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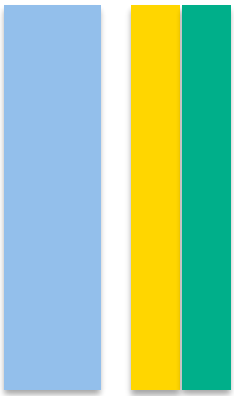
CIÊNCIAS DO CONSUMO ALIMENTAR E NUTRIÇÃO

DIS!ArrozPortuguês – Design, Innovation and Health, an approach in Food Design Thinking to promote Portuguese rice

Ana Castanho

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Ana Lídia Vargas Castanho

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Authors' Declaration

Under the terms of the "Decreto-lei nº 216/92, de 13 de Outubro", the author declares that the articles included in this thesis are original and prepared within this scope; the author also declares that she had the major contribution to the conceptual design, technical execution of the work, interpretation of the results and manuscript preparation of the all the articles included in this thesis:

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To the FUTURE

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ABSTRACT

Rice is a staple food in many countries, with significant differences in rice consumption levels. According to FAO, in Asia, rice consumption in 2020 was 115.05 kg *per capita*, while in European countries, it only corresponded to 7.22 kg *per capita*. In the European context, there are also significant differences, with Portugal showing the highest yearly consumption with 19.29 kg *per capita*, which is double the European average; these values were also confirmed by the National Food Consumption Survey (IAN-AF) performed in 2015-2016, where Portuguese consumers reported to consume 23.47 kg *per capita*.

Rice is usually consumed dehulled and milled, leading to a vast amount of side streams with bioactive potential RB, mainly used as animal feed. The percentage of rice side streams is variable, which ranges from 10 to 13 % in the case of bran. RB contains mainly oil, protein, and dietary fibre; other beneficial properties have been related to its potential to improve the blood lipid profile. Those benefits arise mainly from phytochemicals existing on RB lipid fraction. Brown rice has a higher nutritional value than milled rice, and the bran is very attractive for food applications, so it is essential to communicate to consumers the beneficial properties of its bioactive compounds.

The rice type *Carolino* was the market leader for many years; however, as the market changed during the last decade, the *Agulha* rice type became the market leader, most of it being imported *indica* from South America. Other imported rice types, such as the aromatics (*Basmati* and *Jasmin*) and varieties for risotto (mainly *Arborio* and *Carnaroli*), increased their sales, showing a demand for novelty.

Given the challenging market context and the complexity of the problem, Design Thinking was studied, as it is an important approach to problem-solving, which has expanded to areas other than design. Design Thinking, a user-centred way of solving problems using design tools, can also be applied to New Product Development and should be incorporated throughout the iterative creative process.

The problem framing was divided into two main branches: the study of consumers' choice motives and the study of rice bioactive compounds, mainly γ-oryzanol. Food Choice is a complex system, which may be described using the Food Choice Questionnaire (Steptoe et al., 1995). The FCQ is a widely used complete tool that has been modified and applied to describe determinants of choice for different food products and within different contexts and cultures. However, as the tool was designed for specific cultural contexts, and Food Choice is dependent on the culture, a design tool was created to adapt the FCQ to rice consumption in Portugal. To minimise the researcher bias, a tool based on images elected by consumers was employed to modify the questionnaire items. The questionnaire, consisting of 33 questions, was then implemented together with questions on food consumption

frequency and socio-demographic details. The results showed the Sensory Properties as the main determinants of choice of rice, followed by Convenience and Health & Nutrition. The questions regarding Familiarity & Tradition were the least important. Different consumers' clusters were also identified regarding their consumption behaviours.

A collection of very different rice varieties, including Portuguese and exotic ones (such as purple or orange), was studied for their bioactive potential against tumour and non-tumour cell lines and their antimicrobial potential. Extracts of the selected varieties containing γ-oryzanol were tested against the models. The results show a relation between the γ-oryzanol content and the cytotoxic properties of the extracts, and rice extracts could be used as antimicrobial agents when incorporated in food matrices.

Given these results, two groups of young aspiring chefs were contacted to develop concepts of rice-based meals that could incorporate whole rice or RB. The brainstorming technique is one of the most popular in the Design Thinking approach, so free brainstorming was performed in the first group. However, the results, evaluated by professional chefs, had very low scores. In a second iteration, a design tool based on the Remote Association Test (used to measure creativity) was developed. The second group generated ideas using the tool as a game, obtaining higher scores. Those ideas were tested as prototypes, and a product was elected to be optimised for its health properties.

The elected product, a rice-based beverage composed of rice, RB and sugar, was optimised to maximise γ-oryzanol and γ-aminobutyric acid contents jointly. This approach was studied as fermentation and germination are known to increment the content of those compounds. While fermented beverages are not so popular in Portugal, in Japan, there is a traditional fermented rice beverage which has similarities to the product ideated by the young chefs. Thus, the fermented rice beverage Amazake was optimised, departing from the known Amazake-making process. Rice produced in Portugal from the variety *Ariete* (milled, brown and germinated) was cooked and fermented with *A. oryzae*; a surface response methodology was employed to increment the bioactive compounds values. During the fermentation process, there are produced enzymes such as amylases or proteases; thus, the next step in Amazake making includes the starch hydrolysis of the remaining starch by the amylases produced during the fermentation process. This process breaks the starch in glucose molecules, giving the beverage a naturally sweet taste.

Consumers evaluated the optimised Amazake in a blind sensory test regarding their liking and an informed test elicited by the nutritional properties of the beverage. The results were interesting since half the consumers expressed their liking and the other half did not like the product. These results may reflect that the sensory properties of the beverage were not in accordance with the consumer's

expectations, as it was the main choice motive regarding rice, but also, the consumers were not so detached from Familiarity & Tradition as the questionnaire expressed.

Given this result, and following the natural process of the Design Thinking method, the next step would be to study the relation of the consumers with the beverage-specific traits and to adapt it to the expectations of the Portuguese consumer.

RESUMO

O arroz é um alimento básico em muitos países, com diferenças significativas nos níveis de consumo entre eles. Segundo a FAO, na Ásia, o consumo de arroz em 2020 foi de 115.05 kg *per capita*, enquanto nos países europeus correspondeu apenas a 7.22 kg *per capita*. No contexto europeu também existem diferenças significativas, com Portugal a apresentar o maior consumo anual com 19.29 kg *per capita*, o dobro da média europeia; estes valores foram também confirmados pelo Inquérito Nacional ao Consumo Alimentar (IAN-AF) realizado em 2015-2016, onde os consumidores portugueses referiram consumir 23.47 kg *per capita*.

O arroz é geralmente consumido descascado e branqueado, o que leva a uma grande quantidade de produtos secundários com potencial bioativo, nomeadamente os encontrados na sêmea, e que são usados principalmente na alimentação animal. A percentagem de produtos secundários é variável, e no caso da sêmea variam entre 10 a 13 %. A sêmea contém principalmente óleo, proteína e fibra dietética, mas também compostos com potencial bioativo, com a capacidade de melhorar o perfil lipídico do sangue. Esses benefícios decorrem principalmente de fitoquímicos existentes na fração lipídica da sêmea. O arroz integral tem um valor nutricional superior ao do branqueado, sendo que a sêmea de arroz é um produto com bastante potencial para aplicações na área alimentar; é por isso necessária a divulgação das propriedades benéficas destes compostos bioativos aos consumidores. O arroz Carolino foi o líder de mercado por muitos anos, no entanto, devido às mudanças do mercado na última década, o arroz do tipo Agulha é agora o líder de vendas, sendo na maioria importado da América do Sul. Outros tipos de arroz importados, como os aromáticos (*Basmati* e *Jasmin*) e variedades para risoto (principalmente *Arborio* e *Carnaroli*), aumentaram as suas vendas, mostrando uma procura pela novidade.

Perante este contexto e a complexidade do problema, foi estudada uma abordagem na resolução de problemas complexos, o *Design Thinking,* que se expandiu para outras áreas além do design. O *Design Thinking*, centra-se no consumidor e tenta resolver os problemas recorrendo a ferramentas de design. Esta abordagem pode ser também aplicada ao Desenvolvimento de Novos Produtos e deve ser incorporada deste o início ao fim do processo, que se desenvolve de uma forma iterativa.

O enquadramento do problema foi dividido em dois ramos principais: o estudo dos motivos de escolha dos consumidores e o estudo dos compostos bioativos do arroz, principalmente o γ-orizanol. Sendo as escolhas alimentares um sistema complexo, o *Food Choice Questionnaire* foi a forma eleita para estudar o problema, por ser uma ferramenta completa que foi modificada e aplicada nos mais diversos contextos. No entanto, esta ferramenta foi desenhada perante um contexto cultural específico; sendo que as escolhas alimentares dependem fortemente da cultura, foi criada uma ferramenta de design

para o adaptar à realidade portuguesa e ao arroz como matriz alimentar. Para minimizar o viés relacionado com o investigador, foi criada uma ferramenta baseada em imagens eleitas pelos consumidores para modificar os itens do questionário. O questionário, composto por 33 perguntas, foi então aplicado juntamente com a frequência de consumo alimentar e questões demográficas. Os resultados mostraram que as propriedades sensoriais foram consideradas como o principal motivo de escolha do arroz, seguido pela Conveniência e Saúde & Nutrição. As questões da Familiaridade e Tradição foram tidas como as menos importantes.

Uma coleção de variedades de arroz, incluindo variedades de portuguesas e exóticas (como arroz púrpura ou laranja), foi estudada quanto ao seu potencial citotóxico em linhas celulares tumorais e não tumorais, e ao seu potencial antimicrobiano. Os resultados mostram uma relação entre o teor de γ-orizanol e as propriedades citotóxicas dos extratos, podendo estes extratos de arroz ter a capacidade de ser utilizados como agentes antimicrobianos quando incorporados em matrizes alimentares.

Perante estes resultados, dois grupos de estudantes de cozinha foram selecionados para desenvolver conceitos de refeições à base de arroz que pudessem incorporar arroz integral ou sêmea. O brainstorming é uma das técnicas mais populares para geração de ideias no *Design Thinking*, e foi por isso realizado um brainstorming livre com o primeiro grupo, com vista à obtenção de ideias criativas. No entanto, os resultados, avaliados por *chefs* profissionais, foram bastante baixos. Numa segunda iteração, foi desenvolvida uma ferramenta de design baseada no *Remote Association Test* (usado para medir a criatividade). O segundo grupo gerou ideias utilizando a ferramenta como um jogo, obtendo maiores pontuações relativas à criatividade, quando avaliados pelos *chefs* profissionais. Essas ideias foram testadas como protótipos e um produto foi eleito para ser otimizado relativamente às suas propriedades nutricionais.

