the visual appearance of the grains, which can be evaluated in terms of the colour, size, and shape of the grains, as mentioned by this participant: '*. . . the colour is very important and* [the grain] *shouldn't be too small, it must be an acceptable size rice*', P5. Depending on the rice variety, when making their purchases, they pay attention to a particular sensory attribute compared to others: '*. . . for Basmati rice, for example, I look at the grain. The length and breadth of the grain will tell me if that rice is worth taking. Carolino rice, the grain is shorter and more rounded* (. . .) *I waste a lot of time on choices*', P5.

Nevertheless, some participants (n = 6) consider that carbohydrates in general, and rice in particular, negatively affect health, namely, as a cause of weight gain, as reported by this participant: '*Calories, carbohydrates, that's what I mean* (. . .) *I avoid carbohydrates, rice, and potatoes* (. . .) *She* [daughter] *is entering the stage of looking in the mirror* (. . .) *we have been avoiding rice* (. . .) *I avoid eating those carbohydrates at night, I try to put on more soup to satisfy us* (. . .) *if we eat a lot of rice* (. . .) *then losing weight is very difficult*', P9. By contrast, brown rice, parboiled, and wild rice were positively related to a healthy diet, and most of these associations were made by the "brown rice consumer" group: '*We always try to opt for brown rice or parboiled rice, which is rice that has more nutrition than milled or polished rice. We rarely buy milled rice* (. . .) *I see that it's brown rice and I take it, sometimes I don't even look at the price*', P23. In the same way, brown rice is perceived to be natural, contrasting with polished rice, which is no longer natural.

Some participants emphasised the importance of the origin of rice, indicating their preference for national rice ('. . . *and I pay attention beyond the price if it is Portuguese rice* (. . .) *I try to give priority to what is Portuguese*', P5), referring to some geographic areas of national rice production ('. . . *I buy national rice* (. . .) *I try to choose the rice produced in Portugal. Mondego, Sorraia, I don't know, Alentejo, river Sado. . .*', P11). These participants had a very positive evaluation of national rice, associating it with better quality ('. . . *go to another store* (. . .) *to buy a better one, and I think it's Portuguese*', P18), and a connection to naturalness and more artisanal and sustainable agriculture: '. . . *I don't throw it* [rice] *away because I know how much work it takes to harvest each grain, especially here, which is a very manual task. . .*', P5; '. . . *I look for rice produced in Portugal* (. . .) *that grows slowly, without large amounts of chemical products. I prefer it because it has fewer chemicals*', P11.

3.2.3. Cooking

Rice plays a relevant role in Portuguese cuisine, as the participants considered it an everyday food (a 'staple' food) and an ingredient served as a side dish or a main course. Different varieties are available on the Portuguese market, both of local production and those imported. This assortment allows wide culinary applicability: '*Sometimes Carolino, it depends, depends on the dishes. Agulha rice I even use more if it is, for example, rice with duck, rice in the oven*', P12; '*Everyone likes rice. I use any rice. Carolino, Agulha, Basmati, Parboiled, Risotto, Brown rice* (. . .) *I diversify a lot*', P17. Participants also reported that the consumption of rice adapts to the daily consumption situation, depending on i) the season of the year ('. . . *in winter I eat a lot more rice than in summer but that's just because I like. Because in winter it tastes much better, it's warmer. In summer I go more for salads and vegetables*', P21); ii) its use for a special moment, such as Sunday family lunch day or festive season day; or iii) for everyday dishes: '. . . *during the week I make brown rice* (. . .) *on Sunday I make the normal one* [milled rice] *for everyone*', P9; '*I've been making Basmati when it's something like that better* [special occasion]', P10.

The convenience was particularly associated with *Agulha*, Basmati, and parboiled rice, contrasting with brown rice and *Carolino*, where a certain lack of culinary skills was shown by our participants, reporting that this makes it difficult to reach a good rice dish: '*I think* [*Agulha*] *it's much easier to cook and it also comes out looser* (. . .) *I have to leave lunch for my husband; it's much easier to reheat rice like this* [*Agulha*] *than a Carolino*', P1. In the case of brown rice, in addition to the lack of cooking skills, some participants also mentioned the long cooking time as another barrier to using this type of rice in their daily life: '*It's very difficult* [to cook brown rice], (. . .) *I've tried it in several ways, and it is not the same* [like the restaurant where I usually eat]', P20; '. . . *brown rice* [I buy] *too, but less.* [because] *It takes longer to cook*', P10.

Participants also reported that they used simple tricks when cooking rice to get the desired dish, as a safety measure, or to simplify the cooking process, namely: i) removing rice impurities; ii) soaking rice grains before cooking, so that they can release any toxic or hard-to-digest substances as well as shortening the cooking time and cooking uniformly;

or iii) regulating the hot temperature to obtain loose rice ('*If it's on an electric hot plate when it raises the boil, I immediately turn off the rice, because I don't like sticky rice*', P17).

Participants mentioned adding other ingredients to rice dishes, such as vegetables, pulses, and chorizo: 'Very rarely I'm able to make simple rice, either we put carrots, or we put peas or a little bit of chorizo. It is usually always with vegetables', P19. Malandro rice is a typical gastronomic practice of Portuguese cuisine, traditionally made with Carolino rice (long grain Japonica variety) cooked in plenty of water, which results in a creamy dish with a lot of broth rich in flavour derived from the added ingredients, such as vegetables, meat, fish, or seafood [57]. It is mostly referred to as Malandrinho by participants due to the influence of the brand name of a popularly known brand of Carolino rice. For some of the participants, the intention to add other ingredients is to improve the nutritional content of the dish: 'I try to put in more vegetables than rice to make sure we eat as many vegetables as we need', P5; 'I usually add carrots or peas or beans, and it becomes more nutritious', P6.

In the case of brown rice, the intention is also to mask or improve its flavour. '. . .brown rice doesn't have the same flavour as Agulha rice, for example, if it's plain, my son won't eat it (. . .) as it has a characteristic flavour, it can be masked [with the addition of other ingredients]', P1. Nevertheless, participants considered this practice ineffective, as this type of grain has some difficulty absorbing flavours from other ingredients: '. . . it gets a little rawer and does not seem to absorb as much water and everything else. Of course, it will have less flavour. . .', P16.

3.2.4. Eating

Participants reported that they like rice so much that some of them or their family members eat rice daily: '*They all like and eat rice! If they can, they eat rice every day*', P14. Others reinforce this preference by putting rice as their favourite side dish, compared to other alternatives: '. . . *I prefer rice to French fries* (. . .) *it's my favourite side dish. I've always loved rice*', P4. Others also mentioned that they choose the type of rice according to their taste preferences: '*I really like Basmati rice, it's a rice that tastes good to me*', P4. In this context, the cooked rice grains' appearance, flavour, and texture were the main sensory attributes identified by participants regarding their dish preferences. Independently of the dish, participants expressed their preference for whole kernels and grains with good extensibility (swelling of the cooked grain): '. . . *The growth* [swelling] *of the grains* (. . .) *at the end of the cooking process has a nice appearance, and it becomes thick. It's how I like rice*', P1.

For brown rice, different sensory descriptors emerged, such as hard, dry, dark, brown, dirty, and tasteless, explaining their dislike due to these sensory characteristics: '. . . *brown rice is a little darker, I like it less*', P4; '*I don't like brown rice, it's tasteless, girls* [wife and daughter] *like it anyway*', P13; '*It looks like it gets a little rawer* (. . .) *I think that's why* [I do not like brown rice]. *Because it doesn't have as much flavour, and the texture too* [I do not like it], *I think it's more* [because of] *the texture*', P16. It should be noted that none of these participants belonged to the brown rice consumers group, although these also recognise the fewer appealing attributes. However, they feel motivated to consume brown rice because of its health benefits: '*It's not because of the flavour* [that I eat brown rice], *it's because of the information I have that it would be healthier. It wouldn't be for the taste because it's not very pleasant*', P24.

3.2.5. Glycaemic Index Concept

When the concept of the glycaemic index was introduced, half of the participants declared not knowing about the concept. Several made erroneous associations with nutrition, thinking that the GI was synonymous with the food "calories": '*It will be the so-called calories that we attribute to food* (. . .) *general values of, namely, fats, saturated fats. . .*', P6, or that it was related to fat content: '. . . *it has to do with fat. It is the fat index. In this case, it will be the fat index of the rice*', P24.

To explain the low-GI concept, some interviewees associated it with familiar terms and ideas such as sugar and carbohydrates: '*It has to do with sugars* (. . .) *to have few hydrates.*

Not having high levels of carbohydrates', P1; and gave simple explanations like: '*It is the sugar index that we have in the blood*', P5; '*It's what raises our blood sugar* (. . .) *whoever has diabetes has to be careful with that, right?*', P10. Only fewer (n = 3 of 24) gave a slightly more complex explanation relating the GI to carbohydrates and digestion: '. . . *foods with a lower glycaemic index release sugar more slowly, and a food with a high glycaemic index even makes us want to eat faster*', P20; '*It's basically how far food takes our blood sugar levels. The higher the glycaemic index, the worse the food, because it doesn't leave us feeling satiated for so long, so it's better than the glycaemic index is not so high so that satiety is longer*', P21. They were from the "brown rice consumer" group who, as mentioned above, considered health concerns when choosing rice.

When asked specifically about the GI of rice, most (n = 15 of 24) responded that they have never thought about GI in rice, focusing their concerns for this concept only on sweet foods: '*I don't think about it. We will think of other foods like marmalades, and jams. Not for rice*', P10. In this debate, some participants (n = 5 of 24) considered the impact of rice processing on GI, mentioning that brown rice would have a lower GI than milled rice: '. . . *it depends on the rice, doesn't it? I am aware that the glycaemic index of milled rice is much higher than that of brown rice*', P21; '*A rice with fibre will give us energy for longer. Basically, it will keep us fuller for longer. Refined rice has no fibre, so the glycaemic index is higher*', P23. Among these participants, some even mentioned possibilities in the search for rice with a lower GI: '. . . *I look for one with a low glycaemic index. Brown rice, for example, has more fibre and so on, a low glycaemic index, but as it takes a little longer to cook when we don't have that time, we use parboiled rice or Basmati rice*', P23. Participants who were more familiar with the GI concept applied to the different rice types had higher education or belonged to the "brown rice consumer" group, revealing knowledge and, therefore, health concerns.

3.2.6. Drivers and Barriers of Low-GI Rice Choice

When asking participants about their opinions regarding what would make them buy rice with low-GI instead of other rice types, not surprisingly, health concerns emerged among the 22 participants that discussed this subject: '*I would buy* [low-GI rice] for health *reasons, and not to get fat*', P9. Nevertheless, only a few participants (n = 2 of 22) stated that they would choose a low-GI product only in case of medical recommendation because they think that, for instance, a rice product with a low GI would be too expensive and that the investment would only be justified if it is something essential for health: '. . . *if I go to an appointment and the doctor tells me I must eat. I would eat*', P7; '. . . *if I perceive that it is more beneficial, and the price difference isn't much*', P16.

Participants also demanded convenient solutions for rice with low-GI products, particularly ready-to-eat products ('*for me a quick meal because of time saving and functional*', P3), and ease of handling ('*May it be easier to take with you* (. . .) *to carry in your bag daily*', P6). Nevertheless, others were suspicious regarding these potential convenient solutions because they consider that convenience makes products more expensive, or because they believe that the speed of preparation can compromise the typical flavour of rice ('. . . *being ready-to-eat, the possibility of being able to be made in the microwave also helps us, oh and that it doesn't lose the flavour because it is made quickly*', P16). As the participants idealised these products as convenient and healthy, they perceived them to be expensive because increasing convenience (time savings, ease of preparation, energy savings, etc. . .) adds value to the final product.

Participants declared their interest in the product with a low GI but stressed the importance of maintaining the genuineness of usual rice dishes: '*Just because it has a low glycaemic index is already a factor of interest. But, after trying it, it may be interesting if it resembles other [conventional] products or if it tastes good*', P13. Some participants also reported that their interest in this type of rice would be a function of its sensory attributes (n = 9 of 22) and price (n = 7 of 22). Participants may accept low-GI rice products if they are deemed tasty, have a good appearance, and if they are sold at affordable prices.

Despite participants conceiving of rice with a low GI as a convenient product, some also mentioned naturalness as one of the drivers of choice ('*I look for the most natural product possible. . ..*', P23; '*Everything that is refined is very artificial. Rice, when it leaves the field, is not white*', P20; '*. . . being processed loses quality, so if I could eat rice every day, I would eat this* [brown rice]', P11. Moreover, this concern is related to both the nature of the raw material ('*A Bio Snack, with Bio products. . .*', P18) and the processing technology used: '*I avoid things that are processed* (. . .) *it is like this, the more preservatives things have, the more this and that, it is to be avoided* (. . .) *that does not have many additives*', P10.

Some participants claimed that additional information about this new rice concept should be on the packaging and in advertisements: '*. . . what you were buying, you would be able to buy*', P3. Within this regard, some participants mentioned that communicational campaigns should also consider practical cues regarding how to cook rice with low-GI meals, namely by including recipes: '*Maybe* [I do not buy] *because I don't know how I'm going to use it*', P9; '*. . . but can I use it like this? You know, those questions we ask ourselves in the supermarket* (. . .) *If you have this information in the back like the recipes, it helps. . .*', P15. In addition, they consider it important to clearly state the composition and benefits of the product: '*If I'm satisfied with the nutritional table, ok. If not, I'll go to see what's in the ingredients, and if there's a name I don't know, I'm a little bit wary of* (. . .), *in this case, I always pay attention to the type of initial rice* [base ingredient]', P21.

3.2.7. New Rice Products

As for rice-based products, most participants indicated that they have already consumed some rice products that exist on the market, such as puffed rice cake, crackers, vegetable drinks, and rice-based ready-to-eat meals, and suggested products that they would be interested in purchasing, so long as they do not compromise the food's sensory appeal. Some examples of these new rice products mentioned were rice desserts and dairy substitutes, convenient ready meals of rice/rice side dishes, or healthy rice snacks (Table A3). Participants expect these new rice products/meals to be convenient, healthy, and close to conventional products/meals. The dairy products listed on the FWA could be suggestions for low-GI foods that participants wanted.

4. Study Limitations

Despite the questionnaire sample size and the effort to recruit participants with a meaningful rice consumption pattern, the sampling approach did not follow a probabilistic design, meaning that care should be taken if extrapolating for the whole Portuguese population.

5. Discussion

5.1. Rice Consumption Habits

The survey results emphasise that rice continues to be an important part of Portuguese cuisine. In contrast to most European countries, rice is an almost everyday food for Portuguese consumers. The average rice consumption for French and Spanish consumers is only 0.9 times/week [67]. For the British, rice is considered "neither an everyday food nor a special food" [68], while for the French, it is considered "an exotic food" [69]. Regarding the type of rice, *Agulha* is the most consumed, followed by *Carolino* and Basmati. A previous study suggested that individuals with the highest rice consumption regularly chose *Agulha* rice, whereas those with the lowest weekly intake preferred Basmati and *Carolino* rice [57]. The participants' narratives were consistent with those results, indicating that *Carolino* rice has been partially replaced by *Agulha* rice and Basmati rice has replaced *Agulha* rice.