O produto eleito, uma bebida à base de arroz composta por arroz, farelo de arroz e açúcar, foi otimizado em relação ao conteúdo de γ-orizanol e ácido γ-aminobutírico. Visto que a fermentação e a germinação são conhecidas por incrementar o teor desses compostos, essa hipótese foi estudada. Enquanto em Portugal as bebidas fermentadas não são muito populares, no Japão existe uma bebida tradicional de arroz fermentado, com semelhanças com o produto idealizado. Assim, a bebida fermentada de arroz *Amazake*, foi otimizada, a partir do processo de fabrico tradicional deste produto: arroz da variedade portuguesa *Ariete* (branqueado, integral e germinado), foi cozido e fermentado com *A. oryzae*; uma metodologia de superfície de reposta foi utilizada para aumentar os valores de compostos bioativos. Durante o processo de fermentação, são produzidas enzimas como amilases ou proteases; assim, o passo seguinte na fabricação do *Amazake* inclui a hidrólise do amido restante pelas

amilases produzidas durante o processo de fermentação. Esse processo quebra o amido em moléculas de glicose, dando à bebida um sabor naturalmente doce.

O *Amazake* otimizado, foi avaliado por consumidores num teste sensorial cego, quanto à sua apreciação global, e num teste informado, eliciado pelas propriedades nutricionais da bebida. Os resultados foram interessantes, já que metade dos consumidores manifestou o agrado pelas propriedades sensoriais da bebida enquanto os restantes mostraram o seu desagrado pelo produto. Os resultados podem indicar que as propriedades sensoriais da bebida não estavam de acordo com as expectativas do consumidor, pois esse foi tido como o principal motivo de escolha em relação ao arroz, por outro lado, pode indicar que os consumidores não estão tão alheados das questões da Familiaridade & Tradição como expressa o questionário.

Perante este resultado, e seguindo o processo natural do método do *Design Thinking*, o próximo passo seria estudar a relação dos consumidores com as características específicas da bebida e adaptá-la às suas expectativas.

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LIST OF ABBREVIATIONS

DT – Design Thinking

FDT – Food Design Thinking

GO – γ-oryzanol

GABA – γ-aminobutyric acid

FCQ – Food Choice Questionnaire

RB – Rice Bran

RBO – Rice Bran Oil

Chapter 1. GENERAL INTRODUCTION

1.1 RICE, ITS ORIGIN AND SUB-SPECIES

The genus *Oryza* includes 20 wild species. From those, two were domesticated: Asian rice (*Oryza sativa L.*), early cultivated in East and South Asia and now the most cultivated rice species in the world, and African rice (*Oryza glaberrima Steud.*), cultivated in Western Africa (Muthukumaran, 2014).

The oldest archaeological evidence of human rice use was found in China, dating 11000–12000 BC Zhijun (1998). Asian rice varieties are traditionally divided into two categories, the short-grained *japonica* (*Keng)* and the long-grained *indica* (*Hsien)*, whose genetics point out to two different locations of domestication: the Lower Yangtze valley plain in China, japonica (c. 4000 BC) and the Gangetic basin, including India Pakistan, Nepal and Bangladesh, for indica (c. 2500 BC) (Muthukumaran, 2014). Along with the genetic differences, plant traits have been used to classify *indica* and *japonica,* including grain shape, leaf colour, seed size and apiculus hair length (Chou, 1948; Dabrowski et al., 2021; Oka, 1988; Ting, 1957).

Although *indica* and *japonica* represent the deepest genetic differentiation within *Oryza sativa,* there were identified five major subpopulations: *indica*, *tropical japonica*, *temperate japonica*, *aus* and *aromatic* (Garris et al., 2005). *Aus* and *indica* are grouped within the *indica* subspecies, while the temperate *japonica*, tropical *japonica* and *aromatic* are grouped within the *japonica* subspecies (Figure 1) (Sweeney & McCouch, 2007).

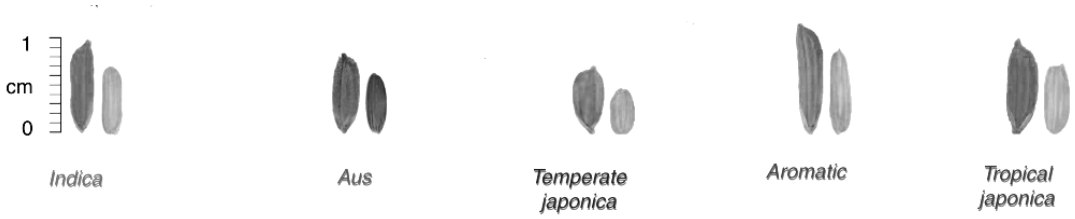


Figure 1. Rice grain shapes by sub type. Based on Zhao et al. (2011).

The improvement of rice varieties from wild to domesticated includes a process of continuous selection for desirable features to make rice grains more appealing as a food source – this includes grain size, shape, colour, fragrance and amylose content (Kovach et al., 2007).

Currently, the most common and fastest method of identifying *indica* and *japonica* rice varieties is based on the *Cheng index* method, while another option is genetic identification. The *Cheng index* method examines six characteristics of rice samples: (1) lemma hairiness, (2) phenol response in rice

grains, (3) inter-node length of panicle axes, (4) colour of grain husks, (5) hairiness of leaf-blades, and (6) length/width ratio of grains (Cheng, 1993; Lu et al., 2009).

Despite the genetic designation, rice is commercially identified according to the grain dimensions – an adaptation of the *Cheng index* method – using only its length/width ratio. Commercial identification is regulated by European and National Portuguese law, as shown in **Table 1**.

Table 1. Commercial designation by grain morphologic measurements ("Decreto-Lei n.º 62/2000 de 19 de Abril do Ministério da Agricultura, do Desenvolvimento Rural e das Pescas," 2000)

Designation	Grain length (cm)	Length/width ratio	
Round grain	≤5,2	< 2	
Medium grain	5,2 < *x* ≤ 6	2 ≤ *x* < 3	
Long grain	>6	Long A	2 ≤ *x* < 3
		Long B	≥ 3

1.2 RICE AND HEALTH

The combination of *rice* and *healthy food* has been highlighted in recent years due to the evolution of consumption patterns, especially the expansion of gluten-free products. However, in the case of rice bran (RB), a side stream of milled rice, there is still a great potential to incorporate this ingredient in food products. RB comprises the pericarp, seed coat, nucellus, aleurone, pulverized embryo, hull, and endosperm fragments (**Figure 2**) (Orthoefer & Eastman, 2004).

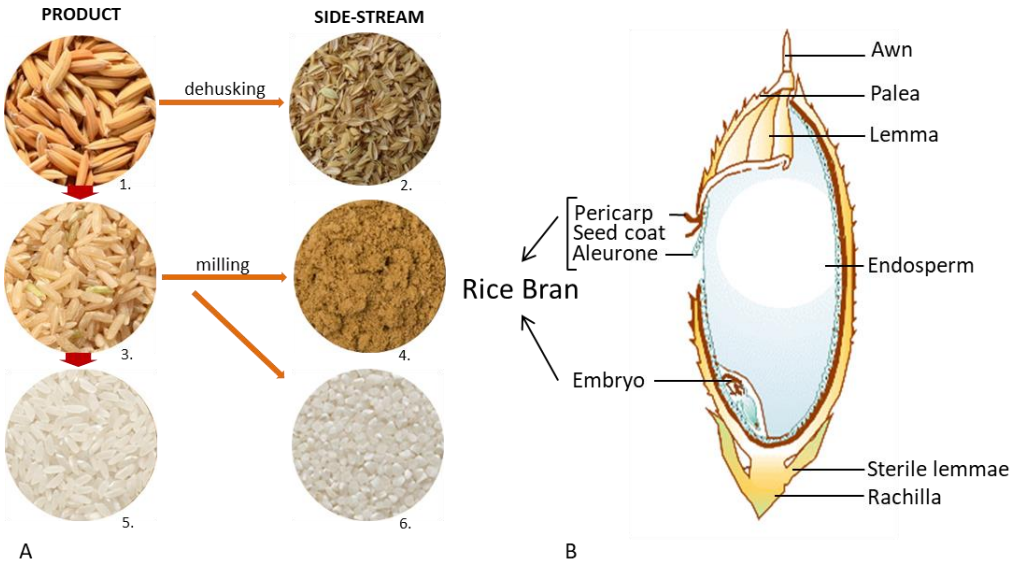


Figure 2. A) Industrial products and side-streams of rice. 1. paddy rice, 2. Rice husks, 3. Brown rice, 4. Rice bran, 5. White rice, and 6. Broken milled rice. B) Rice grain constitution (Castanho, Pereira, et al., 2019)

Milled rice consumption is much higher than brown rice, possibly due to its organoleptic qualities. Still, when comparing the nutritional characteristics of milled rice with brown rice, there are significant differences due to the presence of bran (**Table 2**). According to Goufo and Trindade (2014), RB has high protein and lipid content with nutraceutical potential derived from its bioactive compounds, such as phytic acid and tocopherols, tocotrienols and γ-oryzanol, which are present in the lipid fraction.

Table 2. Comparison of nutritional composition between brown rice and milled *Carolino* rice (macroconstituents, vitamins and minerals) (INSA, 2016).

	BROWN CAROLINO RICE	MILLED CAROLINO RICE
Energy, kcal/100g	352,00	363,00
Macroconstituents (g)		
Protein	8,60	7,40
Total fat	2,50	0,50
Carbohydrates	71,60	79,60
Fibre	3,80	2,20
Fatty acids (g)		
Saturated	0,50	0,10
Monounsaturated	0,60	0,10
Polyunsaturated	0,90	0,20
Linoleic acid	0,80	0,20
Vitamins (mg)		
α-tocopherol	0,70	0,10
Thiamine	0,40	0,07
Riboflavin	0,10	0,03
Niacin equivalents	6,00	3,60
Niacin	4,10	2,00
Tryptophan/60	1,90	1,60
Vitamin B6	0,60	0,30
Folates	0,06	0,02
Minerals (mg)		
Sodium (Na)	3,00	6,00
Potassium (K)	248,00	110,00
Calcium (Ca)	9,00	11,00
Phosphorus (P)	267,00	92,00
Magnesium (Mg)	109,00	13,00
Iron (Fe)	1,70	0,60
Zinc (Zn)	1,40	1,30

1.3 RICE HISTORY, EXPANSION AND USES

Rice was only brought to Europe by Alexander the Great in his Indian campaign circa 319 BC and known in the Iberian Peninsula when the Arabic expansion occurred circa 711; however, it was only started to be farmed in the reign of D. Dinis (1279-1325). If rice was only consumed by the noble classes at the time, the incentive to production given by D. José (1714-1777) allowed the cultivation of Tagus and Sado estuaries (Faísca et al., 2021).

Despite the late expansion of rice farming in Portugal, there is evidence of early uses, namely in the 15th century, in Princess Maria's cookbook; after that date, there are also reports of rice trading, maybe brought from the West, as rice was farmed in Europe only in small scale. In the 18th century, Brazil was the leading rice supplier for Portugal (Faísca et al., 2021).

With Brazil's independence, rice was needed; thus, at the beginning of the 20th century, the government adopted measures to expand the rice culture (Faísca et al., 2021). The measures included the creation of the Rice Trade Regulatory Commission in 1933 and the technical and scientific support to improve rice cultivars to better fit the edaphoclimatic conditions, started in 1941 in the National Agronomic Station (now known as National Institute of Agricultural and Veterinary Research – INIAV). The implemented measures increased rice production, surpassing the consumption rate (Faísca et al., 2021; Vianna e Silva, 1969). Despite the importance of these policies, it is also interesting to verify that rice cultivation was impossible without the favourable edaphoclimatic conditions in the country (Faísca et al., 2021).

1.4 PORTUGUESE RICE TRADITION

Portuguese gastronomic culture is supported on rice due to two main factors, tradition, as it has been included in meals since the 15th century, and availability, since rice was later turned into a widely accessible cereal due to government production incentives. Dias and Dias (2018) explored traditional Portuguese gastronomy by analysing dishes as they are in selected cookbooks. Although the authors look at the data as the expression of each recipe and ingredient in each Portuguese region, there are some interesting conclusions when further exploring the dataset. When considering the names of Portuguese traditional recipes, one can divide them into starters, main courses, side dishes, and soups; in the case of main dishes, when looking at the structure of the recipe names, one can see that in some cases, main courses do not need side dishes, as they are blended in a *one pot* meal. This idea becomes very evident in the case of rice, stews or gruel, where the main ingredient is not meat nor fish but cereals, pulses or tubers, there are usually served as a side dish. The count of *one pot* meals using cereals or tubers other than rice (n = 103) mainly contained corn or wheat bread used in different ways, such as stews (n = 19), *migas* (n = 14), cornmeal (n = 3), bread soup (n = 31) and potatoes (n = 3). When looking at rice *one pot* meals (*arroz de*), there were found 62 recipes, of which 34 included meat (with blood and/or offal (n = 12)) and 28 included fish or shellfish.

The analysis of data from Portuguese traditional recipes published in cookery books provides information on the importance of rice in Portuguese gastronomy.

1.5 RICE MARKETS

1.5.1 Global and European rice market

For centuries, rice has been one of the most fundamental staple foods in the world for about half of the population. **Figure 3** shows world resources by staple food (which includes cereals, tubers and pulses) in 2019, where rice appears as Rice is the main food supply source (FAO, 2022).

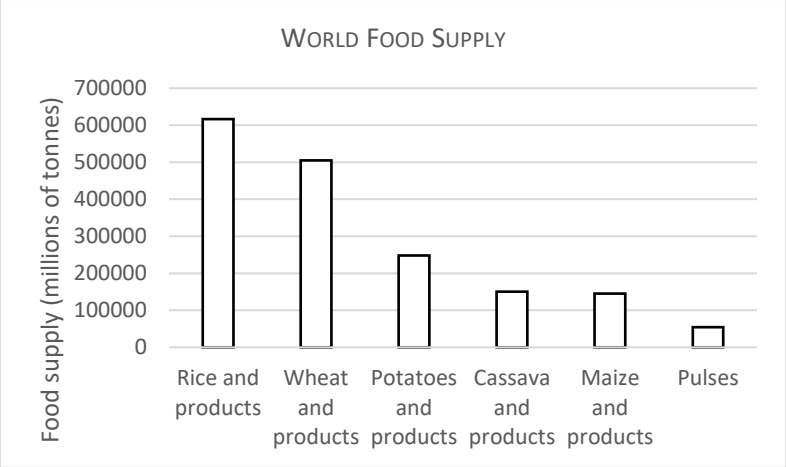


Figure 3. World food supply of the main staple foods in 2019 reported in millions of tonnes (FAO, 2022)

Table 3 shows the apparent consumption of staple foods in the different continents. Wheat is the most consumed staple food in America, Europe and Oceania, while Cassava is the most consumed in Africa. Rice is the most consumed staple food in Asian countries; in the other continents, rice appears in fourth place with relatively consumption values, mainly in Europe, where the apparent consumption was only 6.68 kg/capita in 2019 (FAO, 2022).

Table 3. Apparent consumption of staple foods in each continent by order of consumption in 2019 (kg/capita/Yr) (FAO, 2022).

Africa		**Americas**		**Asia**		**Europe**		**Oceania**	
Cassava	87,30	Wheat	60,55	**Rice**	**117,88**	Wheat	112,29	Wheat	66,93
Wheat	46,79	Maize	36,43	Wheat	64,90	Potatoes	71,23	Potatoes	34,63
Maize	43,20	Potatoes	36,01	Potatoes	30,28	Maize	7,89	Sweet potatoes	20,96
Rice	**34,82**	**Rice**	**26,06**	Maize	10,40	**Rice**	**6,68**	**Rice**	**19,25**

As shown in **Figure 4**, Asian countries were the leading rice exporters in 2019 (FAO, 2022). India, Thailand, Vietnam, China, Pakistan, USA and Myanmar are responsible for more than 80 % of the exports, with India, Thailand and Vietnam accounting for approximately 50 % of the global exports.

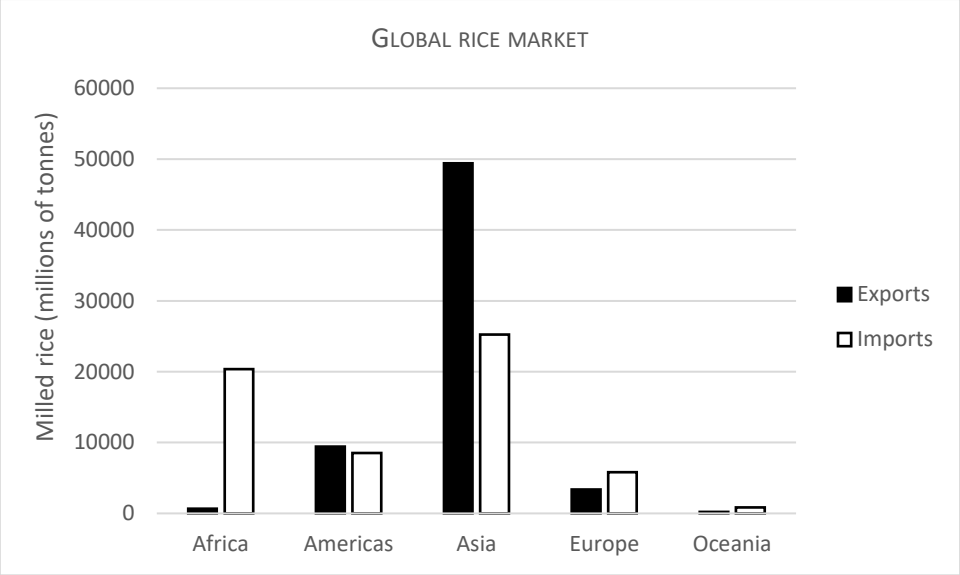


Figure 4. Global imports and exports by continent (millions of tons) in 2019 (FAO, 2022).

Due to the temperate edaphoclimatic conditions, about 80 % of the rice area is cultivated with japonica varieties in Europe. The remaining 20 % is cultivated with adapted *indica* varieties (Ferrero & Nguyen, 2004; Oka, 1988). With the availability shaping the tradition, the European population consumed primarily *japonica* rice. Nonetheless, the consumption of *indica* rice has increased in recent years, surpassing *japonica* rice consumption since 1999/2000. The change in market needs led Europe to import husked rice (as shown in **Figure 5**), mainly from the US, Thailand, India and Pakistan (Ferrero & Nguyen, 2004).

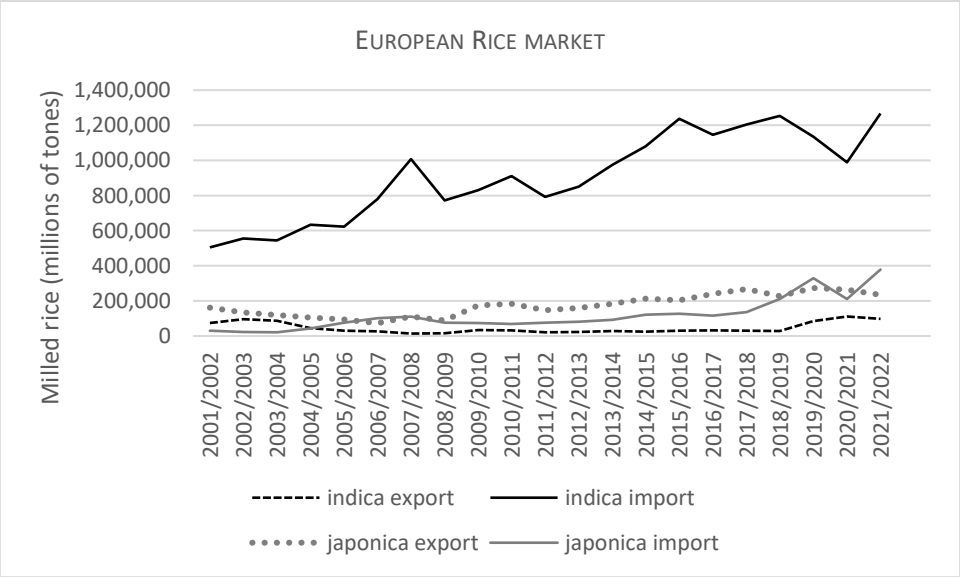


Figure 5. Evolution of European rice exports and imports (European Comission, 2022).

1.5.2 Portuguese rice market

Figure 6 shows the Portuguese milled rice supply in 2020, which represents double the EU global supply (19.29 and 10.2 ± 4.7, respectively) (FAO, 2022); these values were also confirmed by the National Food Consumption Survey (IAN-AF) performed in 2015-2016 (Lopes et al., 2017), where Portuguese consumers were reported to consume 23.47 kg *per capita*. However, Portuguese rice production accounted only for 6 to 7 % of all the EU rice production, of which 87 % corresponds to the traditional *japonica* rice (most of which is suitable for the commercial type *Carolino*, long grain A) and 8 % to the *indica* rice type (suitable for the commercial type *Agulha*, long grain B) (GPP, 2019).