Parboiled, Jasmine, and Risotto were consumed less than one time per week. This consumption pattern tends to mimic the actual national pattern of usage. The most comprehensive collection of sales data is done by the Nielsen company, which for the 12-month average, from March 2023, of rice consumption in Portugal gives: 47% *Agulha* rice, 22%

Carolino, 13% Basmati, 11% parboiled, 1.3% jasmine, 0.9% risotto, 0.7% brown, and 4% other types (percentages of tonnage sold in the country, Nielsen, 2023).

According to these participants' narratives, despite rice consumption negatively affecting health, namely, as a cause of weight gain, the flavour, versatility in cooking, convenience, accessibility, and availability of various types of rice (market dynamics) contribute to the high consumption of rice. Respondents acknowledged that rice contains a high level of carbohydrates, which is why they linked it to weight gain, as has been observed in other studies on this macronutrient [70,71].

The familiarity with rice culinary practices may be explained because they were transmitted over generations, building the country's gastronomy [57], and by the presence of a wide offer of rice varieties and types in the Portuguese market, allowing for a large culinary applicability. In the same way, versatility, positive sensory attribute evaluation, and positive perception of safety and speciality have contributed to increased rice consumption in Western societies [68,72].

The opposite was verified for brown rice, which is perceived as unpleasant, inconvenient, and a food not part of the traditional cuisine. These barriers to brown rice consumption were also found among consumers in Costa Rica [73]. Brown rice takes longer to prepare because the bran layer hinders water absorption [74], which will slow the meltdown of the crystalline structure of starch [75]. In addition, brown rice makes it difficult to achieve a good culinary result and has a higher unit price than polished rice, and the market is not so dynamic in terms of competing brands and promotions offered. As Selvam et al. [8] adverted, the low demand makes a product more expensive because of lower supply. Other studies have also identified the lack of convenience as a barrier to rice consumption, in which ready-to-eat rice formulations have been suggested to overcome the possible effects of this factor on rice intake [48,76,77]. This can be a valid solution, especially for *Carolino* and brown rice, the varieties considered more difficult to prepare.

The main reason consumers buy brown rice and parboiled rice is that they are perceived as more nutritious, healthier, and more natural than milled rice. Brown or parboiled rice has a lower GI than its polished forms [30,78].

There was a positive perception of local rice's quality, naturalness, and sustainability, which other cultures also consider when selecting local rice over imported rice [79]. This is in contrast with the continued decrease in the consumption of local rice, giving way to imported rice [3].

The sensory preference for rice differs among cultures [80–83], in which texture is considered the main sensory attribute in the consumer acceptability of cooked rice [83,84]. The grain's length, width, and thickness were characteristics that participants weighed most when choosing raw rice, who believed that these attributes allow the prediction of the quality of cooked rice, a similar attitude of Asian consumers [85]. In the consumption stage, participants preferred rice with a soft and loose (non-stick rice) texture, like consumers in South Asia and other southern European countries, though unlike the rest of Europe, which prefers firmer rice [80,86]. Regarding appearance, participants preferred firm, thick grains (great swelling capacity), whole, closed (non-crack), and shiny grains, in agreement with the study by D'Hauteville et al. [87]. The panel expressed their preferences for each rice dish by describing the appearance of grains, flavour, and texture. Independent of the dish, they preferred whole kernels and grains with good extensibility (swelling of the cooked grain), which is considered an important cooking quality of rice by the Southern European consumer [86].

Baking, roasting, grilling, *estrugido*, braising, boiling, porridge, and stir-frying were the most prominent cooking methods reported, revealing familiarity with these cooking methods. *Estrugido* (Portuguese word) is a specific term for braising rice, which is frying garlic and onion in olive oil (may include other condiments) and adding colour without burning, where the other ingredients of the dish to be cooked are later added. Preferred cooking methods are usually associated with greater sensory benefits [67,88]. Thus, to cook rice, participants selected the best method for achieving the desired sensory properties,

limiting the amount of water, and varying the rice-to-water ratio depending on the intended final dish, unlike consumers in northern Europe, who generally cook rice with large amounts of water and then discard the remainder of the water [86]. For example, French consumers prefer cooking in large amounts of water due to its ease and speed [67,88]. Cooking conditions such as temperature, time, cooking water, and pre-cooking steps such as soaking have been shown to affect the sensory properties of cooked rice [74,89,90]. Soaking improves texture, reduces cooking time, and improves safety [91]. In addition, pre-cooking steps, such as removing impurities from rice and soaking rice, are traditional practices in Japan, Korea, and other Asian countries [48,69]. The participants showed the habit of adding other ingredients when making rice; some of them did it to increase the nutritional value, and others added it to add more flavour. Masking the perceived unpleasant sensory characteristics of brown rice through the incorporation of ingredients and use in traditional dishes was one of the strategies indicated by Monge-Rojas et al. [73] to promote the consumption of brown rice among Costa Ricans. Similarly, in Korea, other cereals, vegetables, and/or pulses are traditionally added to rice to obtain more nutritious and healthy dishes [88,92]. This reinforces the similarities between Portuguese consumers and typical rice-consumer countries, as previously reported by Cabral et al. [57].

The preparation and eating stages also influence the initial decision to buy rice (acquisition stage): consumers choose according to the desired culinary result, available time, cooking skills, and market opportunities (price and rice types). These factors confirm that Portuguese consumers are mainly motivated by the utilitarian and experiential dimensions of rice [57]; in the sense that the value of rice is determined by how well it performs, namely, considering its use as a side dish or main course, as a source of nutritional properties, or as a means of preparing a conventional meal, as well as by the fact that they appreciate the sensory properties of rice, as it offers pleasure and evokes feelings of pleasure [93].

5.2. Determinants of Choice of Low-GI Rice

For free word association with the "low glycaemic index foods" stimulus and the words related to health and benefits of low-GI foods, "Sugar" was the sixth most cited word, generating a double interpretation. On the one hand, this could be a sign that some participants were completely unaware of the concept of GI; on the other hand, it could be a direct association between sugar and what GI is, and not necessarily a mention of sugar as a low-GI product. Therefore, in-depth interviews are important for clarifying this issue.

In the interviews, we verified that to define GI, several participants answered "... it has to do with sugar." Although some participants were unaware of this concept, the erroneous association was related to the GI of fat and food colour. Those who mentioned sugar believed that there was a dependence between GI and sugar (not to classify the GI of sugar), since the glycaemic index depends on the amount and nature of the sugar contained in food [20].

Participants associated food items such as "Fruits and vegetables", "Whole grains", "Dairy products", "Fish and white meat", and "Pulses and seeds" to the stimulus, which are foods consensually perceived as healthy and recommended in the main healthy eating guides [94]. Whole grains have been spontaneously connected to health, even when studying terms or phrasal stimuli without product exposure [95]; therefore, these categories reinforce a positive perception of the health benefits associated with the "Low GI food". The category "Fish and white meat" was formed predominantly of fish (only 6 out of 25 mentions were for white meat), which is justified by the familiarity with this food, since Portugal is one of the largest consumers of fish in Europe [96].

Older participants expressed more "Positive attitudes and emotions" when hearing about "foods with low GI" than younger participants. In this age group, we believe that even if they did not have full knowledge of the concept, there was some idea of the benefits that might have been gained from medical contact (it can be part of medical advice in routine appointments). This finding corroborates previous studies that have reported that ageing is associated with greater awareness of the relationship between health, diet, and disease [97,98]. Participants with a higher education showed greater knowledge of

the concept of low GI than those without a higher education. This result is in line with those already mentioned by several authors that demonstrated the influence of the level of education on knowledge about healthy eating [99,100]. These findings reinforce that foods with special claims should be designed for specific groups rather than targeted at the general market.

Some participants understood the low-GI concept and its impact on health, while others were misinformed with huge misconceptions. Lack of information/knowledge was identified as a barrier to choosing rice products with a low GI. These results suggest greater reflection on the role of information in the promotion of low-GI rice, both to inform about the product and to raise awareness about the concept. Correcting inaccurate beliefs regarding nutrition can improve the nutritional quality of choices [101]. For example, Arslain et al. [102] show that even a short message about the benefits of fibre significantly increases consumption of dietary fibre; Gustafson et al. [103] showed that more specific prompts about healthy foods at the point of decision can motivate healthier choices; and Jo and Lusk [101] found that information about health benefits makes consumers more willing to sacrifice their tastes for healthy foods. Urala and Lähteenmäki [104] found that some health claims can be so strong that consumers are ready to compromise on taste. However, this depends on the consumption values and degree of interest in that claim. We believe that consumers affected by diabetes or other diseases that can be controlled through food intake would be more willing to make these sacrifices, since it is recognised that the diagnosis of health problems related to food intake is one of the exceptions to the domain of hedonic reasons for one's food choices [105]. Therefore, including information on the label, such as short and simple explanations about the impact of a low-GI diet, prompts at the point of sale, and health goal priming can be a potential tool for promoting rice/low-GI products.

Participants showed an interest in low-GI rice-based healthy products that offer convenient solutions without compromising taste and price, showing concerns about more immediate aspects of food consumption decisions, such as taste and price [106]. As participants idealised these products as convenient and healthy, they perceived them as expensive and tasteless. Increasing convenience (time savings, ease of preparation, energy savings, etc.) adds value to the final product, which translates to a higher price [107], and healthy foods are perceived as more expensive [102]. In some cultures, there is an intuition that healthy foods are not tasty [108,109]. Consumers have even reported this belief with a low food pleasure orientation [110].

The naturalness emphasised by participants may be related to the desire for convenience foods to be the closest to homemade foods, as verified by Peura-Kapanen, Jallinoja [111]. The lack of naturalness has been reported as a barrier to consuming conventional food substitutes [112]. For many years, convenient products were perceived as unhealthy [111]. However, changes have reinforced the use of convenience as a tool to support healthy eating habits [113].

Studies continue to support using low-glycaemic index diets as a treatment for diabetes [23]. However, the potential applications of these diets extend beyond diabetes management, and they may also be effective in preventing and managing other chronic diseases, including cardiovascular disease, some types of cancer, and obesity [114]. Taking advantage of the country's culinary habits, using ingredients that can potentially lower the glycaemic response to rice meals can be encouraged. The method of adding ingredients such as vegetables, beans, and ancient grains has been used to obtain rice dishes with a lower GI [40,42–45]. Moreover, Chang et al. [115] found that adding vegetables when cooking rice increased satiety and decreased daily energy density, owing to the reduced amount of rice consumed in the meal. This can be a good strategy for weight control and the maintenance of diabetes.

Rice has proven to be a raw material with great potential, owing to its profitability, ease of transportation for strengthening nutrients, versatility, and ability to be integrated into conventional formulations or specific products for consumers with special diets, such as

celiacs. Therefore, the food industry plays an important role in developing and promoting healthier ways of consuming rice, whether through product formulations resembling conventional products or using traditional ingredients with which consumers are familiar.

Researchers and industries have investigated the processes of the nutritional optimisation and reduction of the GI of rice, such as germination, which gives rise to the so-called GABA rice—rice with a natural content of gamma-aminobutyric acid, a neurotransmitter with calming effects on the brain, fermentation to obtain rice-based probiotics such as Amazake, and ready-to-eat rice meals mixed with beneficial ingredients such as ancient grains, pulses, and vegetables [54,116–119].

6. Conclusions

Unlike most European countries, rice is an almost daily staple for Portuguese consumers, and rice remains an important part of Portuguese cuisine. The factors considered in the choice of rice vary throughout the rice supply and use method. Consumers tend to try new varieties, listing sensory aspects, price, and convenience as preponderant factors. The participants' narratives suggest that three main factors may explain why this consumption frequency is so high in comparison to other European countries: (i) rice was considered convenient for different culinary situations (cooking stage), (ii) the taste was very well accepted (eating stage), and (iii) the high cultural/traditional identity associated with rice consumption in Portugal, which is also observed in the market dynamics (acquisition stage).

Low-GI rice foods/products were considered interesting and healthy due to their perceived nutritional and general health benefits. On the other hand, consumers were concerned about their sensory dimensions. Therefore, sensory analysis using consumer panels is essential for developing low-GI rice products. As traditional habits and naturalness are drivers of the willingness to choose low-GI rice foods, food manufacturers must take heed to offer healthier rice products that resemble conventional rice dishes. To achieve this, it is essential to employ processing technologies perceived as natural, and to incorporate sustainable natural ingredients commonly used in everyday cooking.

Moreover, the findings suggest that educational actions should be considered to change negative perceptions of brown rice and low-GI foods. Examples of such actions could be the dissemination of diversified recipes that include brown rice and a strategy for preparing white rice with ingredients that help reduce GI, considering the gastronomic value of the ingredients for the Portuguese population. GI labelling can be a valuable tool for the promotion of such products. For a successful launch of a rice product with a low GI, it is necessary to invest in disseminating its benefits and to bring it as close as possible to a familiar product for the consumer.

The insights from this study can be used in future research with a more quantitative approach to evaluate the factors underlying the choice of rice and low-GI rice products, the most attractive sensory and non-sensory attributes, and the segmentation of consumers willing to choose this type of product. Regarding ways to promote rice consumption in its healthiest form, it is important to understand the impact of information about GI and the awareness of healthier rice alternatives in shaping rice choices.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/foods13020301/s1, File S1: In-depth interview guide on determinants of the consumption of rice and products with a low glycaemic index; File S2: self-reported electronic questionnaire.

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Institutional Review Board Statement: The current study followed the ethical guidelines outlined in the Declaration of Helsinki and received approval from the Ethics Committee of the Faculty of Sciences of the University of Porto (50/2023). The informed consent met the established guidelines, and the protection of information and ethical data treatment were demonstrated.

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: Data is contained within the article or Supplementary Materials.

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Appendix A

Table A1. Characterization of the participants in the questionnaire.

Characteristic		Absolute Frequency	Relative Frequency
Gender			
	Female	164	64%
	Male	92	36%
Age group (mean ± SD: 40 ± 12.8 year)			
	[18–34]	90	35%
	[35–54]	124	49%
	≥55	42	16%
Educational level			
	no higher education	164	64%
	higher education	92	36%
Household size			
	1 and 2	77	30%
	3 and 4	158	62%
	5 or more	21	8%
Monthly household income per capita			
	EUR ≤ 250.00	65	25.4%
	EUR [250.01–400.00]	66	25.8%
	EUR [400.01–550.00]	62	24.2%
	EUR > 550.00	63	24.6%

Sample size = 256.

Table A2. Characterization of the participants in the interviews.

Consumption Group (Average Age ± SD)	Participant (P#)	Gender	Age Group	Education Level
G1—Daily rice consumers (minimum consumption once a day)	P1	Female	[35; 54]	no higher education
	P2	Female	[18; 34]	no higher education
	P3	Male	[35; 54]	no higher education
	P4	Male	≥55	higher education
	P5	Female	[35; 54]	higher education
	P6	Female	[35; 54]	no higher education
	P7	Male	[18; 34]	no higher education
	P8	Male	[18; 34]	no higher education

Table A2. *Cont.*

Consumption Group (Average Age ± SD)	Participant (P#)	Gender	Age Group	Education Level
G2—Light rice consumers (consumption of rice up to three times/week)	P9	Female	[35; 54]	higher education
	P10	Female	[35; 54]	no higher education
	P11	Male	≥55	no higher education
	P12	Female	[35; 54]	no higher education
	P13	Male	[35; 54]	no higher education
	P14	Female	≥55	no higher education
	P15	Female	[18; 34]	higher education
	P16	Male	[18; 34]	no higher education
G3—Brown rice consumers (consumption of at least three times/week of brown rice)	P17	Female	≥55	no higher education
	P18	Male	≥55	no higher education
	P19	Male	[35; 54]	no higher education
	P20	Female	[35; 54]	higher education
	P21	Female	[18; 34]	higher education
	P22	Female	≥55	no higher education
	P23	Male	[18; 34]	no higher education
	P24	Male	[18; 34]	no higher education

Sample size = 24.