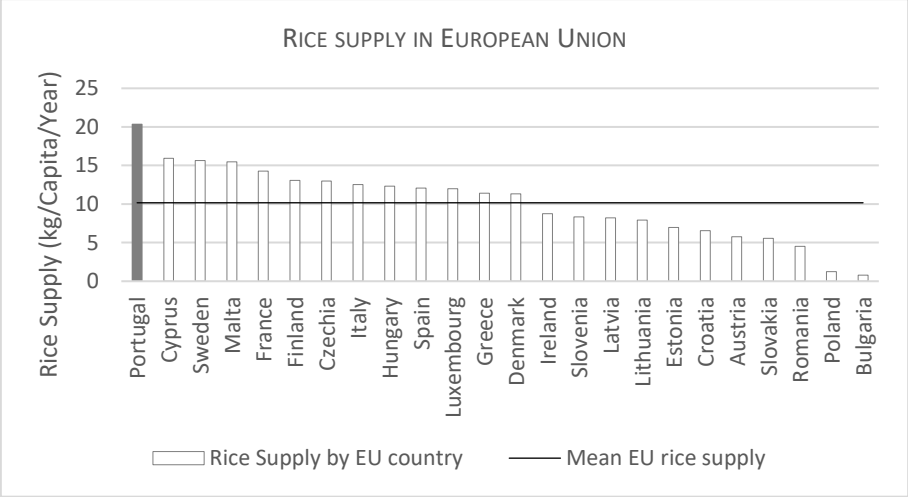


Figure 6. *Per capita* milled rice supply in the EU countries in 2020 and EU milled rice supply average (FAO, 2022)

In Portugal, *Carolino* commercial rice type had been the market leader for many years; however, a shift in the market in the last decade led to the *Agulha* type being the market leader, with 45 % of sales according to the most recent Nielsen data, almost twice the sales of *Carolino* by quantity. As the production of *Agulha* rice type is not high, and the grain properties differ from the imported ones, Portugal acquires it mainly from South America (GPP, 2019). Other commercial rice types, such as the aromatics Basmati and Jasmin and varieties for risotto (mainly *Arborio* and *Carnaroli*), must be fully imported as they are not produced in Portugal. According to the most recent Nielsen data, Basmati sales in value are already slightly higher than *Carolino* (21 % *versus* 20 % of market sales value, indicating an increasing demand for novelty.

Figure 7 shows the trading data in Portugal in millions of tonnes. Although the exports have increased in the past decade, the imports increased very sharply; this means Portugal exports the produced *Carolino* (and other imported and transformed rice) and imports significant quantities of rice, which according to the previously reported data, may include mainly the aromatic rice type Basmati and *Agulha*.

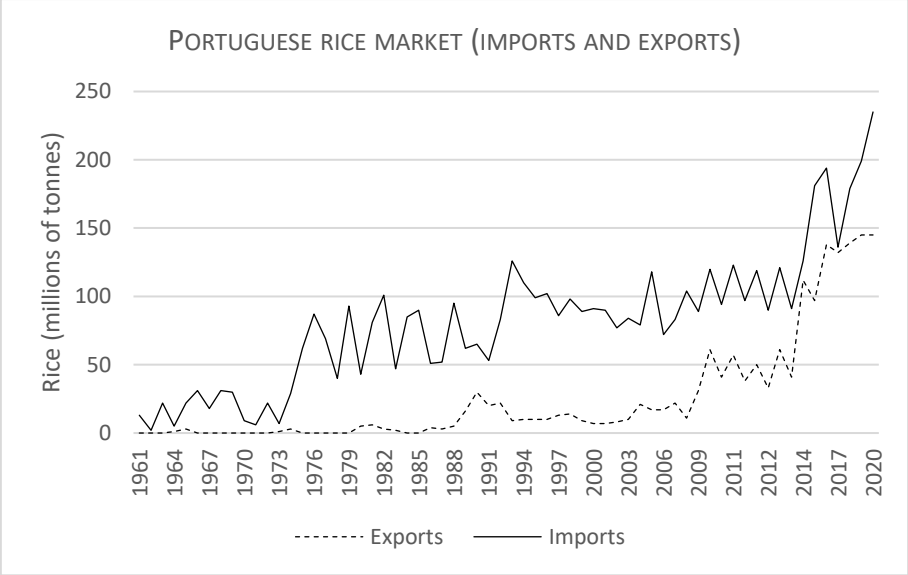


Figure 7. Imports and exports of rice (in all forms) in millions of tonnes per year (FAO, 2022).

Chapter 2. FRAMEWORK

2.1 FOOD CHOICE AS A COMPLEX SYSTEM

Food choice is a very complex concept and is influenced by many factors (Köster, 2009). According to the author, although different disciplines have studied those factors, they did not work in a multidisciplinary environment. The author also refer to the lack of importance given to psychological factors in an early stage of consumer sciences history, when trying to be perceived as a scientific discipline in the academic realm, and how it led to fallacies: 1) the fallacy of *uniformity*, meaning the behaviour doesn't change in its essence; 2) the fallacy of *consistency*, or the idea that behaviour don't change; 3) the fallacy of *conscious choice*, meaning choices are rational; 4) the *perceptual* fallacy, or the idea that the individuals only remembers what they perceive, and 5) The *situational* fallacy, meaning eating situations can be analysed objectively.

Over the past three decades, a profound alteration has been observed in the psychological realm, stemming from the recognition that a substantial proportion of our behaviour is governed by influences beyond the scope of our consciousness, in contrast to prior assumptions (Köster, 2009). This paradigm shift can also be observed in food consumption sciences. 1) Learning and memory is no longer seen as an acquisition, storage and retrieval phase, but as a complex process that starts when the individual born. Therefore, the eating behaviour can be learned in a non-intentionally way and/or in the most sensitive periods of life, such as childhood, and that non intentionally learned behaviours are the most difficult to change. 2) perception, once seen as a passive and receptive process is now accepted as more interactive, and accepted as existing with or without awareness, thus, the use of indirect methods in food consumer sciences now viewed as important ways of access unconscientious perception of food. 3) thinking, reasoning and decision making is now viewed as more intuitive, being actually seen as more used than rational thinking, thus, implicit methods, might be more used than the explicit ones. 4) emotion, motivation and decision take place unconsciously and are reflected on behaviour, as emotions triggers somatic markers and, when connected by learning, can predict future outcomes; however, the role of emotions is not only influenced by the individual, but also by empathising or imitating others. Continuing from this reflection, and grounded in the alteration of paradigm, the author proposes a redirection of emphasis within food consumer sciences toward a greater inclination for indirect methodologies.

2.1.1 Studies on food choice factors

This section presents a series of studies regarding food choice factors, based on the a model presented by Mojet, 2001, in a proposal to develop a European network for sensory and food consumer research

(Köster, 2009). In the original model, data integration and coordination appear as a central point, while other points, presented in **Table 4** appear as contributing factors.

Table 4. Representative factors of Food Choice, as proposed by Mojet (Köster, 2009).

1. Intrinsic product perception	Appearance, interaction taste-smell, texture Complexity, adaptation, and dynamic contracts Irritation, boredom, aversion
2. Biological and physiologic factors	Genetic factors, immune system, brain imaging Age/gender, physical condition Oro-gastro-intestinal physiology
3. Psychological factors	Cognition, emotion, motivation, decision making Memory, previous experiences, learning Personality traits, neophobia
4. Situational factors	Time, social surroundings, physical surroundings Coping, assimilation, habituation Intentionality, signification, attribution
5. Socio-cultural factors	Cultural and economic influence Trust in industry and government Changing beliefs, norms, habits and attitudes
6. Extrinsic product characteristics	Claims/brand label packaging Integrity, sustainability Risk perceptions

2.1.1.1 Intrinsic product perception

Classical sensory attributes such as visual cues, taste, odour, flavour and texture have been studied in as predictors of food choice.

McCrickerd and Forde (2016) explored how senses influence food intake. Visual food cues help locate foods and can influence consumption by triggering portion norms; vision can also trigger learned beliefs about the anticipated taste and satiating properties, shaping food choice. Odour, such as visual cues, also predicts food intake by stimulating the desire to eat. Boesveldt and de Graaf (2017) propose that the choice happens at the sub-conscient level, and odours may trigger the desire for particular food or macronutrient. According to the author, odours can also suggest specific frameworks for particular food or macronutrient class, priming a context in which the product is most commonly consumed. This effect may be related to how the odour perception activates a cephalic trigger to responses such as helping the body prepare for the consumption and digestion of that particular food or ingestion and digestion of that specific food.

Taste is perceived during eating and provides a rapid evaluation of a food's quality (McCrickerd & Forde, 2016). While odour perception can be triggered by an infinite number of specific chemicals, taste perception is based only on a handful of primary qualities (sweet, salt, umami, bitter, and sour); therefore, when taste and odour are experienced together, as flavour, it emerges as a powerful tool that allows the evaluation and choice of food (Boesveldt & de Graaf, 2017). Texture perception, triggered by visual cues or the sense of touch, can also shape our beliefs about the satiating power of food and trigger anticipatory physiological responses to nutrient ingestion, contributing to the complexity of food choice (McCrickerd & Forde, 2016).

While sensory attributes of food might be perceived as the key to food choice, they can be changed by other factors, as for example memory, that can shape the perception of stimuli, or the cultural environment which may lead to different hedonic values for the same stimuli (Köster, 2009).

2.1.1.2 Biological and physiologic factors

Biologic and physiological effects are related to appetite control, which is regulated by neural end endocrine signals; food choice can, therefore, be regulated by metabolic hormones, mainly ghrelin and leptin: while ghrelin anticipates and motivates food consumption, leptin affects food reward by interacting with the dopamine system (Leng et al., 2017).

2.1.1.3 Psychological factors

As pointed out by Köster (2009) and later by Cuevas et al. (2017), food choice is profoundly shaped by learning and memory, perception and thinking, and reasoning and decision-making for food choice. The learning of a behaviour is not always conscient, and some of them are learnt in the early years of the most sensitive periods of life and may continue throughout time; those habits affect not only the food preferences but also sensory expectations and are more difficult to change. Perception also plays an essential role in food preference; the authors refer that sensations are not objective and depend on perception. For instance, when losing some basic sense, preference may be maintained; preferences can also be modulated by culture, even when the same stimuli are presented. As individual perception may change preference, the authors suggest using indirect measures to determine food preferences. Thinking, reasoning and decision-making imply the recognition of errors through reasoning, and corrective action is influenced by cognition and is, therefore, difficult to address as a food choice motive.