Table A3. New rice-based products as cited by participants during the in-depth interviews.

Type of Rice Products (No. of Participants)	Rice Products (No. of Participants Who Cited the Products)	Example of Quotations
Products recently tasted by participants (n = 18)	Puffed rice cake and crackers (n = 15)	*'I also buy rice cake. They're white, I call them Styrofoam, it doesn't even remind me that it's rice. I quite like it'*, P9 *'Sometimes I buy [crackers] to take with me when I'm going to be away from home for a long time, so I take it with me'*, P6 *'It's great, it's great! They are delicious [rice cake]. It really has cocoa; the chocolate is made from cocoa'*, P14 *'. . .chocolate rice cake, rice crackers. These are the ones I've tried'*, P15
	Rice drinks (n = 8)	*'One thing I drink every day, rice drinks because at home I try to cut out lactose'*, P20 *'. . .rice milk. I happened to have a drink last week'*, P7 *'Rice drink, we've already tasted it'*, P13
	Ready-to-eat (n = 4)	*'I liked vegetable risotto'*, P3 *'I really like new products (. . .) we tried noodles, noodles with egg. We like it because I just add hot water'*, P19 *'What I bought new was rice that is prepared in the microwave (. . .) cod rice'*, P22 *'I have already used the ready-to-eat, especially the plain rice. It's just that I have a problem with [to make] plain rice: it never comes out well. I use it when I want it to look really good. It goes in the microwave, and it's done, and I don't have to worry'*, P15
	Rice flour and noodles (n = 4)	*'. . .rice noodles, for example, is something that I like'*, P4 *'I have used rice flour'*, P5 *'I use rice flour a lot, I like it a lot'*, P17

Table A3. *Cont.*

Type of Rice Products (No. of Participants)	Rice Products (No. of Participants Who Cited the Products)	Example of Quotations
Product concept proposed by participants (n = 15)	Snack and breakfast cereal (n = 7)	*'Cereal is what I always eat at home from morning to afternoon and before bed too. And since it has a lot of sugar, if there was one with a lower glycaemic index, maybe I would opt for this product instead of the conventional one'*, P8 *'Crackers always go well. And if it has a low glycaemic index all the better. At least I eat crackers and I was quenched for longer'*, P12 *'For example, cereal bar. Of those bars that you sometimes buy with mixed fruit. Some different bars with [puffed] rice'*, P20 *'A snack would be interesting. Like a bar. People are looking for a lot of bars and the bars are loaded with sugar. It is very difficult to find a healthy one'*, P21 *'Rice-based breakfast cereals, kind of oat'*, P24
	Ready-to-eat meal/side dish (n = 6)	*'. . .for me a faster meal because of gaining time (. . .) Rice noodle, I would eat it often. Pasta, pizza'*, P3 *'An easy-to-prepare rice'*, P9. *'Ready-to-eat rice, not to use regularly, but to save time when necessary'*, P16 *'I really like rice, I like a lot of hearty food, (. . .) if it's a good seafood rice, I don't know, a risotto, a good risotto'*, P18
	Desserts and dairy substitutes (n = 5)	*'Yogurt containing rice would be interesting. I don't know, it's a suggestion (. . .) A milk-like drink that had some components like fruit. That it was more consistent than the rice drink. Like yogurt. I think something like that was needed [for eating] there in the middle of the afternoon'*, P1 *'Only if it's in the form of desserts, (. . .) as we want to get away from the traditional dessert, maybe, having a low glycaemic index we say: ok, this is good'*, P5 *'A smaller yogurt-sized product I think would be interesting'*, P6 *'. . .rice drink. I shop at stores that sell healthy products. If it is a rice drink with a lower glycaemic index, I would opt for the healthier one'*, P8

Sample size =24.

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3.3. Paper III – Sensory profile, overall liking, and wellbeing perception of ready-to-eat rice products: effect of product information prior to consumption.

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Sensory profile, overall liking, and wellbeing perception of ready-to-eat rice products: effect of product information prior to consumption.

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Sensory profile, overall liking, and well-being perception of ready-to-eat rice products: *effect of product information prior to consumption.*

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Abstract

Purpose – This study aimed to evaluate the overall liking, sensory profile, and well-being perception of different ready-to-eat rice (RTE-rice) and to understand the effect of product information before consumption on consumer perception and evaluation.

Design/methodology/approach - In two trials, consumers evaluated five RTE-rice samples: Carolino white, Carolino brown, Basmati white, Carolino brown with quinoa, and *Carolino* brown with ancient grains. In Trial 1 (blind), consumers rated their overall liking of the samples and filled out a Check-All-That-Apply ballot with 45 descriptive attributes, followed by an adapted well-being scale. In Trial 2 (informed), the same panel evaluated the samples after more than 90 days, with prior knowledge of the rice variety and ingredient list following the same procedure.

Findings – The study showed that *Carolino* white rice was the most liked, whereas *Carolino* brown rice with ancient grains was the least liked. Soft, shiny, and loose grain attributes were positively associated with liking, whereas brown, dry, and sticky grains were negatively associated. Disclosure of the rice information helped to distinguish between milled and brown rice samples, with the most complex sample (*Carolino* brown rice with ancient grains) perceived to have higher well-being scores in the informed trial. This suggests that providing information can help consumers make more conscious choices by considering factors beyond simple hedonics.

Originality/values – This work introduces a quantitative well-being evaluation of RTE-rice rice products, enhancing the understanding of how varieties and ingredients affect well-being and liking. It also offers valuable insights for creating healthier food products that cater to consumers' demand for specific benefits.

Key Words ready-to-eat rice, sensory, well-being, information, multidimensional alignment analysis.
Paper type Research paper

1. Introduction

Rice provides approximately 20% of daily energy intake, is a staple for nearly half of the world's population (FAO, 2021; Jones and Sheats, 2016), and is mainly consumed in its milled/polished form (Fukagawa and Ziska, 2019). Carbohydrates (CHO) represent approximately 90% of the nutritional composition of milled rice, resulting in fast-digesting food that causes a rapid increase in blood glucose after ingestion (Foster-Powell et al., 2002; Jenkins et al., 2002). Owing to these nutritional issues, high rice consumption has been positively associated with non-communicable chronic diseases, such as diabetes, obesity, and cardiovascular diseases (Hu et al., 2012; Jenkins et al., 2002; Yu et al., 2022; Bhavadharini et al., 2020; Saneei et al., 2017; Livesey et al., 2019). White rice is a milled/polished rice resulting from the additional removal of bran and germ, leaving only the endosperm, which is mostly CHO. Because the most nutritious parts of the grain are removed, white rice is left with very few essential nutrients (Zhou et al., 2019). Additionally, the amount and nature of refined CHO converts white rice into food with a high glycaemic index (GI) (Atkinson et al., 2021). Brown rice, which results from husked paddy, is considered healthier owing to its nutritional components, such as lipids, proteins, dietary fibre, γ-oryzanol, and other phytochemical constituents (Mir et al., 2019; Castanho et al., 2019). It is associated with a risk reduction of several chronic diseases, including various types of cancer (Verma and Srivastav, 2020; Henderson et al., 2012), a decrease in blood cholesterol levels (Seetharamaiah and Chandrasekhara, 1989; Zavoshy et al., 2012), and the ability to decrease the risk of type II diabetes (Mahdavi-Roshan et al., 2021; Cheng et al., 2010). Nevertheless, the consumption of brown rice, in general, is very low relative to white rice, as it is less liked in terms of texture (too hard and too chewy), colour, and flavour (Gondal et al., 2021; Zhou et al., 2019; Cabral et al., 2024).

A study conducted by Cabral et al. (2024) revealed that Portuguese consumers identified rice varieties such as *Agulha*, Basmati, and parboiled rice as convenient while expressing a lack of culinary skills to prepare Carolino—the traditional local japonica rice variety—and brown rice and unfamiliarity with the latter. The participants expressed a desire for convenient solutions for low GI rice, including ready-to-eat products and user-friendly services.

These trends encourage the food industry to develop convenient, tasty, and healthier forms of rice by replacing white rice with brown rice or other grains. This is particularly relevant in countries where rice is the main side dish of every day, as is the case in Portugal, the major *per capita* consumer of rice in Europe (Cabral et al., 2022).

However, in everyday life, consumers make a series of decisions about what they eat based on many factors and their interactions (Cunha et al., 2018). In fact, in the food-related context, greater emphasis has been placed on aspects of well-being related to health (Jaeger et al., 2022; Ares et al., 2015), pleasure (Sulmont-Rossé et al., 2019), and emotional and spiritual aspects (Jaeger et al., 2023).

Measuring the perception of well-being in relation to food consumption can inform the development of nutritious food items that are highly acceptable to consumers (Ares et al., 2015). A variety of methods and instruments have been employed to assess well-being, including direct self-assessment (Reeves et al., 2013; W.H.O., 1998) and indirect scales (Ares et al., 2015; Ares et al., 2016; King et al., 2015; Boelsma et al., 2010).

Previous studies have shown that information about food products can affect perceptions of health and well-being (Jindahra and Phumpradab, 2023; Thurecht et al., 2018; Motoki et al., 2021; Jo and Lusk, 2018; Reis et al., 2017; Apaolaza et al., 2018; Oliveira et al., 2017), as well as hedonic perception and sensory evaluation (Reis et al., 2017; Shankar et al., 2009; Suzuki and Park, 2018; Lee et al., 2006; Litt and Shiv, 2012; Jo and Lusk, 2018; Lee et al., 2022; Grasso et al., 2017).

This study examined the sensory profile, overall liking, and well-being perception of various ready-to-eat rice (RTE-rice) products using a panel of over one hundred Portuguese consumers. It also aimed to determine the effect of product information awareness on overall liking and the perception of well-being. The findings of this study could be beneficial in creating rice-based products that fulfil consumers' sensory and non-sensory requirements and promote healthier eating habits.

2. Materials and methods

2.1. Ready-to-eat rice samples

Five commercial samples of RTE-rice, differentiated by variety (Carolino, Basmati), processing (milled, brown), and composition (plain recipe and recipe with the addition of one or more ingredients) from two different brands were evaluated (Figure 1). Each sample was heated in a microwave at 800 W for 60 s, and each assessor received approximately 30 g of the sample for evaluation on a white porcelain plate. The samples were randomly encoded using three-digit numbers.

Figure 1 - Images of the ready-to-eat rice samples.

Table I lists the ingredients of the ready-to-eat kinds of rice under evaluation. These products were considered because of their composition and nutritional properties to allow comprehension of the differences in liking and well-being perception regarding the varieties and ingredients and to identify the main characteristics that influence these parameters in this product category.

The CarBQ and CarBAG samples were more complex, with some unusual ingredients in rice cooking. These ingredients, such as quinoa (Békés et al., 2017), buckwheat (Tömösközi and Langó, 2017) and other whole grains (Spaggiari et al., 2019), are recognised for their interesting nutritional properties, health, and well-being.

Table I. Composition of the tested ready-to-eat rice products.

Abbreviation	Sample	Ingredient
BasW	Basmati white rice	Basmati rice (44%), water, extra virgin olive oil, salt, thickener.
CarW	*Carolino* white rice	*Carolino* white rice (51%), water, extra virgin olive oil, onion, salt, thickener, garlic.
CarB	*Carolino* brown rice	*Carolino* brown rice (51%), water, extra virgin olive oil, onion, salt, thickener, garlic.
CarBQ	*Carolino* brown rice with quinoa	*Carolino* brown rice (53%), water, white and red quinoa (5.1%), extra virgin olive oil, salt.
CarBAG	*Carolino* brown rice with quinoa and other ancient grains	*Carolino* brown rice (21%), mixture of buckwheat, barley, rye, and oats (25%), quinoa (4%), sunflower vegetable oil, emulsifier, salt.

2.2. Experimental procedure

This study was conducted during two periods, Trials 1 and 2, using the same commercial samples of RTE-rice. In Trial 1, each sample's overall liking, sensory profile, and perception of well-being were evaluated sequentially under blinded conditions, indicating that no packaging or product information was provided to the participants. The samples were presented in a sequential monadic manner, following a balanced order (Macfie et al., 1989; Wakeling and MacFie, 1995).

In Trial 2, after over 90 days from Trial 1, the same participants were called in for a similar evaluation, except they were informed about the rice variety and ingredients at the start of each sample presentation. For instance, the following introduction was presented before consumption of the CarBAG sample: "You are about to taste a ready-to-eat *Carolino* brown rice that contains quinoa, buckwheat, barley, rye, and oats". The assessors completed the overall liking and then were instructed to re-taste the samples and complete the well-being scale, the same procedure used in Trial 1.

Both experiments were conducted on the premise of a sensory analysis company (Sense Test, Lda.) Each assessor was placed in a booth designed following the standard ISO 8589:2007.

2.3. Participants

A panel of 105 consumers (40.3 ± 11.8 years) was initially recruited through convenience sampling, balanced for sex (male, female) and age group (18 to 39 and 40 to 60 years old), as presented in Table II. Of the previous assessors, 82 participated in Trial 2, representing approximately 78% of the previous participants, and an average age of 40.6 (± 11.8) years was observed, maintaining the relative distribution of sociodemographic characteristics.

Table II. Characterisation of participants (Trial 1 and Trial 2).

	Trial 1 (n=105)		Trial 2 (n=82)	
Characteristic	**Absolute Frequency**	**Relative Frequency**	**Absolute Frequency**	**Relative Frequency**
Gender				
Female	59	56%	46	56%
Male	46	44%	36	44%
Age group				
[18-39] years old	50	48%	39	48%
[40-60] years old	55	52%	43	52%

All participants provided informed consent before their participation. The study was approved by the Ethical Committee of the Faculty of Sciences of the University of Porto (reference number 50/2023).

2.4. Sensory evaluation

The Check-All-That-Apply (CATA) methodology (Ares et al., 2010) was used to evaluate the sensory profiles of each sample. This involved the preparation of a CATA ballot containing 63 descriptors derived from bibliographic research and insights gathered from previous studies with the same consumers using free word association and individual interviews (Cabral et al., 2022; Cabral et al., 2024). A preliminary test was conducted with six expert assessors, during which sensory terms deemed irrelevant to the task were excluded. The final CATA ballot consisted of 45 descriptors divided into four sensory dimensions: appearance (A), odour (O), texture (T), and flavours (F) (Table

III). The presentation of the descriptors was balanced between participants but not between samples, as Meyners and Castura (2016) recommended.

Table III. List of sensory descriptors used in Check-all-that-Apply methodology.