Krause et al. (2016) studied how food and nutrition literacy could impact food choice. The authors established three forms of literacy: functional, interactive and critical health. 1) Functional literacy ("those needed to be able to function effectively in everyday situations") includes the practical

knowledge to make decisions and prepare food (including planning, shopping, identifying the quality of food and knowledge of basic hygiene rules); to understand the origin of food, interpret nutritional labels and food composition, understanding the effect of food on health, and understanding food history and habits. 2) Interactive literacy ("used to actively participate in everyday activities and to apply new information to changing circumstances"), including sharing life experiences, empathizing with others, cooperative learning, using storytelling and narratives to explore the meanings of food, joining in and eating socially, the ability to share information, transfer skills and creating community. 3) Critical literacy ("the most advanced cognitive skills which can be applied to critically analyse information, and to use this information to exert greater control over life events and situations") includes the ability to judge the quality of nutrition information (interpret claims and analyse advice from experts), the ability to critically reflect on factors that influence dietary behaviour (understand and reflect on the effect of social, cultural, historical and religious factors on eating habits) and the ability to recognize the effect of food and nutrition decisions on society (contributing toward sustainability and democratic development, globally and locally, and helping people understand the how food choices influence social development).

Evaluation-based cognitive factors also affect food choice. It includes attitude evaluation, which represents an implicit evaluation of food based on its positive or negative characteristics, and liking, which is based on the sensory evaluation of food and preference when comparing foods. Another cognitive factor influencing food choice is the expected consequences for health (Chen & Antonelli, 2020).

Psychological components, such as individual emotions or personality traits, also can affect food choice. Emotional responses are deeply related to biological responses to certain types of food, as, for instance, sugar and fat have positive responses, while bitter compounds related to dangerous foods evoke negative responses. Emotions can thus influence preference when elicited by a stimulus or induce emotions such as strong desire (cravings) or rejection (neophobia) (Macht, 2008). Esposito et al. (2021) studied the personality influence on food choices in a literature review. The authors confirmed that personality traits may play a role in food choice: unhealthy eating habits are associated with more dysfunctional personality traits, as those people tend to increase the consumption of sugar, saturated fatty acids and alcohol, while what the authors describe as individuals with more "favourable personality traits" (low neuroticism, low alexithymia, openness, agreeableness, extraversion, sense of coherence, and conscientiousness) tend to consume more fruit and vegetables.

2.1.1.4 Situational factors

Time, social surroundings, physical surroundings The role of time scarcity in food choice is discussed by Jabs and Devine (2006) as a "sign of the times". The authors approach time scarcity as seen by the individuals, highlighting that although the work hours have decreased since 1870, people (mainly low-income families) feel mode pressured nowadays; on the other side, the food system (food design and products, and food availability) evolved in response to that lack of time, with more convenience food, fast-food restaurants and a series of tools that could help save time, such as the microwave or the rice cooker. The whole-time scarcity/time-saving situation led to time-dependent behaviours that can be observed in people's food choices by eating faster, eating on the go, and choosing ready meals over home dinners.

Larson and Story (2009) reviewed several studies regarding environmental factors that could impact food choices. Family and home environment play a central role in the development of food behaviours and food choice, as relatives and parents serve as mirrors models for eating behaviour, use eating habits and feeding practices that develop their children's aptitude to self-regulate ingestion, transmit nutrition values, and determine the structure of communally shared meals. The authors point out the factors that can affect food choices at home: 1) food availability, 2) the role of parents towards children (authoritative or authoritarian); 3) having family meals; and 4) the characteristics of the meal environment (the foods served, the accessibility of food at the table, the size of dinnerware and utensils, and media related to the types or amount of food individuals consume). Social and peer networks are also related to food choice, as individuals are influenced by interactions with others beyond the family unit, including co-workers, peers, and close friends. Social norms and attitudes among members of a group may also impact the type or number of foods that individuals consume regardless of whether they eat together; phenomena such as *social facilitation*, where individuals use the behaviour of others to judge "appropriate" portions and avoid incurring the stigma of excessive eating, or the *weight stigma*, where social norms idealizing thinness are examples of how social environment can influence food choice. Physical environments also play a role in shaping eating behaviour; for instance, children are mainly fed in daycare, adolescents at school have access to foods that compete with the school meals (for instance, vending machines), and adults are influenced by the physical availability of food at the workplace and surrounding neighbourhood, as well as workplace policies regarding food and healthy promoting eating. Access to restaurants, food stores and their quality may also influence food choice; other factors are income, socioeconomic status, education, cultural values and norms, food advertisement, and marketing.

Personal identity, including demographic features such as age, gender, ethnic identity, and education, can also affect food choices, as they may also represent important personal meanings such as family

story, migrations, assimilation, resistance, and changes over time, or even cultural values and beliefs (Chen & Antonelli, 2020).

2.1.1.5 Socio-cultural factors

As a system of shared understandings and interactions, culture promotes sharing values and beliefs and can shape perceptions of food, health, and illness. Cultural behaviours, values, and beliefs are learned early in life, transmitted from generation to generation, and are often deeply held. However, culture is a dynamic construct that evolves and changes over time. Food behaviours, as an expression of cultural identity, are learned from one generation to the next, therefore influencing food choice by shaping food preferences and perceptions, dictating what food is eaten, when it is eaten, and how it is prepared; by using food as a cultural representation in traditions and even as medicine. Globalization and acculturation can impact cultural changes and homogeneity, including dietary patterns; this phenomenon can affect health by changing eating habits but also by changing values and perceptions about body image and can be either positive or negative depending on what the old habits and its changes (Larson & Story, 2009).

Lower socioeconomic groups tend to consume fewer whole grains, vegetables, fruits, low-fat milk, and lean meats, have a more energy-dense diet, and consume more sugars and fast-food meals. Consequently, these people have lower intakes of fibre and essential micronutrients (Larson & Story, 2009). These health and diet inequalities between groups may be explained by factors such as the availability of healthy foods, economic barriers to purchasing food, and having limited time or resources for food preparation. There is evidence that residential segregation by income may contribute to many of these disparities, as many low-income communities tend to have poor access to supermarkets and chain grocery stores; the costs of preparing healthy foods, including the time of preparation, are additional barriers to good nutrition, as when there is a limited budget, people tend to select lower-cost, energy-dense foods to meet their energy needs and save time (Larson & Story, 2009).

Government policy can also change food choices. Mozaffarian et al. (2018) analysed the role of government policy in promoting a healthy diet. The authors classified it into policy interventions (in cities, communities, can institute), targets (consumers, industry), domain (economic policies, education) or mechanism (modifying formulations or food accessibility), and reported 13 policy strategies along with their strengths, limitations, uncertainties and recommendations (i.e., education measures, such as five a day, economic interventions, such as soda taxes). Despite these measures' positive or negative outcomes, they will intervene in the food choice model.

2.1.1.6 Extrinsic product characteristics

Nutritional labelling, food consumption environment and the general societal environment are external factors that can contribute to food choice.

Cecchini and Warin (2016) studied the effect of labelling on consumers' eating behaviour in a meta-analysis. The authors reported that interpretative food labelling (such as semaphore labelling) affected food choice, pointing out the negative and positive effects of such labelling. On one side, the consumers tend to generalize information on a piece of the label to the whole food product (i.e. nutrition and health claims), ending up eating more or less of those products, or the consumers may compensate a healthy dietary choice with consumption of other unhealthy food; on the other side, food labels empower consumers by providing nutrition information and motivates the industry to produce healthier food as well as for the policymakers to establishing better nutritional policies. The authors conclude that food labelling schemes would have a statistically significant effect in steering consumers' choice towards healthier products, and interpretive nutritional labels may be more effective than other approaches. The complexities of the stimuli' influence on food choice and behaviour change are well documented. However, enhancements in nutrition information labelling could make a small but relevant contribution towards helping to make the existing point-of-purchase environment more conducive to the selection of healthy options choices (Cowburn & Stockley, 2005).

2.1.2 Measuring Food Choice Motives

Given the complexity of Food Choice, Steptoe et al. (1995) created a tool to assess the motives. The Food Choice Questionnaire (FCQ) measures the importance of 36 items grouped into nine factors (health, mood, convenience, sensory appeal, natural contents, price, weight control, familiarity, and ethical concern). FCQ has been used in cross-cultural studies by some authors (Markovina et al., 2015; Pieniak et al., 2009), while other authors consider that some points, such as the evolution of the concepts and their interpretation, may be taken into account (Eertmans et al., 2006; Pula et al., 2014). Furthermore, as food choice can be considered a learned behaviour based on past experiences, it is important to understand that it changes over time; therefore, the questionnaire results interpretation should take into account the cultural and temporal environment of the responses (Köster & Mojet, 2007). Despite the importance of cross-cultural studies, cultural differences are known to be predictors of food preferences and even overlap the effect of individual differences (Ares, 2018; Prescott & Bell, 1995; Rozin, 1988).

The FCQ has been modified in many ways to adapt to the respondents' research purpose, culture or language. Modifying the dimensions by including or removing items is the most frequent modification (Cunha et al., 2018). The large majority of the adaptations are small and carried out by the authors to

better fulfil the final objective of the study (Abdul Rahman et al., 2013; Carrillo et al., 2011; Russell et al., 2015). While many authors use the existing adaptations, mainly the one performed by Lindeman and Väänänen (2000) (Dowd & Burke, 2013; Lindeman & Sirelius, 2001; Lockie et al., 2002; Mitterer-Daltoe et al., 2013), other authors added items from other questionnaires (Evans & Cox, 2006; Hoek et al., 2011).

2.2 DESIGN THINKING

2.2.1 Design thinking roots

The expression "Design Thinking" (DT) has been increasingly referred to in the literature (**Figure 8**). This expression is also common in various research areas, such as engineering, computer science, education, economics, social sciences or healthcare, to solve design problems. However, the use of DT related to food product development is not so present in the literature. As noted by Olsen (2015), DT can be useful for food innovation; as for this approach, the consumer is not only inquired about product acceptance but is a point of departure for product innovation.

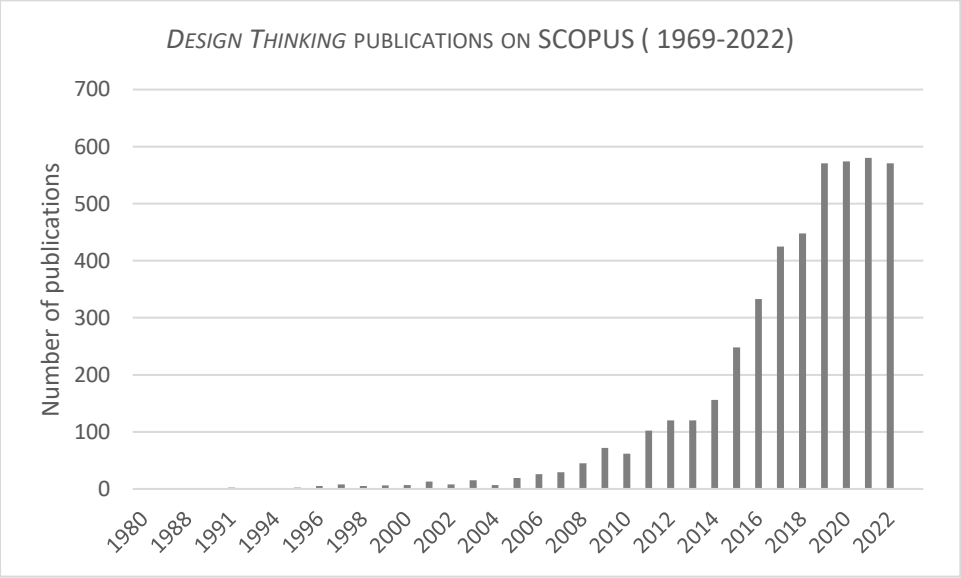


Figure 8. Yearly Publications on 'Design Thinking*' research in Scopus database from 1969 to 2022.

Traditionally, the designer was seen as an artefact maker, and the design and the making co-occurred. In recent years, however, the process of making something does not usually start before the process of designing is complete (Cross, 2011). The two main visions of design are given by Alexander (1964) and Simon (1969) and are still present in recent discussions. For Alexander, design is about doing physical things (giving form, organisation and order, working on the CONCRETE realm); for Simon, it is the "knowledge" that allows human action to respond to problems, working on the ABSTRACT realm (Kimbell, 2011; Simon, 1996).

The Sciences of the Artificial, by Herbert Simon (Simon, 1969), whilst the first edition was published in 1969, had a significant impact on the literature in different knowledge areas and is considered “one of the most influential texts in the 50-year history of the development of design theory” (You & Hands, 2019) and has been reviewed by authors since it was first published (Huppatz, 2015; Michalos, 1970; You & Hands, 2019).

Simon describes design through the concept of artificial. Artificial things are material (or conceptual) things created by men in opposition to natural things. There is, therefore, a distinction between science and engineering as disciplines. While science is interested in observing and analysing what things are, engineering is concerned with creating the artificial or achieving a specific goal and function. For Simon, the natural and the artificial interact and influence each other as a system, as the artificial things are made of natural materials, and the artificial influences the natural. This interaction is mediated by the artefact, which is the interface between this system's interior and exterior. Thus, the designer's role is to draw the limit between the interior and exterior, which functions as a homeostatic mechanism.

This theorisation led to the idea of design as “The Science of the Artificial”, the same way there are “Natural Sciences”. Additionally, a designer is seen as someone who changes “existing situations into preferred ones”, which presupposes a problem-solving approach, a broader definition of what a designer is, bringing professions such as engineering, architecture, business, education, law and medicine to the design field.

While Simon proposes a “scientification” of design, the author believes a set of problems cannot be solved linearly. Rittel and Webber (1973) have a different view regarding problem-solving. As Simon, these authors also view the natural and the artificial as different willing approaches; however, they point out not only the differences in the object of study and the kind of reasoning but the kind of problems themselves. In “Dilemmas in a General Theory of Planning”, Rittel and Webber define Design problems as “wicked” and cannot be solved in the linear way science proposes. For Rittel and Webber (1973), natural sciences’ problems are well-defined, separable and have findable solutions, while the design problems need to find the problem definition (the difference between the observed and the desired) and problem location (where the problem is), therefore being “wicked”.

Due to the differences between design and other knowledge areas, Cross (1982) explored the idea of design as a discipline, as designers are responsible for making things and designing them; for the author, there is a “designerly way of knowing”. Cross (1982) proposed that the design discipline could be distinguished for 1) the ability to solve wicked problems focused on the solution, instead of optimising, as the design is a process of “satisficing” (not optimising), as already introduced by Simon

(1969); 2) a specific mode of cognition, using the abductive reasoning, and synthesis (Lawson, 2006; Simon, 1969); 3) the use of mental imagery, as a nonverbal form of thinking and communicate, in particular, the use of sketches as a code that transforms thoughts in words and the use of objects as a language that designers can write and read.

Schön (1983) continues defining the way designers think. Schön describes technical rationality as limited by focusing on the solution instead of the problem, the decision-making process, the objectives to meet and the means to reach. The author introduced the process as the reflection in practice: how the individual thinks of his knowledge while practising it. Reflection in practice requires a constant reframing of the problem and a constant understanding of the interactions between the means and the end (needing to adapt to the situation as the unexpected results emerge), as evident in professions such as clinic psychology, design and architecture.

While for Schön (1983), the design process is based on a dialogue between the designer and the situation, Rowe (1987) approaches structures it in a way of inquiry, such as the scientific method (Rubin, 1990). Based on their experience with architecture students, the author wrote about DT as a decision-making process, denying, however, the idea of an ideal step-by-step sequence; instead, for the author, design follows an episodic structure, described as a "movement back and forth between areas of concern" with periods of speculation and contemplation. Rowe tries to identify a generic problem-solving procedure and understand the source of the concepts that construct the frameworks, as the answer is not only in the problem-solving methods but also in the frames applied to them. However, the constant reframing of problem-solving leads to uncertainty, which is both frustrating and joyful for the designer, as conflicts often stimulate creativity (Cross, 2007).

Dorst (2011) describes the DT framework using formal logic (induction, deduction and abduction) and compares the framing application by novice or expert designers. While students generate proposals for the 'how' and the 'what' and match them, experts develop 'frames'. However, when the problem is a paradox, even an expert need to keep reframing the problem. Experienced designers only start working on a solution once the core paradox has been established; thus, they search for clues by broadening the problem context. To create new frames, expert designers deal with analysis, creating 'themes', or "a sense-making tool". Despite 'themes', which can be seen as outside the core of the problem, they become the triggers for creating new frames and finally finding a solution. Thus, personal traits, skill training, and experience contribute to how designers solve problems.

Although Simon (1969) already expanded the discourse of design to other areas, Buchanan (1992) popularised it, referring to design as a flexible area still expanding to very different knowledge fields. Buchanan defines DT as a "liberal art", as it may present in daily lives and every knowledge area,

resulting from integrating disciplines towards a productive end. According to the author, design as the "new liberal art" makes part of the expansion of design as a technical profession to an art that renews the connection between the various specialisations.

Brown (2008) describes DT as a human-centred design methodology, where the innovation is powered by the direct observation of the end user's needs; the process is described as a system of spaces: inspiration, ideation, and implementation, which are used iteratively. In the inspiration phase, the problem (or opportunity) is explored; the ideation is the phase of generating ideas, developing, and testing them; and the implementation phase is the project delivery to the consumers (Brown & Wyatt, 2010). The author describes DT as a team-based approach to innovation and defines DT as "a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity", referring some aspects to take in consideration for the process to succeed: involving DT since the beginning, taking a human-centred approach, using experimentation and prototype in early stages, use co-creation, blend big and small projects, adjust the budget to the speed of the project, look for an interdisciplinary team, and design by cycles. Collaboration and integration are also essential for the design's success so everyone can participate.

2.2.2 Design thinking reviews

Liedtka (2015) reviews the definition of DT, dividing it into two branches: the used by Rowe (1987), empirical and oriented to architecture, and the popularised by Kelley and Littman (2005), based on companies' experiences and used in management. This view is also shared by Kimbell (2011), who divides the DT views into three parts: DT as a cognitive style, DT as the general theory of design and DT as an organisational resource. Johansson-Skoldberg et al. (2013) also divided DT: 1) "the designer's practice" and academic theory of design and 2) the use of design practice and competence by non-designers (for example, managers) in a simplified designer way. According to the authors, both refer to design practice; however, while Designerly Thinking is academic, the DT discourse is written for a management audience, leading to a non-empirically based discourse. The authors conclude by outlining that both concepts are so different that they cannot be merged.

Micheli et al. (2019) define DT as an "umbrella construct"; If it provides a way to organise findings, these constructs are also at risk of being untenable due to a lack of clarity and coherence. The authors started by reviewing the literature, seeking commonalities in descriptive elements of the term and patterns of its use, namely 1) Creativity and Innovation; 2) User-centeredness and involvement; 3) Problem-solving; 4) Iteration and experimentation, 5) Interdisciplinary collaboration, 6) Ability to visualise; 7) Gestalt view; 8) Abductive reasoning; 9) Tolerance of ambiguity and failure; and 10)

Blending rationality and intuition. The authors also referred to the tools and methods used: prototyping, visualisation, ethnography, experiments, brainstorming, journey maps, personas and mind map (for order of frequency).

2.2.3 Design Thinking as a process

The implementation of the DT approach as a method has also been studied. Carlgren et al. (2016) found five common characteristics that define the DT approach as a method: 1) user focus: 2) problem framing, 3) visualisation techniques, 4) experimentation and 5) diversity. Despite these common characteristics, the author concluded that how each company employs DT depends on their needs, sources of knowledge and organisational context. Waidelich et al. (2018) also studied the typical characteristics of the various theoretical DT methods, finding three main phases: the understanding, the ideation and the prototyping phases. Similarly to Carlgren et al. (2016), the author states there is no standardisation; however, Waidelich et al. (2018) relate the similarities to the popularity of the IDEO model and the Stanford d.School (Brown, 2008; Dunne & Martin, 2006; Kelley & Littman, 2005).

2.2.4 Bias and their mitigation

According to Liedtka (2015), DT applied to innovation may suffer from some cognitive bias. The author presents those biases and how they can be minimised.

Idea generation bias (designer-related bias)

Idea generation may suffer from three types of bias produced by decisionmakers: 1) The projection bias, as the designer may see others' past experiences as their owns, impacting the generation of new ideas; 2) The egocentric empathy gap, or de idea that the designer preferences are the users' ones, which impact the creation of ideas that generate valuable outcomes for the consumer and 3) The focusing illusion, where the designer narrow his attention to one focus and forgets about alternatives, thus leading to a narrow range of ideas.

This bias can be minimised by 1) collecting consumers' data from the beginning, including their concerns and perspectives, by using ethnography; *2)* improving designers' capacity to better emphasise the consumers by using visualisation techniques (ex. Journey maps) and 3) to work on teams and using collaborative ideation tools.

Biases Introduced by consumers

Consumers can also be responsible for biases as they struggle to express their needs. The authors encourage the use of projective methodologies and prototyping and the use of methods that do not rely only on consumers to find their needs, including observation.

Biases on testing

Biases can also be found in the testing phase. The author names four biases: 1) Planning fallacy, which can be described as overoptimism, 2) Confirmation bias, as the designer looks at his hypotheses as the chosen by the consumers; 3) The endowment effect, described as the attachment to the first solution; and the availability bias, described as the preference for what can be easily obtained.

To minimise these biases, the authors propose 1) helping designers to become better testers through ethnography; 2) working with more options at the testing phase; and 3) reflecting on the real experiments, as failed experiments act as if they are a way of learning and improve the method.