Appearance (A)	☐ Yellowish	☐ White	☐ Brown	☐ Parched	☐ Sticky grains	☐ Dull grains
	☐ Shiny grains	☐ Thick grains	☐ Long grains	☐ Broken grains	☐ Irregular sized grains	☐ Loose grains
	☐ Beige	☐ Thin grains	☐ Tiny grains	☐ Cracked grains		
Odour (O)	☐ Typical	☐ Sweetish	☐ Hay / straw smell	☐ Cereal smell	☐ Wet cardboard-like odour	☐ Onion
	☐ Parboiled rice smell	☐ Green corn smell				
Texture (T)	☐ Rough	☐ Hard	☐ Glue to teeth	☐ Dry	☐ Moist	☐ Greasy
	☐ Grainy	☐ Hardened[1] grains	☐ Soft	☐ *Al dente*		
Flavour (F)	☐ Sweetish	☐ Bitter	☐ Tasteless	☐ *Estrugido*[2]	☐ Dairy	☐ Metallic
	☐ Nuts	☐ Popcorn	☐ Earthy	☐ Salty	☐ Cereals	

[1] Related to lack of uniform cooking of rice kernel

[2] "*Estrugido* is a specific term for braising rice, which is frying garlic and onion in vegetable oil (may include other condiments) and gaining colour without burning, where other ingredients of the dish to be cooked are later added" (Cabral et al., 2022) p. (7).

For the overall liking assessment, the classic 9-point hedonic scale (Peryam and Pilgrim, 1957), ranging from 1 - "disliked extremely" to 9 - "liked extremely", was applied before evaluating the CATA ballot to avoid potential hedonic score bias (King et al., 2013). The overall liking question enables the implementation of penalties (Plaehn, 2012) by relating sensory attributes to hedonic scores.

2.5. Well-being perception

The questionnaire proposed by Ares et al. (2016) was adapted to assess the perceptions of well-being associated with each RTE-rice sample. This questionnaire

comprised 31 items distributed across six dimensions: General, Physical, Intellectual, Emotional, Social, and Spiritual. The respondents were required to indicate their degree of agreement with each statement on a 7-point anchored scale, from 1 - “strongly disagree” to 7 - “strongly agree”.

The relevance of a given dimension in the assessment of well-being depends on the food item, cultural context, the purpose of the study, and specific aspects of consumption (Ares et al., 2015; King et al., 2015; Jaeger et al., 2022; Sulmont-Rossé et al., 2019). Thus, the perception of well-being in the context of rice consumption may be more focused on specific dimensions, such as health and nutritional (Physical aspect), Social, and Emotional aspects, since Portuguese consumers associate the word "rice" with these dimensions, as found by Cabral et al. (2022). In addition to these utilitarian and experiential values, consumers also made symbolic associations with rice, influenced by a tremendous cultural expression around this food in Portugal; hence, it was also considered the spiritual dimension of the well-being questionnaire in this study. Therefore, the Intellectual dimension of well-being, which includes cognitive stimulation, personal growth, and learning, was considered irrelevant to rice consumption, and was not included in this study. Four emotional items were also excluded, resulting in 22 items selected for evaluation (Table IV).

In fact, in food-related contexts, well-being has been directed towards health, pleasure, and emotional and spiritual aspects (Jaeger et al., 2023; Jaeger et al., 2022; Sulmont-Rossé et al., 2019), with none of these studies finding any association with intellectual dimensions.

Table IV. Structure of the wellbeing questionnaire adapted from Ares et al. (2016) to evaluate ready-to-eat rice, with its 22 items.

Dimension	Wellbeing items adapted to the ready-to-eat rice (22 items)
General	It is good for wellbeing
	It makes me feel good
Physical	It is good for my health
	It is nutritious
	It makes me feel satiated
	It helps me control my weight
	It keeps me fit
	It keeps me healthy
	It gives me energy
Emotional	It gives me pleasure
	It makes me feel satisfied
	It makes me feel happy
Social	It is good for sharing with family
	It makes me feel connected to others
	It improves what others think of me
	It makes me feel supported by others
	It is good for sharing with friends
Spiritual	It makes my life closer to my ideal
	It makes me feel closer to nature
	It gives me a sense of gratitude
	It gives me inner peace
	It is good for my soul

2.6. Data analysis

Descriptive statistics were used for the participants' characterisation and to calculate the average and standard error of the hedonic scores and scores of the well-being items for each sample. Friedman's non-parametric and Wilcoxon pairwise comparison (post hoc) tests were used with a 5% significance level to evaluate differences in hedonic scores among the samples (within trials). The Wilcoxon non-parametric test, with a 5% significance level, was used to verify the mean differences in the liking scores between Trial 1 (without product information prior to consumption) and Trial 2 (with product information prior to consumption).

Cochran's Q test was used to assess the effects of the sensory descriptors on rice sample differentiation. The frequency of attribution of each sensory descriptor in the CATA question for each sample was calculated, and the resulting contingency table was used to perform a Correspondence Analysis and a Multidimensional Alignment Analysis (MDA). MDA has been proposed as a valuable complementary method for investigating the association between products and attributes, providing more complete information (Meyners et al., 2013).

Non-parametric Kruskal–Wallis's test with multiple pairwise comparisons were performed on the well-being item scores between samples (within each trial). To determine the effect of product information prior to consumption on hedonic and well-being scores, a Wilcoxon's non-parametric test with a 5% significance level was used for each sample under evaluation.

Data were analysed using XLSTAT (version 2020; Addinsoft, France, Paris) and SPSS 27 (IBM Corp., Armonk, NY, IBM Corp.).

3. Results

3.1. Overall liking

Under both test conditions, CarW received the highest liking score despite all the samples being in the positive part of the hedonic scale (Table V). The overall liking scores were not significantly affected by the test conditions; however, in Trial 2, the liking scores of the BasW sample improved, becoming the second-most appreciated sample after the CarBQ.

Table V. Overall liking of ready-to-eat rice samples (over a 9-point hedonic scale), with or without product information prior to consumption (n=82)

Sample	**Without information** (mean ± SE)	**With information** (mean ± SE)	**P-value**
BasW	6.8 ^{c} ± 0.2	7.1 ^{b} ± 0.2	0.236
CarW	7.7 ^{a} ± 0.1	7.6 ^{a} ± 0.1	0.364
CarBQ	7.1 ^{b} ± 0.2	7.1 ^{b} ± 0.2	0.856
CarB	6.7 ^{c} ± 0.2	6.8 ^{c} ± 0.2	0.721
CarBAG	6.7 ^{c} ± 0.2	6.7 ^{c} ± 0.2	0.753

$^{a, b, c}$ significantly (collum) different according to Friedman's test ($p < 0.001$) and Wilcoxon post hoc test.

3.2. Sensory profile

According to Cochran's Q test, 34 sensory descriptors significantly differentiated the samples. The correspondence analysis map with a confident ellipse presents the first and second dimensions contributing to 83.2% of the explained variance (Figure 2). The composition of samples with brown rice differed from that of milled rice.

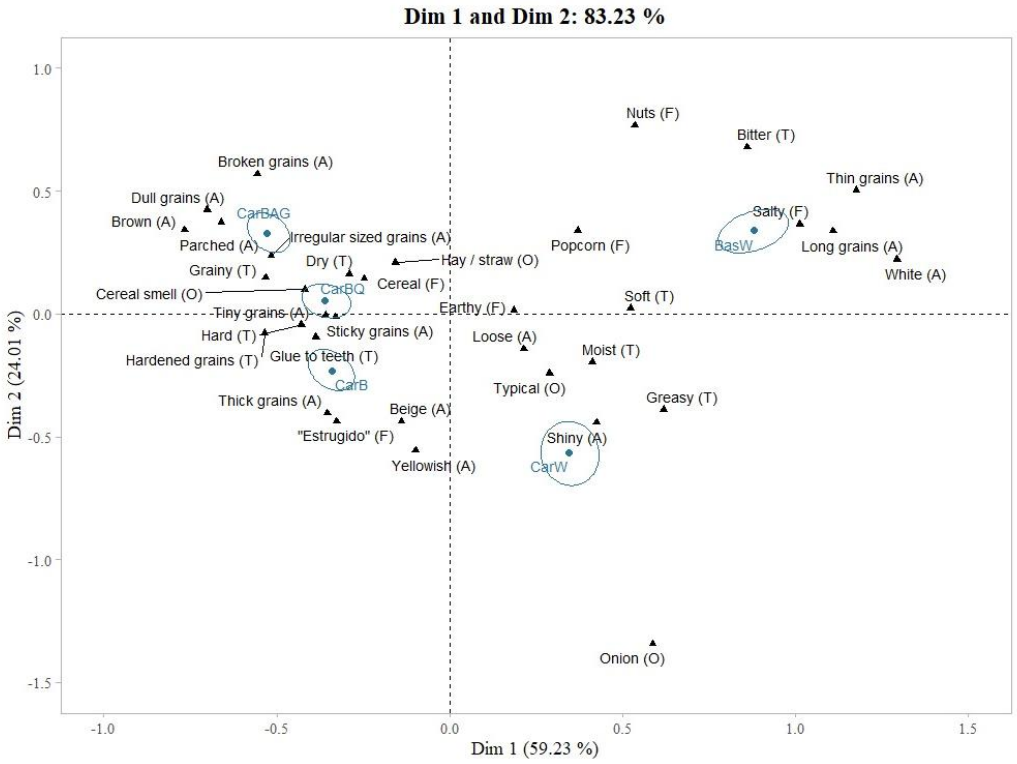


Figure 2. Perceptual map of association of sensory attributes to ready-to-eat rice samples with confidence ellipses.

The CarW was more associated with shiny grains, greasy, typical odour, loose, moist, and onion odour, while BasW was more associated with white, long grains, thin grains, and salty. The two most similar samples (CarBQ and CarBAG) were closer, sharing several attributes, making it more challenging to highlight their singularities. An MDA analysis was performed to understand in more detail the differences between the samples and their correlation with sensory attributes. Figure 3 shows the results of the MDA, in which the filled bars correspond to the attributes with significant effects on the characterisation of the respective samples. Angles smaller than 45º correspond to a positive correlation between the attribute and sample, and angles greater than 135º correspond to a negative correlation between the attribute and sample; observations outside these specified parameters indicate no significant correlation between the attributes and sample.

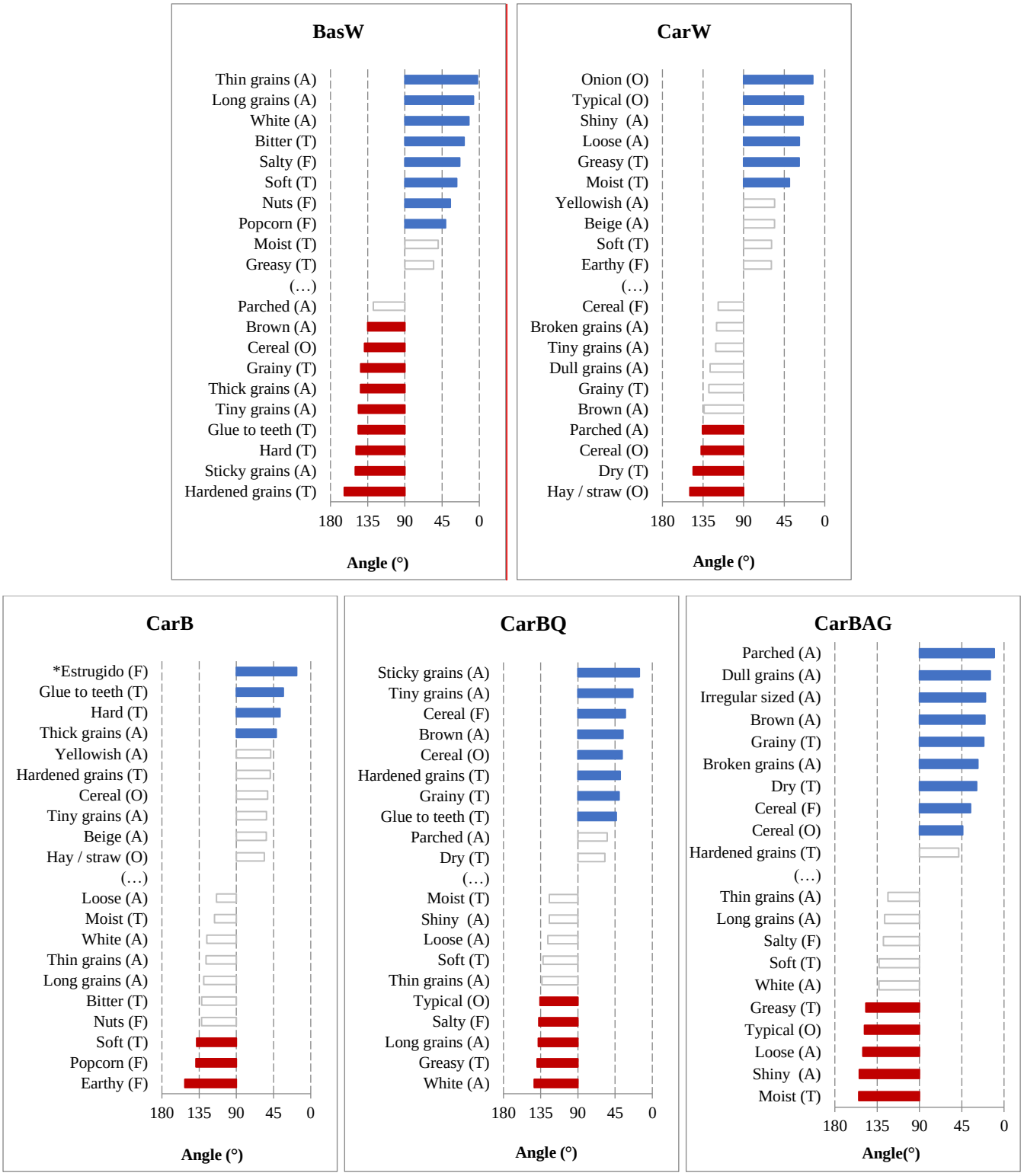


Figure 3. Distance (angle) between ready-to-eat rice samples and sensory attributes. The filled bars correspond to the attributes with significant effects on product sensory characterization (blue – positive correlation and red – negative correlation).

The CarW sample was positively correlated with onion odour, shiny grains, typical odour, greasy, loose grains, and moist grains and negatively correlated with parched aspect, cereal odour, dry, and hay odour. The CarBQ sample was positively correlated

with sticky grains (aggregated grains forming lumps), tiny grains, cereal taste, brown colour, cereal odour, hard grains, grainy, and glue to teeth. Most of these attributes usually penalise the liking score for rice; however, its liking scores were considerably high (7.1, on a 1 to 9 scale). There was a positive correlation between thin grains, long grains, white colour, bitter, salty, soft, nut, dairy, and popcorn tastes in the BasW sample. In contrast, hardened grains, sticky grains, hard, small grains, glue to teeth, thick grains, grainy, cereal odour, and brown colour had a negative correlation. CarBAG was positively correlated with the attributes of parched aspect, dull grains, brown colour, irregular-sized grains, grainy, broken grains, dry texture, cereal flavour, and cereal odour (Figure 3).

The results of the penalty analysis presented in Figure 4 indicate the descriptors that penalise the overall liking and those that benefit from it. Soft grains, bright, typical odour, loose grains, and thick grains drive liking. In contrast, brown, dry, and sticky grains were preferred penalises. The CarBAG sample correlated negatively with the drivers of liking, such as shiny grains and typical odours, and positively with penalty attributes, such as brown and dry.

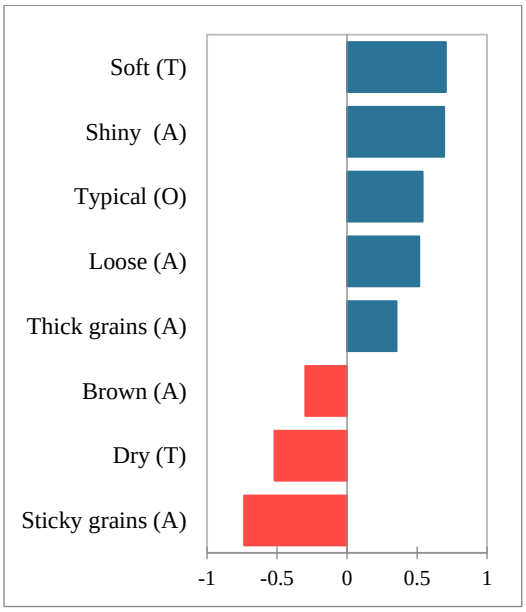


Figure 4. Sensory descriptors with an effect on sample liking scores (penalty analysis).

3.3. Well-being perception

Table VI shows the average well-being dimension for each sample in both condition tests. Significant differences were found among the dimensions of the well-being scale within the samples in each trial. The Physical dimension was perceived significantly better in all samples, while the Social and Spiritual dimensions were

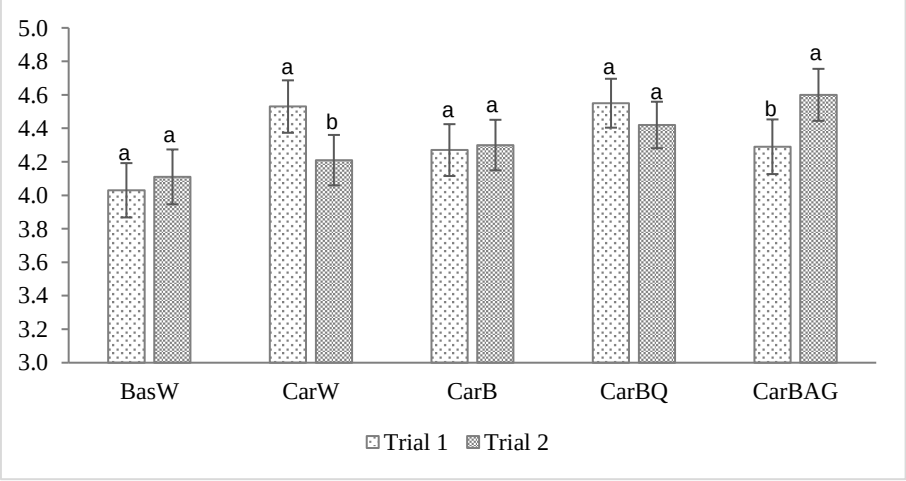
evaluated significantly less, except for CarW. The two samples with white rice had an emotional dimension score statistically identical to the General and Physical dimensions, unlike the remaining samples, in which the Emotional dimension was significantly smaller than the General and Physical dimensions.

Table VI. Evaluation of wellbeing dimensions for each sample in two different tests conditions (n=82).

	Trial 1 - Without information					Trial 2 - With information				
Dimension (Cronbach α)	**BasW**	**CarW**	**CarB**	**CarBQ**	**CarBAG**	**BasW**	**CarW**	**CarB**	**CarBQ**	**CarBAG**
General (0.88)	$4.3^{a, A} \pm 0.2$	$4.9^{a, A} \pm 0.2$	$4.6^{a, A} \pm 0.2$	$5.0^{a; A} \pm 0.2$	$4.6^{a, B} \pm 0.2$	$4.4^{a; A} \pm 0.2$	$4.6^{a, A} \pm 0.2$	$4.7^{a, B} \pm 0.2$	$4.9^{a, B} \pm 0.2$	$5.0^{a, A} \pm 0.2$
Physical (0.95)	$4.5^{c, A} \pm 0.2$	$4.9^{b, A} \pm 0.2$	$5.0^{a, b, A} \pm 0.2$	$5.4^{a, A} \pm 0.1$	$5.1^{a, b, A} * \pm 0.2$	$4.6^{b, A} \pm 0.2$	$4.6^{b, A} \pm 0.2$	$5.2^{a, A} \pm 0.2$	$5.4^{a, A} \pm 0.1$	$5.4^{a, A} * \pm 0.1$
Emotional (0.90)	$4.3^{b; A} \pm 0.2$	$5.1^{a, A} * \pm 0.2$	$4.3^{b, B} \pm 0.2$	$4.6^{b, B} \pm 0.2$	$4.2^{b, C} * \pm 0.2$	$4.3^{a, A} \pm 0.2$	$4.7^{a, A} * \pm 0.2$	$4.1^{a, C} \pm 0.2$	$4.4^{a, C} \pm 0.2$	$4.6^{a, B} * \pm 0.2$
Social (0.89)	$3.6^{b, B} \pm 0.2$	$4.2^{a, B} \pm 0.2$	$3.6^{b, C} \pm 0.2$	$3.9^{a, b, C} \pm 0.2$	$3.6^{b, D} * \pm 0.2$	$3.8^{a, B} \pm 0.2$	$3.9^{a, B} \pm 0.2$	$3.6^{a, D} \pm 0.2$	$3.6^{a, D} \pm 0.2$	$3.9^{a, C} * \pm 0.2$
Spiritual (0.94)	$3.5^{a, B} \pm 0.2$	$3.9^{a, C} \pm 0.2$	$3.7^{a, C} \pm 0.2$	$3.9^{a, C} \pm 0.2$	$3.8^{a, D} \pm 0.2$	$3.5^{a, B} \pm 0.2$	$3.5^{a, C} \pm 0.2$	$3.6^{a, D} \pm 0.2$	$3.7^{a, D} \pm 0.2$	$4.0^{a, C} \pm 0.2$

$^{a, b, c}$ values (row) significantly different according to non-parametric Kruskal-Wallis's test ($p < 0.05$).
$^{A, B, C, D,}$ Average values (Column) significantly different according to non-parametric Friedman test with pairwise comparison ($p < 0.05$).
* Significantly differences between the Trial 1 and Trial 2 according to the non-parametric Wilcoxon test ($p < 0.05$).

Figure 5 presents the overall well-being perception of each RTE-rice sample according to product information prior to consumption. Only the overall well-being perception of the CarW and CarBAG samples was influenced by the awareness of the product information (rice variety and ingredients). CarW had a significantly higher perception of well-being in the non-informed trial, whereas CarBAG had the opposite effect.



$^{a, b}$ values differed significantly according to the non-parametric Wilcoxon test ($p < 0.05$).

Figure 5. The overall wellbeing perception of each ready-to-eat rice sample between tests.

In the blinded test, the samples differed in the Physical, Emotional, and Social well-being dimensions (Table VI). CarW was perceived as having more emotional and

social well-being, and the Physical dimension was perceived as significantly lower in the BasW sample. After introducing this information, differences were only found in evaluating the Physical dimensions between samples, in which CarB, CarBQ, and CarBAG stood out among the white rice samples.

A comparison of the scores of the well-being dimensions between the trials revealed significant differences in the perceptions of Physical, Emotional, and Social well-being for the CarW, CarB, and CarBAG samples (Table VI). This information benefited the CarBAG sample because it was perceived as having significantly greater physical, emotional, and social well-being than the blinded trial. In contrast, it decreased the perception of emotional well-being in the CarW sample.

4. Discussion

This study evaluated the overall liking and sensory profile of RTE-rice samples and analysed the effect of information on liking and consumers' perceived well-being. These tasks involved tasting samples under blinded and informed conditions (rice type/variety and ingredient information).

The CATA analysis identified many significant attributes, differentiating the rice samples, showing that these consumers could characterise them and that their preferences were evident about this food category. This can be explained by the fact that Portuguese consumers have a long-time experience with rice, reinforcing the dimension of consumer expertise provided by familiarity. Indeed, greater familiarity with a product has been associated with a greater understanding of its attributes, translating into more conscious sensory evaluations (Banović et al., 2012; Alba and Hutchinson, 1987).

The rice type/variety and ingredient information did not affect the overall liking scores of the RTE-rice samples. Asioli et al. (2018) found that the effect of information may depend on the product categories and type of information provided. This implies that information and sensory descriptions may have no/positive/adverse effects on certain products (Imm et al., 2012; Ng et al., 2013; Oliveira et al., 2017). Nevertheless, there is evidence that expectation-based cognitive inputs, which can be created, for example, by label information, combined with chemosensory information, exert a significant influence on liking perception (Shankar et al., 2009; Suzuki and Park, 2018; Wilcox et al., 2011). According to Taylor's mobilisation-minimisation theory (1991), when an experience is very negative, it arouses stronger responses and stimulates more cognitive analysis than neutral or positive events. Based on these precepts, one can hypothesise that the information may not have had an effect because, in general, the rice samples were pleasant for the assessors, and the information introduced was not strong enough to

exert a significant effect on the perception of liking. Furthermore, all samples in both tests had positive overall liking scores (with mean values varying between 6.6 - 7.7, on a 9-point scale), particularly if one considers we are evaluating a staple food and not an indulgent one, where higher mean liking scores may be expected. Additionally, if one compares with evaluating a fermented rice-based drink by Portuguese consumers (Castanho et al., 2023), where a mean overall liking score of 4.7 was reached, the positive evaluation of the rice samples is precise. Alternatively, one may suspect that the information provided to the assessors did not add to the expectations generated by the visual cues of the product's appearance, mainly as the information had no direct reference to hedonic/sensory attributes.

The samples significantly influenced overall liking, with the plain *Carolino* rice sample (CarW) being the most appreciated in both tests. Although there is a decrease in the consumption of *Carolino* rice in Portugal (GPP, 2019), it is confirmed that the reasons are not due to flavour questions but due to a lack of product convenience and consumers' cooking skills (Cabral et al., 2024). In this sample, the attributes of onion odour, typical odour, and loose grains stood out, bringing the product closer to homemade rice. Previous studies found that consumers prefer RTE-rice as close as possible to conventional rice (Cabral et al., 2024; Antúnez et al., 2019), which also occurs for other ready-to-eat categories (Peura-Kapanen et al., 2017).

This study showed distinct variations in the well-being of each sample across trials. Taste is often associated with intuitive thoughts, whereas vision and hearing, which gather external hints, are more closely related to rational thinking (Neisser, 1994). This may be why the information did not impact liking but rather influenced the perception of well-being.

In the blinded test, the CarW sample provided a significantly better perception of emotional well-being than the other, demonstrating a positive relationship between the perception of emotional well-being and overall liking scores. These findings are consistent with those of other studies that have found that emotional evaluation provides additional information for the overall evaluation of taste (Cardello et al., 2012; Gutjar et al., 2015; King et al., 2013; Reis et al., 2017).

When information was introduced, the CarW sample showed a decreased perception of total well-being. In this case, it is believed that CarW's higher liking scores promoted largely positive perceptions. However, when consumers consciously assessed the functional properties of the ingredients in each recipe, they reported significantly lower well-being.

The information increased the respondents' focus on well-being evaluation, emphasising the differences between the white and brown rice samples. This shows that rice type/variety and ingredient information reflected the benefits each sample brought to the consumer, making the assessment less spontaneous and more cognitive. Although brown rice is often associated with unappealing sensory attributes (Adebamowo et al., 2017), its beneficial health properties have been highlighted. Participants showed that they were aware of these benefits and assigned higher scores for the Physical well-being.

Information had a more significant impact on the CarBAG sample, in which scores were significantly higher for the Physical, Emotional, and Social dimensions on the informed test than on the blind test, in contrast to their lower acceptance. King et al. (2015) stated that well-being is not always related to product liking because they found that the variation in the perception of well-being according to the characteristics of the products occurred, both when there was a difference in liking and when the overall liking scores were similar between the products.

The significantly better perceived Physical well-being of the CarBAG sample in the informed test confirmed consumer awareness of its ingredients and their impact on health. It was concluded that this sample was perceived as healthier, as there is a positive relationship between healthiness and the perception of well-being (Ares et al., 2015; Ares et al., 2018). For instance, information regarding the presence of healthy ingredients in probiotic dairy products has been found to positively affect the perception of healthiness (Oliveira et al., 2017).

When participants made a more cognitive assessment of their perception of well-being (informed trial), a negative relationship between hedonic perception and well-being perception was verified. This was contrary to the findings of Kuznesof et al. (2012) and Mora et al. (2020), who reported a positive association between liking scores and perceived well-being.

Despite the valuable insights provided by this study, the number of participants was limited, owing to the high dropout rate from the first to the second trial. Methodologically, we did not recruit additional participants who had not participated in the first test (Trial 1) to avoid including additional sources of individual variability.

5. Conclusions

These results allow us to understand the critical drivers of liking and well-being for a set of RTE-rice samples. It also shows that information enlightened consumers about the functional benefits of the ingredients in the samples, positively impacting their

perceptions of emotional, social, and physical well-being. Furthermore, the perception of well-being differentiated the samples based on their characteristics, even when there were no significant differences regarding the overall liking scores. This suggests that well-being measurements can provide additional insights into consumer preferences, thereby offering a more comprehensive understanding of food choices beyond liking.

The study also found that brown rice, seeds, and other whole grains positively influenced well-being perception. As these products presented positive overall liking scores, they could contribute to increasing brown rice consumption and promoting Portuguese rice consumption. Marketing promotion techniques can be used to increase familiarity with such products, reducing the glycaemic index of rice-based meals.

These findings provide valuable insights for developing and optimising healthier rice-based food products that meet consumers' demands.

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3.4. Paper IV – Evaluation of the trade-off between variety, processing, and low-GI claim in ready-to-eat rice

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Evaluation of the trade-off between variety, processing, and low-GI claim in ready-to-eat rice.

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Keywords:	Acceptance, Consumer studies, Food packaging, Sensory properties
Abstract:	An increasing number of consumers demand healthier, more convenient, and sustainable food products, including rice, a staple worldwide. Food manufacturers have responded to this trend by considering food's intrinsic and extrinsic aspects. This study evaluated the importance of variety, processing, and claims on willingness to try ready-to-eat rice (RTE-rice). It also analyses the influence of consumer attitudes on the importance of attributes and willingness to try. The results showed that processing significantly influenced willingness to try RTE rice, revealing consumers' greater preference for whole grain than milled rice with added bran. Claims had the least relevant importance. However, " low-GI " had a positive impact, indicating its potential to influence consumer purchasing attitudes and promote healthier rice consumption. Additionally, three groups were created based on attitudinal factors.

	Naturalness-oriented and convenience-oriented groups were more likely to try ready-to-eat rice. However, the reasons that motivate them may be different; this latter could be the ease of the service offered, while for the group focused on naturalness, they may have perceived through the ingredients and claimed that the product, despite being convenient, can bring benefits, thus perceiving them as natural.