2.2.5 Food Design Thinking

Although few authors have theorised about Food Design Thinking (FDT), it has emerged as a promising approach to revolutionize food product development by strongly emphasising consumer empathy and early-stage consumer involvement. One of the first works regarding FDT has been published by Olsen (2015). The author highlighted the significance of consumer empathy and early-stage consumer involvement in food development, contrary to the prevailing industry practice of treating consumers as validators. Olsen considers that consumers should be involved in a starting point of food innovation and collaborate with the industry through the process, testing prototypes and giving feedback. Supported by Liedtka's (2015) bias reduction proposal, Olsen suggests that DT offers a cost-effective and expeditious approach to generating radical innovation.

Zampollo and Peacock (2016) define FDT as creating food products, services, or systems with design methods and tools tailored to foster reflection on the eating experience. The authors developed the Themes for Eating Design (TED) method, recognising the necessity for dedicated design methods and tools. TED is based on a tool comprising food-related images and adapted to generate descriptive elements related to the food experience. Building upon TED, the authors designed the Thoughts for Food tool, which consists of cards featuring icons with a corresponding word on the front and a description on the back. Empirical testing of TED and Thoughts for Food yielded highly positive outcomes, leading the authors to conclude that these tools pave the way for establishing FDT as a distinct and promising discipline in food innovation and development.

Stage-Gate (Cooper & Kleinschmidt, 1993) has historically been the most widely utilized framework for food product development, offering advantages such as accelerated development. However, its rigidity has prompted the need for updates and modifications over time. Franchini et al. (2017) delve into the coexistence of Stage-Gate and DT approaches within organizations. They conducted a study employing both methodologies in a company, employing DT to generate ideas and Stage-Gate to

process them. The findings revealed that the traditional Stage-Gate model tended to "fail in balancing exploration and exploitation, " leading to internal challenges concerning employee and resource management. Despite these limitations, the authors acknowledge the potential benefits of integrating both approaches and call for further research to explore their harmonious integration to effectively enhance food product development processes.

Shimek (2018) underscores the importance of adopting the DT approach in the cereal industry. The author attributes this significance to several factors, including the advent of new technologies, ingredients, and products, but also the changes in consumer attitudes towards carbohydrate-rich foods, with the popularity of "low-carb, high protein" diets. Recognising the importance of consumer behaviour, the author suggests that the focus should be on identifying novel opportunities based on their beliefs. DT emerges as an innovation process that effectively bridges qualitative consumer studies with tangible product design, fostering enhanced consumer engagement. Shimek highlights five essential characteristics of DT that benefit product development in the cereal industry: 1) Multidisciplinary Collaboration, emphasizing the importance of cross-disciplinary teamwork to pool diverse perspectives and expertise; 2) Building Empathy, fostering a deep understanding and connection with consumers, customers, and key stakeholders to align products with their desires and needs; 3) Idea Development with Consumer Involvement, involving consumers directly in the ideation process to co-create and refine concepts; 4) Rapid Prototyping, utilizing swift and iterative prototyping to test ideas, gather feedback, and refine product concepts; and 5) Human-Centered Storytelling, creating narratives that resonate with consumers, ensuring that products are meaningful and relevant to their experiences and aspirations.

The few results found on FDT applications in new food product development reflect the novelty of the concept in the realm. Bunyamin et al. (2020) used a DT approach to solve the problem of the great production and low consumption of Tengkawang oil by developing food products with community collaboration. Hastie et al. (2021) also employed a DT approach to promote the consumption of aged Cull Ewe meat in Australia, and Tkaczewska et al. (2021) proposed a protocol to design food products with functional properties based on the DT approach, applying it to the case of an antioxidant-rich snack.

2.3 RICE AND ITS COMPOSITION

Usually, rice is consumed after dehulling and milling. The milled grain (endosperm) consists of 70 % of the whole paddy grain; the other 30 % are side streams of the process and include husk, bran, and germ. RB accounts for 8 % of the grain (Van Hoed et al., 2006) and, despite being rich in protein (17–

30 %) and oil (20–23 %) and a source of bioactive compounds (Saunders, 1985), is still used mainly as animal feed (Esa et al., 2013).

Milled rice is composed essentially of starch and protein, while RB contains mainly oil, protein, and dietary fibre, including cellulose and hemicellulose, which are known for their functional properties (Revilla et al., 2009; Qiu et al., 2017).

2.3.1 Rice composition

2.3.1.1 Rice starch

Rice grain consists of about 80 % starch (USDA, 2016), which are polysaccharides composed of glucose units linked by α-D- (1-4) and/or α-D- (1-6) bonds that are composed of two different molecules: amylose, a linear chain molecule and amylopectin, a branched glucan (Sajilata et al., 2006).

According to Juliano et al. (1981), rice grains are classified according to their amylose content as very low (5–12 %), low (13–20 %), intermediate (21–25 %), and high (25–33 %). The relation amylose/amylopectin content influences the 1) cooking and eating properties and 2) the digestibility characteristics of starch, as a different molecular composition, including molecular bonds, leads to different results when exposed to physicochemical inputs.

The amylose content is negatively correlated to cooked rice's volume expansion, water absorption, and the amount of soluble starch during cooking. The amylose content is also related to hardness, stickiness, colour and gloss, being higher amylose rice harder, crumblier, white and dull (Juliano, 1992).

As rice is consumed after cooking, after the gelatinization of starch (at 85 °C), the granular structure is destroyed, and the starch breaks down to glucose, increasing its availability for enzymatic digestion; starches with higher amylose content are less susceptible to gelatinization, producing a lower glycaemic Index, which is typically in the range of 54 to 121, varying among genotypes and growing regions (Mahasukhonthachat et al., 2010; Mahender et al., 2016; Nugent, 2005).

2.3.1.2 Rice protein

Although the protein content of rice could be influenced by factors such as management and cultural practices, climate and genotype (Champagne et al., 2004), the reference value points out to 6,5 % to 7,5 %; despite has lower protein content than wheat (~13,2%) (USDA, 2016), its lysine content (~3,8%) makes it a high-quality protein (Mahender et al., 2016). Han et al. (2015) showed that RB protein has a higher nutritional quality than rice endosperm protein regarding protein efficiency ratio (PER), net

protein retention (NPR), net protein utilization (NPU), higher digestibility (TD), biological value (BV) and protein digestibility-corrected amino acid score (PDCAAS).

Whole rice protein content is higher than in milled rice due to the bran's protein, which is also high digestible than other animal or vegetable proteins. Due to the higher quantity of bran protein, the grain milling fractions' protein content differs (Han et al., 2015).

Data reported in the literature regarding rice protein solubility fractions vary widely, depending on the rice variety and the extraction procedures. Thus, milled rice is composed of 5-10 % albumin, 7-17 % globulin, 75-81 % glutelin, and (3-6 %) prolamin, whereas in brown rice, it corresponds to 4–6, 6–13, 79–83 and 2–7 %, respectively (Zhao et al., 2012).

The utilization of rice proteins as food ingredients depends on their functional properties, determining the behaviour and performance of food matrices during preparation, processing, storage and consumption; those properties are influenced by the nature and extent of interactions of the proteins with themselves, with other components, and with water in the food system (Panyam & Kilara, 1996). The functional properties required depend on the application of the protein ingredients, namely, solubility, heat stability and surface-active properties, and water and oil absorption.

As rice protein is hypoallergenic food, rice protein-based formulas represent a suitable alternative for children allergic to cow's milk, being an alternative to the hydrolysed cow's milk formulas, soy protein-based formulas or amino acid-based formulas, which can cause allergic reactions, have poor palatability and high cost. Several studies have shown that hydrolysed rice protein-based formulas are tolerated by and nutritionally adequate for infants with cow's milk allergy and thus represent suitable alternatives to the formulas mentioned above, especially when partially hydrolysed and fortified with lysine and threonine (Amagliani et al., 2017).

Rice flour is also a commonly used ingredient in producing gluten-free products (Moroni et al., 2010). Despite the technological difficulties related to the use of gluten-free flour in bread-making, the textural quality of brown rice bread was shown to improve following transglutaminase treatment. According to Renzetti et al. (2012), this effect is to be ascribed to the formation of large protein complexes resulting from glutelin polymerization and the new and stronger hydrophobic interactions among proteins induced by transglutaminase treatment (Renzetti et al., 2012).

2.3.2 Rice Bran and its bioactive compounds

RB is the rice kernel part containing germ, pericarp, aleurone, and sub aleurone (Friedman, 2013). This grain fraction is rich in fibre, containing lipids, protein, and carbohydrates (decreasing order). The compounds found on the bran's layers, as well as its concentrations, vary according to their positioning

in the inner or outer fraction; according to Schramm et al. (2007), the protein was found to be higher in the outer portion of the RB, while RB saccharides, were found to be more concentrated in the inner portion of the bran layer.

RB lipid fraction is the nutritionally richest one, accounting for 20-25 % of the whole RB (Patel & Naik, 2004). The production of rice bran oil (RBO) is one of the utilisations of RB. The oil can be extracted with food-grade solvents, ohmic heating or supercritical fluid. The nutritional importance of RBO arises from its fatty acid profile, as it presents a high content of Linolenic acid. Reis et al. (2022) studied the fatty acid profile for three varieties of *Carolino* rice founding high contents of Linolenic acid 2.00 ± 0.00, higher than the reported for other rice varieties (Chia et al., 2015; Cui et al., 2017; Goffman et al., 2003; Nakajima et al., 2017; Rudzinska et al., 2016) and other vegetable oils, such as olive oil (Orsavova et al., 2015). The analysed samples also presented a PUFA:SFA ratio > 2; given the evidences that the substitution of SFA intakes with PUFA decreased cardiovascular and coronary heart disease events (SACN, 2019). Thus, Carolino RBO has the potential to be used in healthy food formulations (Reis et al., 2022).

RB and RBO are also important sources of bioactive compounds, which are nutrients or non-nutrients present in foods and can produce important physiological effects by protecting against diseases (Cazarin et al., 2022). The lipidic fraction of rice is rich in bioactive compounds, including antioxidants, mainly phenolic acids, flavonoids, anthocyanins and proanthocyanins, tocopherols and tocotrienols, γ-oryzanol, and phytic acid (Goufo & Trindade, 2014) as well as carotenoids, phytosterols, vitamin E, coumaric acid and tricin (Verma & Srivastav, 2020) (

Table 5). The presence of those bioactive compounds and their quantity depends on several factors, such as the degree of milling, variety and colour of the pericarp (Verma & Srivastav, 2020).