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Evaluation of the trade-off between variety, processing, and low-GI claim in ready-to-eat rice.

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ABSTRACT

An increasing number of consumers demand healthier, more convenient, and sustainable food products, including rice, a staple worldwide. Food manufacturers have responded to this trend by considering food's intrinsic and extrinsic aspects. This study evaluated the importance of variety, processing, and claims on willingness to try ready-to-eat rice (RTE-rice). It also analyses the influence of consumer attitudes on the importance of attributes and willingness to try. The results showed that processing significantly influenced willingness to try RTE rice, revealing consumers' greater preference for whole grain than milled rice with added bran. Claims had the least relevant importance. However, " low-GI " had a positive impact, indicating its potential to influence consumer purchasing attitudes and promote healthier rice consumption. Additionally, three groups were created based on attitudinal factors. Naturalness-oriented and convenience-oriented groups were more likely to try ready-to-eat rice. However, the reasons that motivate them may be different; this latter could be the ease of the service offered, while for the group focused on naturalness, they may have perceived through the ingredients and claimed that the product, despite being convenient, can bring benefits, thus perceiving them as natural.

Keywords: rice, ready-to-eat, Low-GI claim, bran, naturalness, wellbeing, convenience.

INTRODUCTION

Rice is one of the most important staple foods in the world (Worldatlas, 2019), and is consumed mostly in milled form (white rice) which is richer in starch and poorer in other nutrients such as protein, fibre, vitamins, mineral salts, and phytochemical components than its whole grain counterpart (Mir et al., 2020). Rice provides

approximately 25% of the world's daily calorie needs and has been considered as a solution to eradicate hunger in resource-limited countries (Yadav and Kumar, 2018). It is an excellent vector for micronutrient fortification (Dipti et al., 2012) and has been vital in fighting malnutrition. In addition to its role in food security, rice is considered one of the most strategic commodities because of its low price, high yield, and support to the subsistence of many families in rural areas of developing countries (Yadav and Kumar, 2018). However, the most common form of consumption, white rice, has been linked to various chronic diseases, such as type 2 diabetes, obesity, and other metabolic syndromes, owing to its high glycaemic index (Yu et al., 2022; Bhavadharini et al., 2020; Golozar et al., 2017; Liu et al., 2022; Saneei et al., 2017; Seah et al., 2019).

Recent years have seen nutritional challenges due to excessive consumption fuelled by sociodemographic and lifestyle changes (Dipti et al., 2012). Changes in the human social environment, disposable income, and food supply and demand have altered eating patterns, whereby consumers turn to more convenient products to cope with a faster-paced lifestyle (Buckley et al., 2007). The main challenges to society's eating patterns are deeply intertwined with the loss of skills in preparing meals from scratch. This skill is influenced by cultural, social, familial, professional, and educational situations (Lavelle et al., 2016). Busier lifestyles, long working hours, and multiple commitments leave less time to cook from scratch, so there is an appreciation for ready-made or quickly prepared food. These changes reduce the need for culinary skills and decrease their transmission of culinary skills. Thus, the population has been losing the necessary skills to prepare meals from scratch (Worsley et al., 2015), leaving aside healthy food (Reipurth et al., 2019).

In addition to the importance of health and convenience in food choices, there has been a growing awareness of food waste and its environmental impacts (Griffen, 2020; FAO, 2022; Bisoffi et al., 2021; Alsaffar, 2016), including the origin of raw materials (Gonçalves and Maximo, 2023; Lucarini et al., 2020). Incorporating by-products as ingredients and using local products are strategies to achieve this goal (Jurgilevich et al., 2016).

To overcome these issues, industries and researchers are focusing on healthier, more convenient, and sustainable diets (Hassoun et al., 2022; Bisoffi et al., 2021). The combination of convenience and health has been considered incompatible for many years because of the negative perceptions of the effects of processed foods on health (Rogus, 2018; Lavelle et al., 2016; Peura-Kapanen et al., 2017). The EAT-Lancet Commission has reinforced that convenient and healthy products must be available for staple foods such as rice, to help with everyday life without harming consumer health

(Willett et al., 2019). To achieve more sustainable products, food manufacturers must consider the origin of raw materials (Gonçalves and Maximo, 2023; Lucarini et al., 2020), the incorporation of by-products as ingredients, and the use of local products (Jurgilevich et al., 2016).

In this study, we evaluated the willingness to try ready-to-eat rice products, considering variety, processing, and label claims as attributes for designing healthy and convenient rice products. In addition, we explored the relationship between the importance of attributes and consumer attitudes.

Brown rice and milled rice supplemented with bran, both rich in dietary fibre, were used as the processing attributes. Fibers play an essential role in reducing the glycaemic response of rice (Chiu et al., 2011; Nakamura et al., 2022; Augustin et al., 2015). Brown rice is obtained by dehusking while maintaining the bran, while milled rice loses bran, germ, and nutritional value due to the milling process. Brown rice is less popular because of its texture, colour, flavour, and longer cooking time (Gondal et al., 2021; Zhou et al., 2019), however, it is a healthier alternative to milled rice.

Rice bran, a by-product that accounts for 5-10% of paddy rice weight, is rich in nutrients such as protein, fat, dietary fibre, minerals (potassium, calcium, magnesium, and phosphorus), and bioactive components (tocopherols, tocotrienols, and γ-oryzanol) (Castanho et al., 2019; Wang et al., 2023; Saji et al., 2019). These compounds possess antioxidant, anti-inflammatory, hypocholesterolaemia, antidiabetic, and anticancer properties (Sohail et al., 2017; Tan et al., 2023). Due to its nutraceutical properties, rice bran has potential applications in the pharmaceutical and food industries, including the development of cooking oils, food colouring, edible coatings, and bakery products (Tan et al., 2023; Yadav et al., 2021; Bodie et al., 2019).

Informative labelling, such as the health benefits of food products, can significantly influence consumers' food choices (Jindahra and Phumpradab, 2023; Ballco et al., 2020; Hallez et al., 2023). Since 1998, WHO and FAO have recommended using GI as a valuable indicator for choosing a healthy diet. They advise consumers to opt for foods rich in non-starch polysaccharides and low in GI (FAO/WHO, 1998). High-GI diets have been linked to an increased risk of developing chronic non-communicable diseases, and some countries have addressed this issue in their health policies (Barclay et al., 2021).

MATERIAL AND METHODS

Participants

Sampling was selected based on the age and sex quota, with the following inclusion criteria: i) being Portuguese, ii) consuming rice at least three times per week, and iii) being responsible or sharing responsibility for grocery shopping and preparing meals. Participants were recruited from the sensory evaluation company, Sense Test's consumer database (Vila Nova de Gaia, Portugal). They were mainly residents of the Porto metropolitan area in northern Portugal.

All participants provided informed consent before participating, which was approved by the Ethical Committee of the *Faculdade de Ciências da Universidade do Porto* (reference number 50/2023). This work was undertaken with the support of the Sense Test Company, ensuring the protection and confidentiality of data through the authorisation 2063/2009 of the National Data Protection Commission. Internal conduct, following the General Data Protection Regulation standards and implementing informed consent was accomplished. All the participants received a small amount of financial compensation for their participation.

Experimental design

A structured questionnaire was administered using the Lime Survey software, which comprised five sections: conjoint task, perception of well-being related to rice choice, the importance of naturalness and convenience in rice choice, and sociodemographic characteristics. The questionnaire was completed in person using a computer provided by the recruitment company. This study identified eight different combinations of ready-to-eat rice, based on three attributes: variety, processing, and claims. These attributes and their levels were determined using inputs from previous studies on rice consumption, perception of brown rice, and expectations of low-GI rice products (Cabral et al., 2024a).

Table 1. Selected profiles created by combining different levels of the attributes: variety, processing, and claims.

	Variety		**Processing**		**Claim**	
Profile #	**Carolino**	**Basmati**	**Brown**	**milled + bran**	**Low-GI**	**Source of fibre**
profile 1	No	Yes	No	Yes	Yes	No
profile 2	Yes	No	No	Yes	Yes	No
profile 3	No	Yes	No	Yes	No	Yes
profile 4	Yes	No	No	Yes	No	Yes
profile 5	No	Yes	Yes	No	Yes	No
profile 6	Yes	No	Yes	No	Yes	No
profile 7	No	Yes	Yes	No	No	Yes
profile 8	Yes	No	Yes	No	No	Yes

Basmati and Carolino rice varieties comprise the levels of the variety attribute. Basmati rice, which has a low GI (Atkinson et al., 2021), has gained popularity among Portuguese consumers, while Carolino rice, the local rice, has experienced a decline in consumption (Castanho et al., 2023; Cabral et al., 2024a). Brown rice and milled rice supplemented with bran, both high in dietary fibre, were used for processing. Claims play a crucial role in informing consumers about the intrinsic properties of food. Two levels of claims were utilised: the source of the fibre and the low-GI.

All attributes were integrated as text and symbols in mock-up package images. Eight digital cards with packaging images were designed using Adobe Photoshop® software 2022 v. 24.7.1 (Figure 1).

Figure 1. Examples of the cards (in Portuguese) used in the conjoint analysis exercise, corresponding to profile #4 (left) and profile #1 (right), as coded in Table 1.

Each card was coded with a three-digit random number presented to the participants, as depicted in Figure 2, and a sequential monadic presentation was implemented in balanced order (Macfie et al., 1989). The experiment commenced with a welcoming introduction and brief overview of the symbols and information displayed in the packaging of ready-to-eat rice to ensure a uniform understanding of the experimental attributes. Each aspect of the packaging was thoroughly explained to the participants. They were then asked to rate their willingness to try (WTT) the product on a 9-point scale ranging from 'extremely unwilling' to 'extremely willing'.

Figure 2. Photo illustration of the setup used for the conjoint task.

Attitudinal evaluation

Previous studies have shown that in addition to healthiness, convenience and naturalness are values consumers consider essential in a rice product with a healthier profile and label information (Cabral et al., 2024a). Therefore, the importance levels of these dimensions were measured using established measures. The importance of naturalness in choosing more often consumed rice was measured using a New Naturalness Scale (NNS) consisting of nine items (Michel and Siegrist, 2019). Seven items were selected from Convenience Food Lifestyle (CFLs) to evaluate consumer convenience orientation (Buckley et al., 2007). Twelve items of the well-being scale developed by Ares et al. (2016) were used to assess consumer perceptions of well-being with the rice they frequently choose. These items were selected based on the results of a previous study that evaluated the perception of well-being of different ready-to-eat rice varieties available in the Portuguese market (Cabral et al., 2024b). This study assessed the perception of well-being of five different ready-to-eat rice varieties, based on Carolino and Basmati varieties: whole, milled, or mixed with seeds and other cereals. Only the items perceived as significantly different among the different ready-to-eat rice samples in that study were considered.

Finally, questions were asked regarding self-rated health status, financial situation, residence location, and price influence on the quality choice. All measurements were rated on a 7-point anchored scale from 1 (strongly disagree) to 7 (strongly agree). Table 2 presents the items in each scale used in this study.

Table 2. Items of the attitudinal measurement scales used in the applied questionnaire.

Attitudinal measurement	Item
Well-being Scale (Ares et al., 2015)	It is good for wellbeing
	It makes me feel good
	It is good for my health
	It is nutritious
	It makes me feel satiated
	It helps me control my weight
	It keeps me fit
	It keeps me healthy
	It gives me energy
	It gives me pleasure
	It makes me feel satisfied
	It makes me feel happy
New Naturalness Scale (Michel & Siegrist, 2019)	I make sure to buy products that are preferably free from artificial ingredients.
	I avoid food that contains preservatives.
	I avoid food that contains additives.
	I avoid food that contains artificial colours and flavours.
	I am worried about residues from chemicals in food.
	I avoid food that is made from genetically modified plants.
	It is important to me that foods contain as many natural ingredients as possible.
	I avoid highly processed foods.
	I prefer unprocessed foods over processed foods.
Convenience food lifestyle (Buckley, Cowan & McCarthy, 2007)	We use a lot of ready-to-eat foods in our household
	I choose easy, quick-to-prepare food for weekend evening meals
	I choose easy, quick-to-prepare food for weekday evening meals
	Convenience foods allow me to have something that I wouldn't normally know how to cook
	I don't like spending too much time on cooking
	I love spending time in the kitchen preparing food (R)
	Preparing meals gives me a lot of satisfaction (R)

Data analysis

The participants' sociodemographic characteristics were summarised using descriptive statistics.

To identify which product attributes and levels most influence the willingness to try, conjoint analysis was performed to determine the part-worth utilities of the attribute level and the relative importance of attributes, using XL-STAT®, v. 2023.1.6 (Addinsoft, New York, NY, USA). The preferred level within each attribute and the most important attributes were identified.

A descriptive statistical analysis was conducted to summarise the sociodemographic variables and determine the mean WTT score for each ready-to-eat rice (RTE-rice) profile. Friedman's test was employed to evaluate differences in the importance of RTE rice attributes and assess differences in the WTT between the RTE rice profiles.

Exploratory factor analysis (EFA) was conducted for each attitude scale using principal component analysis with varimax rotation as the extraction method. Reliability was measured using Cronbach's alpha.

Hierarchical cluster analysis was applied to the factors that emerged from the EFA using the Ward method for agglomeration and square Euclidean distance as the similarity measure. A nonparametric Kruskal–Wallis's test and a pairwise comparison were used to compare the scores for each attitudinal factor between the formed clusters. Differences between the frequency distributions of sex, age, and education level by cluster were evaluated using the chi-square test. All statistical tests were performed at a 95% confidence level. Statistical analyses were performed using the IBM SPSS Statistics version 27.0.

RESULTS AND DISCUSSION

Participants' characterization

As shown in Table 3, the 106 participants recruited for the study had a mean age of 40 ± 12.8 years old (range, 19–64 years), with equal sex partitions spread across three age groups. Most participants had not completed higher education. Respondents self-reported good health status (5.7 ± 1.23) and financial situation (4.6 ± 1.21). As for sacrificing price for quality or vice versa, they were more inclined to sacrifice price in favour of quality (4.5 ± 1.51). Regarding place of residence, they reported living in a more urban area (2.2 ± 1.76).

Table 3. Characterization of the participants (n=106).

Characteristic	Absolute frequency	Relative frequency
Sex		
Female	54	50.20%
Male	52	49.80%
Age group (mean ±SD: 40.8 ±12.8 yr.)		
[19-34[	34	32.10%
[34-49[	40	37.70%
[49-64]	32	30.20%
Educational level		
No higher education	67	63.2%
Higher education	39	36.8%

[1] **Self-rated health status (mean ±SD)**

Characteristic		Absolute frequency	Relative frequency
	5.7 (± 1.23)	106	100.00%
[1] **Self-rated financial situations (mean ±SD)**			
	4.6 (± 1.21)	106	100.0%
[2] **Trade-off price vs. quality of product**			
	4.5 (± 1.51)	106	100.0%
[3] **Self-rated urbanisation level (mean ±SD)**			
	2.2 (± 1.76)	106	100.0%

[1] Rating by 7-point scale. It is used to measure self-rated health status (1 - not at all healthy to 7 - quite healthy) and financial situation (1 - difficult to 7 - quite good).

[2] Indicate how your food expenses are influenced by the cost of products: 1 - price to the detriment of quality to 7 - quality to the detriment of price.

[3] Rating by 7-point scale: 1- urban zone to 7- rural zone.

Conjoint analysis

A recent study on rice consumption habits showed that although Portuguese consumers consider using RTE-rice, they establish a series of criteria, such as sensory aspects, naturalness, and the perception of healthiness (Cabral et al., 2024a). The same study demonstrated that these consumers vary between rice varieties depending on convenience, type of dish, and occasion and that the choice of brown rice is reduced mainly because of the kernel texture. They also demonstrated the importance of information when choosing healthier rice options.

Consumers scored their willingness to try (WTT) ready-to-eat rice as positive, with mean scores varying between 6.1 and 6.9, on a 9-point scale ranging from 1 - 'extremely unwilling' to 9 - 'extremely willing'. Significantly lower scores in the WTT for RTE-rice made with milled *Carolino* rice with the addition of bran, independently of the claims: "Source of fibre" or "Low GI" (Figure 3).

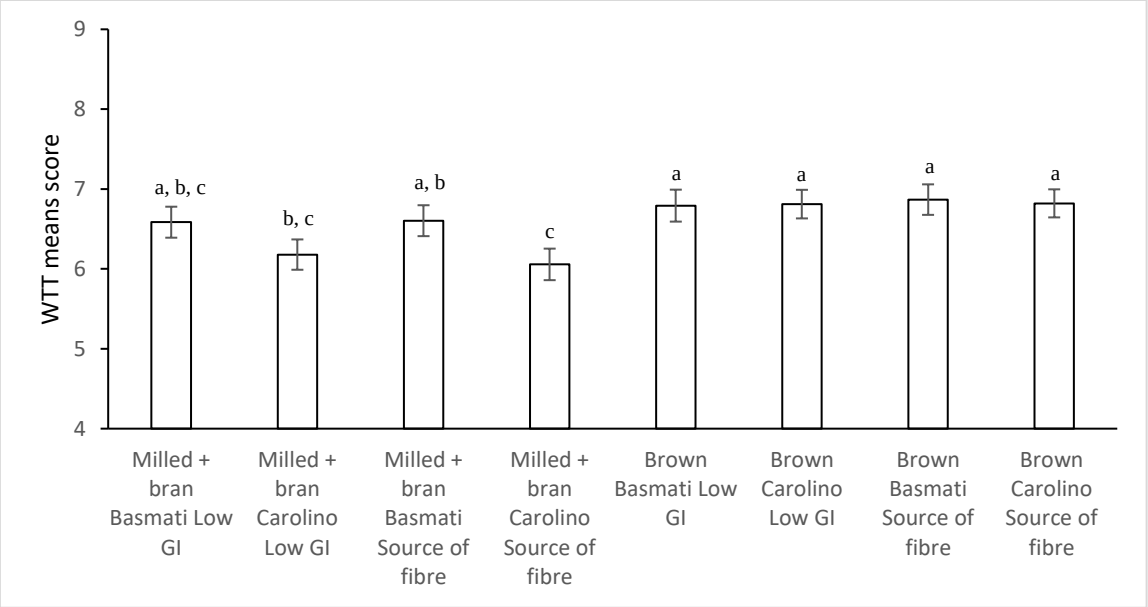

Figure 3. Willingness to try (WTT) means scores (± standard error) for each ready-to-eat rice profile.

[a, b, c] - Significant groups according to the Wilcoxon test, with a significance level of < 0.05

To create eight hypothetical ready-to-eat rice varieties with lower GI, brown rice was used as a base, as it naturally has a lower GI due to the presence of bran, which is commonly removed during milling (Kabir et al., 2021). Adding bran to milled rice improved the nutritional value and GI without changing the texture, a critical factor in rice selection, and the rejection of brown rice (Suwannaporn and Linnemann, 2008). The addition of bran provides nutritional components such as lipids, proteins, dietary fibre, γ-oryzanol, and phytochemical components (Tan et al., 2023), which are associated with a reduced risk of chronic diseases, including cancer (Henderson et al., 2012; Moon and Shibamoto, 2009), lower cholesterol levels (Saji et al., 2019; Zavoshy et al., 2012), and type II diabetes (Mahdavi-Roshan et al., 2021; Cheng et al., 2010). Using bran, typically discarded as waste or used in animal feeds, will reduce waste in the rice processing industry.

Processing and variety attributes had a significantly more significant impact on WTT RTE-rice than claims (Table 4). Based on the part-worth utility value, participants were more WTT RTE-rice with the following attribute levels: brown (0.233), Basmati variety (0.123), and low GI (0.002). The product comprised of the brown basmati variety and with the low-GI claim showed positive part-worth utilities, indicating that these levels (basmati and brown) increased consumers' intent to try more than milled Carolino with added bran (Table 4). Claims were less critical, as reported in other joint studies (Rebouças et al., 2021; Carneiro et al., 2005). Although the "claim" attribute showed to

be less important (Table 4), it still had an impact on consumer preference, as demonstrated in other studies (Rebouças et al., 2019; Jindahra and Phumpradab, 2023); "Low GI" claims had a more positive effect than "Source of fibre". The two levels of the claim reflect the benefits associated with the product's healthiness; however, they may not have been highly valued because of the food matrices of the products. Studies have found that claims are better accepted for products that are already considered healthy or perceived naturally with the benefits claimed (Ares and Gámbaro, 2007; van Kleef et al., 2005). Therefore, the fibre in the samples would be the most natural; however, the mention of "low-GI" had a more positive effect, contradicting these studies.

Brown rice was found to have higher part-worth utilities than milled rice with the addition of bran, despite previous studies showing a high rejection of this type of rice (Cabral et al., 2024a). The same study also confirmed that consumers buy brown rice because it is more nutritious, healthier, and natural than milled rice. Another reason for the preference for brown over milled rice may be the addition of bran, which is an unfamiliar ingredient, as new forms of processing can generate repulsion among consumers, as verified by other studies (Giordano et al., 2018).

Table 4. Part-worth utilities and importance for the different attributes of RTE-rice.

Attribute	Level	Part-worth utilities	Mean importance (± Std. Error)	Relative importance
Processing	Brown	0.233	9.7 [a] ± 0.72	42%
	milled + bran	-0.233		
Variety	Basmati	0.123	8.2 [a] ± 0.64	36%
	Carolino	-0.123		
Claim	Low-GI	0.002	4.9 [b] ± 0.47	22%
	Source of fibre	-0.002		

Friedman' test (two-way ANOVA by ranks as post hoc), with a 95% confidence level. [a, b] $p<0.05$

Regarding the claims, "low-GI" had higher part-worth utility than nutritional claims related to fibre, despite this already being a claim used in the European market established by Regulation (EC) No 1924/2006 of the European Parliament and Council. This result contrasts with that of Lähteenmäki (2013), who found that familiarity with a claim positively influences product acceptance. This demonstrates that consumers are interested in and aware of GI's role in healthier diet choices. Experts in the field have discussed the importance of GI labelling (Chiu et al., 2011; Barclay et al., 2021; Augustin et al., 2015; Wolever, 2013). Although there is no comprehensive regulation for all regions, there seems to be a consensus among competent authorities that low-GI foods

and diets generally benefit people with diabetes and impaired glucose metabolism (Zafar et al., 2019; Yu et al., 2022). Food Standards Australia New Zealand provides voluntary guidelines for labelling the GI of food products (GIF, 2022) and has seen significant improvements in GI in the population after its implementation (Yeung et al., 2018). Another example of the application of food GI as an effective tool to control metabolic syndrome is commercial meal-type food for diabetes in South Korea, which the Korean Food and Drug Administration regulates (Lee et al., 2024).

Consumer attitudes toward rice

The EFA was performed on the psychometric scales administered: the well-being scale, NNS, and CFLs. All scales had a KMO > 0.70 and a significant Bartlett's Test of Sphericity (< 0.001), which demonstrates high correlations between the items that make up each of the factors (Hair et al., 1999).

Table 5 presents the reliability measures of all scale factors with the respective means and standard errors for each item. Cronbach's alpha revealed very good internal consistency among the factors (Hair et al., 1999).

Table 5. Factors resulting from the EFA to the items of scale measures (wellbeing, new naturalness scale, food-related lifestyle).

Factor (α-Cronbach)	Items	Mean (± std. Error)
Emotional (0.898)		**5.5 ± 0.04**
	It gives me pleasure	5.4 ± 0.13
	It makes me feel happy	5.2 ± 0.14
	It makes me feel good	5.6 ± 0.11
	It makes me feel satisfied	5.8 ± 0.12
Physical (0.882)		**5.2 ± 0.04**
	It helps me control my weight	4.6 ± 0.15
	It is good for my health	5.5 ± 0.12
	It keeps me healthy	5.4 ± 0.12
	It keeps me fit	4.9 ± 0.14
General and nutritional (0.872)		**5.6 ± 0.03**
	It is nutritious	5.6 ± 0.12
	It gives me energy	5.6 ± 0.12
	It is good for wellbeing	5.4 ± 0.12
	It makes me feel satiated	5.8 ± 0.10
New Naturalness Scale (0.938)		**5.5 ± 0.04**
	I make sure to buy products that are preferably free from artificial ingredients	5.4 ± 0.16
	I avoid food that contains preservatives	5.3 ± 0.15
	I avoid food that contains additives	5.3 ± 0.16
	I avoid food that contains artificial colours and Flavours	5.7 ± 0.15
	I am worried about residues from chemicals in food	5.8 ± 0.15
	I avoid food that is made from genetically modified plants	4.8 ± 0.18
	It is important to me that foods contain as many natural ingredients as possible	6.0 ± 0.14
	I avoid highly processed foods	5.5 ± 0.15
	I prefer unprocessed foods over processed foods	6.1 ± 0.13
Convenience food choice (0.753)		**4.0 ± 0.05**

Factor (α-Cronbach)	Items	Mean (± std. Error)
	We use a lot of ready-to-eat foods in our household	3.5 ± 0.17
	I choose easy, quick-to-prepare food for weekend evening meals	3.8 ± 0.19
	I choose easy, quick-to-prepare food for weekday evening meals	4.9 ± 0.18
Convenience in meal preparation and cooking (0.813)		**3.2 ± 0.06**
	Convenience foods allow me to have something that I wouldn't normally know how to cook	4.0 ± 0.18
	I don't like spending too much time on cooking	3.7 ± 0.20
	I love spending time in the kitchen preparing food	3.3 ± 0.19
	Preparing meals gives me a lot of satisfaction	2.6 ± 0.17

The EFA divided the well-being items into three factors by mixing the original items from the general well-being factor with the physical well-being items. The physical well-being items separated the more nutritional items from the physiological ones, forming the "Physical" and "General and nutritional" factors. The latter includes the item "It is good for well-being, " originally belonging to the general factor. The item "It makes me feel good" originally belonged to the general dimension loaded with emotional factors. This item showed a high correlation with the emotional dimension in seven countries in a cross-cultural study on differences in the perception of well-being in the food-related context (Ares et al., 2016).

The factorial structures of the NNS items and CFLs were similar to those reported in the original publications (Michel and Siegrist, 2019; Buckley et al., 2007, respectively). The first CFL factor corresponds to the convenience of food choice (CFC) items, and the second factor corresponds to the convenience of meal preparation and cooking (CMPC) items, both of which have a very high reliability (Cronbach's alpha > 0.75).

Cluster analysis enabled the identification of a pattern of attitudes by applying the six factors originating from exploratory factor analysis. This analysis revealed three distinct groups that exhibited significant differences. The first cluster accorded greater importance to well-being factors and the lowest importance to convenience factors, thereby earning it a well-being-oriented designation. Conversely, the second cluster, which emphasised convenience in meal preparation and cooking factors and had the lowest naturalness importance, was labelled as convenience-oriented. The third cluster attributed greater importance to naturalness; hence, it was labelled as naturalness-oriented. Table 6 lists the characteristics of each cluster.

Table 6. Socio-demographic and attitudinal characterisation of the clusters of participants.

Consumer characteristics	Wellbeing-oriented (n = 64)	Convenience-oriented (n = 31)	Naturalness-oriented (n = 11)	P-value
Sex (%)				ns*
Male	61.5	32.7	5.8	ns
Female	59.3	25.9	14.8	ns
Mean age (years) ± SE	43.7 ± 1.58	34.5 ± 1.99	41.4 ± 0.641	< 0.001
Age group (%)				< 0.001 *
[19-34[years	41 (-)	53 (+)	6	
[34-49[years	58	28	14	
[49-64] years	84 (+)	6 (-)	10	
Education level (%)				< 0.01 *
Higher education	41 (-)	44 (+)	15	
No higher education	72 (+)	21 (-)	7	
Self-rated health status (mean ±SE)	5.7 ^{b} ± 0.05	5.3 ^{c} ± 0.08	6.4 ^{a} ± 0.05	< 0.001
Self-rated financial situation (mean ±SE)	4.5 ^{b} ± 0.06	4.6 ^{b} ± 0.07	5.1 ^{a} ± 0.10	< 0.001
Trade-off price vs. quality of product (mean ±SE)	4.6 ^{a} ± 0.07	4.0 ^{b} ± 0.09	4.8 ^{a} ± 0.12	< 0.001
Self-rated urbanisation level (mean ±SD)	2.3 ^{a} ± 0.08	2.0 ^{a} ± 0.09	2.5 ^{a} ± 0.24	ns
Emotional	6.1 ^{a} ± 0.10	4.8 ^{b} ± 0.20	4.2 ^{c} ± 0.27	< 0.001
Physical	5.8 ^{a} ± 0.10	4.5 ^{b} ± 0.17	3.8 ^{c} ± 0.30	< 0.001
General and nutritional	6.0 ^{a} ± 0.08	5.0 ^{b} ± 0.18	4.6 ^{c} ± 0.31	< 0.001
Convenience food choice	3.8 ^{c} ± 0.18	4.1 ^{b} ± 0.20	5.3 ^{a} ± 0.29	< 0.01
Convenience in meal prep and cooking	2.3 ^{c} ± 0.14	4.8 ^{a} ± 0.25	3.8 ^{b} ± 0.37	< 0.001
Naturalness	6.1 ^{a} ± 0.09	4.1 ^{b} ± 0.22	6.3 ^{a} ± 0.17	< 0.001

a, b Homogeneous group according to the nonparametric test of Kruskal–Wallis with 5% significance level and the pairwise comparison post hoc test.

* χ^2 test per cell with a significance level of 0.05. (+) or (-) indicate that the observed value is significantly higher or lower than the expected value.

ns – no significant

Older participants were significantly more inclined toward well-being, whereas younger participants displayed a greater propensity for convenience in prep and cooking. Older consumers are more likely to choose food based on health considerations (Chambers et al., 2008). This corroborates other studies that found that younger consumers did not prepare food from scratch (Mantzari et al., 2020); therefore, they are more open to RTE. The naturalness-orientation group reported significantly better health and financial status, while the convenience-oriented group reported significantly worse health status. Well-being-oriented and naturalness-oriented groups place considerably more importance on quality than price than convenience-oriented consumers.

Association between product attributes, acceptability, and consumer characteristic

Consumers inclined toward convenience and naturalness were more willing to try ready-to-eat rice than those oriented toward well-being. Naturalness-oriented consumers valued the claimed attribute significantly more and significantly less variety attribute (Table 7).

Table 7. Average (± SE) willingness to try, importance and its part-worth utility levels for each attribute according to the cluster grouping based on participants' attitudes.

Attribute level	Wellbeing-oriented (n = 64)	Convenience-oriented (n = 31)	Naturalness-oriented (n = 11)	P-value
Willing to try	6.3 ^{b} ± 0.14	6.7 ^{a} ±0.09	6.7 ^{a} ± 0.17	< 0.05
Processing importance	9.1 ± 0.84	10.9 ± 1.51	9.4 ± 2.49	ns
Brown	0.16 ^{b} ± 0.03	0.34 ^{a} ± 0.05	0.36 ^{a} ± 0.05	< 0.001
Milled + bran	- 0.16 ^{b} ± 0.04	- 0.34 ^{a} ± 0.06	- 0.36 ^{a} ± 0.06	< 0.001
Variety importance	8.8 ^{a} ± 0.80	7.6 ^{b} ± 1.20	6.6 ^{c} ± 2.11	< 0.001
Basmati	0.22 ^{a} ± 0.02	- 0.04 ^{b} ± 0.04	0.02 $^{a, b}$ ± 0.02	< 0.001
Carolino	- 0.22 ^{a} ± 0.02	0.04 ^{b} ± 0.04	- 0.02 $^{a, b}$ ± 0.02	< 0.001
Claim importance	5.0 ^{b} ± 0.49	4.1 ^{c} ± 1.09	6.9 ^{a} ± 1.80	< 0.001
Low-GI	0.03 ± 0.01	- 0.04 ± 0.01	- 0.02 ± 0.04	ns
Source of fibre	- 0.03 ± 0.01	0.04 ± 0.01	0.02 ± 0.04	ns

a, b Homogeneous group according to the nonparametric test of Kruskal–Wallis with 5% significance level and the pairwise comparison post hoc test. ns – not significant. The negative signals represent a negative impact on consumer intention to purchase.

The naturalness-oriented group valued convenience in the choice significantly more than the remaining groups and identified with better financial status and a preference for quality at the expense of price. This may indicate that this group perceived the products as natural and was willing to try a convenience product if it met naturalness requirements. This result confirms a change in consumer attitudes toward convenience products in

which convenience is no longer directly perceived as unhealthy or unnatural. Researchers have demonstrated that ready-to-eat foods can be designed to offer a balanced and healthy meal to support the eating habits of consumers who want or need the advantages of products within this range (Nakano and Washizu, 2020; Stranieri et al., 2017). There is a growing trend toward offering healthier, more sustainable, convenient foods such as naturally preserved fresh vegetables and fruits (Piracci et al., 2024).

Label claims were more important to naturalness-oriented consumers. This attribute, along with other cues, may have reinforced this group's interest in this product category, as they were also the most likely to try it. Label information encourages consumers to appropriately replace their culinary efforts with convenience foods (Nakano and Washizu, 2020).

The group with the lowest willingness to try ready-to-eat rice was the wellbeing-oriented group, which attributed less importance to convenience factors and more importance to well-being factors. For this group, it seemed that the fact that it was ready-to-eat was more critical in the decision than the ingredients that made up the product. This group was mainly composed of individuals with no higher education, which may have made it difficult to perceive the relationship between the varieties, the process, and the healthiness or benefits of the product. This group was also composed of significantly more people from the older age group, contradicting previous findings that the most likely niche for these products is older (Cabral et al., 2024a). This can be explained by the fact that older consumers are less open to unfamiliar foods (Tuorila et al., 2001) and desire convenience foods that are more similar to homemade foods (Peura-Kapanen et al., 2017), which was not the case for the product profiles evaluated, as the products corresponded to innovative proposals for the participants.

CONCLUSION

The present study provides initial insights into the perception of carbohydrate-rich foods with GI labelling in Portugal. Although the importance of the GI claim was not a significant factor, it nevertheless positively impacted consumers' willingness to try RTE-rice. These findings provide a better understanding of healthy, sustainable, and GI-claimed food products. These insights can inform policies promoting nutritious, sustainable, and convenient staple food consumption. Specifically, the results can help improve consumers’ perceptions of *Carolino* rice, which is essential for the sustainability of the Portuguese rice industry.

DECLARATION OF CONFLICTING INTERESTS

The authors declare there are no conflicts of interest.

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Chapter 4 – General discussion and conclusion

4.1. Discussion

This study has the broad objective of promoting healthier ways of consuming rice by evaluating consumer perception and the sensory profile of rice-based products with a low glycaemic index. To this end, a mixed methodology was applied using both direct (self-report measures, scaling questionnaires, and interviews) and indirect (free word association) methods.

Direct measures are useful from an analytical and controlled perspective but may introduce some bias due to people's tendency to provide socially desirable reasons for their food behaviours, which are often intuitive (Nisbett & Wilson, 1977). Indirect measures allow users to capture intuitive responses (Jaeger, Hort, et al., 2017). Therefore, the mixed methodology approach allows for the evaluation of the two decision-making systems described in the literature (Kahneman, 2003; Köster, 2009): a more controlled rational behaviour and a more intuitive, spontaneous, and emotional form. Thus, we follow the recommendations of authors such as Köster (2009) and Ares and Varela (2018), who suggest the use of indirect/ implicit measures to complement, compare, and cross-validate the results of direct/explicit measures.

The study began with an assessment of rice consumption habits and the conceptualization of low GI rice using a self-report questionnaire composed of the FWA and an assessment of rice consumption behaviour. FWA allowed us to evaluate the difference between the perception of rice and that of low GI rice (Paper I). A different result was obtained in terms of the values associated with each concept, which, combined with the assessment of consumption, made it possible to differentiate the four groups of consumers according to the frequency and type of rice. Consumer segmentation has many advantages in establishing market niches as well as outlining health or marketing policies (Camilleri, 2018). It is an important approach to dealing with individual differences between food consumers (Grunert, 2019). Segmentation criteria depend on the objective of the study; for example, segmentation based on the factors underlying consumer choices (Ares & Gámbaro, 2008; Cabral et al., 2017), type of diet practised (Cabral et al., 2019), food-related lifestyle (Brunsø et al., 2021), Convenience food lifestyle (Buckley et al., 2007), attitude toward sustainable food consumption (Gazdecki et al., 2021; Verain et al., 2021), healthy diet (Schäufele-Elbers & Janssen, 2023), and Nutrition Information Seeking (Wang et al., 2022).

For an effective intervention, it is necessary to know the consumption habits, understand the attitudes of consumers related to the topic, and identify the key points of intervention. Therefore, in-depth interviews were necessary to complete the questionnaires. Interviews are techniques that allow the study of the nature of phenomena and the context in which they appear, or the perspectives from which they can be perceived (Guion et al., 2011). Paraphrasing Busetto et al. (2020), qualitative designs are needed to discover reasons for observed patterns, especially the invisible or surprising ones. The interview has many advantages, and it has been used to explore new topics or topics that have been little studied, as is our case regarding consumers' perceptions, experiences, and attitudes towards rice and low GI rice. For example, Hoek et al. (2017) used this methodology to assess consumer perceptions and attitudes toward healthy and environmentally friendly foods; Wehling and Lusher (2019) used it to understand the nature, challenges, and coping strategies of food-related thinking styles within a healthy weight range compared to those who are either overweight or obese.

Next, consumers' sensory preferences for ready-to-eat rice were investigated. Sensory evaluation was conducted on ready-to-eat rice products available in the market to translate them into a product with a more balanced nutritional profile, which maintains an appealing sensory profile. Sensory factors are among the main reasons for cross-cultural consumption (Cunha et al., 2018). Furthermore, a product may even be healthy, but it may not be successful if the sensory profile fails to please consumers, because they are not willing to sacrifice the pleasure of sensory for health benefits (Ballco & Gracia, 2022). In our study, consumers reinforced the need for additional information as a prerequisite for purchasing new products, and we found that if there was a health problem, consumers would be willing to make this sacrifice, as has been reported in other studies (Carrete & Arroyo, 2014; Delaney & McCarthy, 2011).

In this context, consumers value both experiential characteristics, such as flavour, and utilitarian characteristics, such as healthiness, in their food decisions (Paper I, II). Healthiness represents consumers’ expectations and beliefs about the influence of a product on their state of health, fitness (Mai & Hoffmann, 2015) and general well-being (Bublitz et al., 2013), and has gained increasing importance in the minds of consumers (Rodrigues Arruda Pinto et al., 2020). These expectations explain the results of Paper III, in which the perception of well-being increased in some products when consumers had information about ingredients that holistically signalled healthiness. This corroborates Otterbring et al. (2020), who found that consumers who value health factors shift more attention to food options with health cues.

Studies have found that prompts, such as short messages and information about food benefits, can help consumers make healthier choices (Arslain et al., 2021; Gustafson et al., 2018), as information correcting inaccurate beliefs regarding nutrition makes consumers more willing to sacrifice their tastes for healthy foods (Jo et al., 2016). Some health claims may be so strong that consumers are willing to compromise their tastes in favour of health (Urala & Lähteenmäki, 2004); however, this depends on their consumption values.

Paper III shows that information enlightens consumers about the functional benefits of products, positively impacting their perceptions of emotional, social, and physical well-being. This finding implies that information can lead to more rational consumption.

Considering these facts, in addition to the fact that food choices are dictated by the extrinsic characteristics of food, conjoint analysis was used to evaluate the importance of attributes for choosing nutritionally more balanced RTE-rice profiles (Paper IV). Insights gleaned from previous tasks have indicated variety, processing, and information about benefits as important extrinsic attributes. RTE-rice concepts were designed considering the strategy of including staples foods in a healthier, sustainable, and consumer-friendly presentation, which are the main objectives outlined by the EAT-Lancet Commission for the transformation of food systems towards more sustainable nutrition (Willett et al., 2019, 2023).

To evaluate consumer attitudes, psychometric measures were considered based on insights from previous studies. Attitudes related to naturalness, convenience, and well-being perception of food were measured. One such tool is the Well-being Scale (Ares et al., 2016), which aims to understand the perception of well-being in a food-related context. The relevance of a given dimension in the assessment of well-being depends on the food item, cultural context, study purpose, and the specific aspects of consumption (Ares et al., 2015; Jaeger et al., 2022; King et al., 2015; Sulmont-Rossé et al., 2019). Thus, the perception of well-being in the context of rice consumption may be more focused on specific dimensions, such as health and nutrition (physical aspect), social, and emotional aspects, since Portuguese consumers associate the word "rice" with these dimensions, as seen in Paper I.

The evaluation of orientation towards naturalness using the NNS demonstrated a high appreciation of this aspect by consumers. One of the requirements for acceptance of an RTE-rice product is to maintain its naturalness, as mentioned in Paper II. Even participants who valued this aspect highly were willing to try this product category, demonstrating that there was no association between ready-to-eat and unnaturalness.

This agrees with a study that states a dissociation between unnaturalness and convenience, reinforcing convenience as a tool to support healthy eating habits by promoting formulation and processing that results in nutritionally more balanced convenience products (Nakano & Washizu, 2020; Stranieri et al., 2017). There is a growing trend toward offering healthier and more sustainable convenient foods such as naturally preserved fresh vegetables and fruits (Piracci et al., 2024).

To change rice consumption habits or to establish acceptance of convenient, healthier, and sustainable rice, some key factors must be considered, such as respecting the country's habits and gastronomy, improving the nutritional profile of familiar dishes, and incorporating commonly used ingredients. In addition, it takes advantage of the younger population's openness to new cuisines to integrate ancient grains and culinary techniques that improve the glycaemic profile of rice.

In general, consumers were interested in low GI rice and revealed positive perceptions; however, it was noted that the lack of information (lack of knowledge) led to misinterpretation of the concept as well as negative perceptions. Therefore, the promotion of healthier ways of consuming rice should begin with consumer awareness and information.

The findings of the four papers have the potential to significantly contribute to devising health-promoting (nutrition-specific) policies and creating a product that caters to the preferences and needs of customers.

4.2. Conclusion

This work covers rice consumption habits to gain insights for developing and promoting healthier ways of consuming rice, specifically allowing an understanding of the behaviour during the rice provisioning process (from acquisition to consumption practices), providing important and specific insights at each point of consumer interaction with the product. The results indicate that three primary factors contribute to the high consumption frequency of rice in Portugal in comparison to other European countries: i) rice is considered a versatile ingredient suitable for various culinary situations (cooking stage), ii) its taste is widely accepted and appreciated (eating stage), and iii) the strong cultural and traditional identity associated with rice consumption in Portugal is also evident in the market dynamics (acquisition stage).

The most important sensory aspect for consumers was the texture and appearance, with white and whole kernels being the most important. When rice is cooked, they prefer loose, soft, and whole kernels, and like rice cooked with other ingredients such as

vegetables, pulses, meat, and fish. The addition of ancient grains and seeds remains an unexplored novelty.

This work took the first approach to GI labelling of rice in a country that is the largest consumer in Europe and showed consumer interest in this information. Therefore, the country must start a debate on this subject considering other countries that encourage the use of GI as a tool for the treatment of diabetes and the management and prevention of chronic illnesses, including diabetes, cardiovascular diseases, and obesity.

This thesis not only contributes to the body of literature on rice consumption behaviours in Portugal but also provides insights into the development of convenient and healthy rice products as well as strategies to promote healthier forms of rice consumption. It also promotes more sustainable consumption, providing clues for the use of by-products from the rice industry, as well as for the promotion of local rice. These results offer important implications for marketers, brand owners, and policymakers regarding product designs and labels. Furthermore, the results highlight the importance of combining direct and indirect measures to capture the behaviours and attitudes that surround consumer decision-making.

The methodological approach employed in this study was effective in achieving its objectives. The four papers that resulted from this investigation represent complementary work, with previous research serving as the basis for subsequent work. However, there is still much more work that can be done in this research area, as outlined in future works section.

4.3. Recommendations for future works

Implicit cues can effectively shape the perception of the naturalness of food products. As such, it is recommended that future research should explore strategies that impart a sense of naturalness to ready-to-eat foods in an implicit or non-verbal manner. Additionally, comparing the effectiveness of implicit (nonverbal) and explicit health cues for this food category would be beneficial.

This study used a panel of consumers selected from a convenience sample, and it would be useful to repeat a study on rice consumption habits in a country with high consumption compared to European countries, with a representative sample of the population, to provide results that allow inferences to be made for an entire country, something that was not possible in a doctoral work due to scarce resources of various types.

Currently, questions regarding the evaluation of sensations (perception of sensory attributes) in a realistic environment are ongoing in the sensory and consumer sciences (Colla et al., 2023; Jaeger, Hort, et al., 2017). Therefore, the use of tools such as virtual reality can be relevant for assessing the acceptance and taste of rice products with healthier nutritional profiles.

Considering these issues, it is suggested that future experimental design research be a combined assessment of willingness to try with visual saliency, measured with eye tracking, to confirm which attributes would attract the most attention and check whether they coincide with the part-worth utilities. Furthermore, it is important to compare the results of acceptance with and without the sample taste (acceptance vs. liking). It is also suggested that packaging mock-ups can be used to make the experience more realistic.

GI labelling of rice and other carbohydrate-rich foods should continue to be explored to inform future debates on their regulations.

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