Table 5. Antioxidant compounds present in the rice endosperm and bran (Goufo & Trindade, 2014)

	Rice endosperm	Rice bran
Phenolic compounds	7.3-8.7 mg/100g	177.6 to 319.8mg/100g
Anthocyanin	245 mg/100g (whole grain)	1252.7 mg/100g
Tocotrienols and tocopherols	14.5 g/kg	247.2 mg/kg
γ-oryzanol	58.9 mg/kg	3067.1 mg/kg

Despite its compounds' value, RB's use in food products is very low. One of the reasons for that limited use can be its rapid oxidation, as it is easily affected by lipase enzymes, leading to the hydrolysis of triglycerides into glycerol and free fatty acids (FFA). An excess of FFA (10 %) makes the RB and RBO

unsuitable for human consumption; as the RB lipase enzymes need to be inactivated prior to use, this process may discourage the use of RB by the industry (Reis et al., 2022).

2.3.2.1 γ-Oryzanol

Of the bioactive compounds of RB, γ-Oryzanol is (GO) one of the most important, as it is related to several health benefits (Ramazani et al., 2021). GO is a mixture of ferulate esters of sterols and triterpene alcohol, and almost 95 % of total GO content is represented by four significant compounds: 24-methylenecycloartanyl ferulate, cycloartenyl ferulate, campesteryl ferulate and β-sitosteryl ferulate, by decreasing order of abundance (Yu et al., 2007). GO is found in RB at a concentration ranging from 59.4 to 912.0 mg/100 g (Castanho, Lageiro, et al., 2019) and from 100.0 to 2410.0 mg/100g in RBO (Massarolo et al., 2017), depending on factors such as the extraction method and RB origin.

The levels of GO may differ according to the genetic diversity and also by the edaphoclimatic conditions of the growing environment (Bergman and Xu, 2003), such as temperature (Britz *et al.*, 2007) and drought stress (Kumar and Krishna, 2015). Genetics also plays a relevant role in GO content, as some specific alleles may be responsible for GO concentration (Kato *et al.*, 2017; Nakano *et al.*, 2018). The sterol biosynthesis pathway of plants is a sequence of enzyme-catalysed reactions. GO is a mixture of sterols esterified to ferulic acids (Hernandez, 2016), and this process is reported to the action of acyltransferase enzyme (Kumar and Krishna, 2015). Plant sterols can be located with a free 3b-hydroxyl group and conjugated by esterification (Piironen *et al.*, 2000). In the particular case of rice, the main sterols are found as esters of phenolic acids, and sterols esterified to ferulic acids (Hernandez, 2016). In the course of the maturation of rice grain, GO acts as the other phytosterols which plays a crucial role in maintaining the integrity and fluidity of the lipidic membrane of plant cells as they are responsible for different regulatory functions, properties and structure, maintaining the homeostasis of membrane lipids, the integrity of the membrane during stress, regulation of membrane permeability, fluidity, signal transduction events for cell division and the activity of membrane-bound enzymes (Kumar *et al.*, 2015; Valitova *et al.*, 2016).

Most of the studies regarding GO bioavailability were performed in mice and rats. Its absorption can be considered very low, as although more than 80 % remained in the digestive system after 72 h, the maximal plasma concentration is very low (40 µg/ml after an oral dose of 300 mg), which may be related to its low intestinal absorption (Fujiwara et al., 1983; Kozuka et al., 2017; Sawada et al., 2019; Tsushimoto et al., 1991); however, human experiments of GO supplementation in humans showed interesting results.

GO has been studied for its health properties in cell lines, animals and humans. The following paragraphs describe some of the benefits of GO, emphasising the ones performed in humans, as they provide more robust evidence than animal ones.

Eslami et al. (2014) studied the effect of GO supplementation (60 mg a day) on resistance training on muscular strength and anthropometric measurements in 16 healthy athletes during nine weeks against a placebo. The authors found that the supplement did not change the anthropometric and body measurements but increased muscular strength.

Fujii et al. (2018) studied the effect of 100 mg of GO supplementation in patients with dementia. The trial was performed for four weeks in 33 patients against a placebo. The authors reported significant improvements ($p < 0.05$) in the Neuropsychiatric Inventory score (mainly in agitation/aggression, anxiety, irritability/lability, and aberrant motor activity) after the supplementation. However, the Mini-Mental State Examination and Barthel index did not change significantly.

The antidiabetic effect of oryzanol has been studied in animal models by several authors (Chen & Cheng, 2006; Ghatak & Panchal, 2012; Hsieh et al., 2005; Zhu et al., 2019), who reported an amelioration of diabetes effects on rats and mice supplemented with oryzanol, which may be related to the antioxidant effect of oryzanol. However, there are few clinical trials in humans and the existing ones present limitations (Cheng et al., 2010; Kim et al., 2011; Patel et al., 2011; Salar et al., 2016).

The anti-carcinogenic effects of oryzanol were mainly studied in human cell lines (Forster et al., 2013; Hudson et al., 2000; Norhaizan et al., 2011) and animal models (Panala et al., 2009; Verschoyle et al., 2007) with overall positive effects. The human trials performed indicate RB can have a positive effect on the gut bacteria of colon cancer survivors; however, as the GO was not isolated, it is not clear if the effects are derived from the GO or the fibre contained in the bran (Brown et al., 2017; Sheflin et al., 2017).

Berger et al. (2005) studied the effect of RBO containing high (800 mg/50g oil) or low (50 mg/50g oil) oryzanol content on 30 mildly hypercholesterolemic. The authors conclude that the RBO significantly lowered the LDL-C/HDL-C ratio by 19 % over four weeks; regarding the differences between groups, the authors found no statistically significant differences ($p < 0.10$) for all measurements; thus, they point out that these results may not be related with GO content only but with the interaction between the compounds in RBO.

Accinni et al. (2006) performed a four-month clinical trial with fifty-seven volunteers suffering from dyslipidaemia, divided into three groups: A, placebo; B, PUFA n-3 and vitamin E; and C, the same as B plus GO and niacin. The authors reported a significantly higher decrease in LDL-C ($P < 0.0001$), an

increase in total antioxidant capacity and reactive oxygen species ($P < 0.0001$) and an increase in vitamin E ($P < 0.0001$) in group C than in groups A and B. Similarly to Berger et al. (2005) the authors mention the interaction effect between the compounds, furthermore, as in this case, where GO was introduced with niacin.

In a randomized, double-blind controlled trial, Bumrungpert et al. (2019) examined the effects of RBO containing different amounts of gamma-oryzanol on blood lipid, antioxidant, and inflammatory markers, in 59 hyperlipidaemic subjects divided into four groups who received RBO containing 4.000, 8,000, 11,000 ppm gamma-oryzanol and soybean oil for four weeks. The authors reported a decrease of 8 %, 11.8 % and 12.2 % in LDL cholesterol according to the quantity of GO taken by the patients. The authors also reported improved antioxidant status with the consumption of RBO.

Mahdavi-Roshan et al. (2021) performed two similar clinical studies in patients with coronary artery disease supplemented with 30 g of RBO against a placebo for eight weeks. The authors found RBO, the parameters related to the blood lipid profile and glucose index, ameliorated significantly ($p < 0.010$) in the supplemented group.

Salar et al. (2016) examined the effects of RBO, canola and sunflower oils in 75 postmenopausal women with type 2 diabetes. Three groups were supplemented with 30 g of the respective oil for eight weeks. The authors found a decrease in triglycerides, total cholesterol, and LDL cholesterol in the group supplemented with RBO compared to other groups. The levels of HDL cholesterol remained unchanged in all the groups.

2.3.2.2 γ-aminobutyric acid (GABA)

RB also contains γ-aminobutyric acid (GABA), which is a non-protein amino acid that acts as the primary neurotransmitter in the human cortex, being responsible for the balance between the excitation and inhibition of neurons by binding to specific membrane proteins (Petroff, 2002). The presence of GABA is ubiquitous in the human diet, as it can be found in plants, animals, and microorganisms (Ramos-Ruiz et al., 2018).

GABA content can be affected by stress conditions during rice growth, such as anaerobiosis, pH, and temperature (Saikusa et al., 1994). Thus, processes such as germination can increment its content (Pokkanta et al., 2019).

During the germination process, the seeds become fully hydrated, and the nutrients are mobilized to grow the radicle, which starts to emerge; as the seed absorbs more water, the nutrients (i.e. carbohydrates) are massively mobilized to make the seed grow (Nonogaki et al., 2010). During those processes, the α-ketoglutarate (contained in large quantities in the bran) is transaminated to glutamic

acid, which is decarboxylated to GABA through glutamic acid decarboxylase (GAD) (Tsuchiya et al., 2003; Zhang et al., 2007). The amount of GABA in RB ranges from 10.7 - 58.0 mg/100 g (before germination) and can be increased by 90.0–350.0 mg/100 g (after 10–12 h of rice germination)(Oh et al., 2019)

The GABA oral supplementation hypothesis and its potential benefits have been investigated (Boonstra et al., 2015). The authors report the limitations regarding the studies on the permeability of the blood-brain barrier to GABA; however, GABA has been studied as a supplement with interesting results.

Abdou et al. (2006) studied the effect of GABA on 13 patients by oral supplementation of GABA and placebo. The authors measured the patient's brainwaves through electroencephalograms, finding GABA increased alpha-waves and reduced beta-waves, thus suggesting the relaxing effect of GABA. In the same research paper, the authors supplemented acrophobic subjects with GABA, compared with a placebo, before crossing a bridge; the authors found that the subjects supplemented with GABA presented lower stress levels.

Nishimura et al. (2016) studied the effect of GABA on the blood pressure of 39 mildly hypertensive adults in a randomized, double-blind, placebo-controlled study. The patients who consumed rice supplemented with 11.2 mg/100g of GABA for eight weeks had lower morning blood pressure after the first week.

Ito et al. (2005) studied the effect of pre-germinated brown rice, naturally rich in GABA, on postprandial blood glucose and insulin concentrations compared to brown rice and milled rice. The authors measured blood glucose at intervals of 30 minutes until 120 min after ingestion. The authors found that brown and pre-germinated rice had a lower glycaemic index. Hsu et al. (2008) studied pre-germinated brown rice compared to milled rice on blood glucose and lipid concentrations of impaired fasting glucose or type 2 diabetes patients. The study was carried out for 12 weeks, separated by two weeks. The patients consumed 180 g of rice daily, and blood samples were collected at the beginning and end of each period. The results revealed that the pre-germinated rice supplementation improved fast blood glucose, fructosamine, cholesterol, and triacylglycerol levels.

Chapter 3. OBJECTIVES AND THESIS STRUCTURE

Given the introductory context, some questions could be raised and defined at the beginning of this work: 1) why is Portuguese rice's traditional consumption pattern changing and how? 2) why do people prefer milled rice despite all the benefits of whole rice? Finally, and most important, 3) how can the benefits of whole rice be incorporated into the Portuguese diet? Thus, the main objective is to create a rice-based food product that approaches the health benefits of RB to consumers, functioning as an easy way of including those products in the Portuguese diet.

As those questions are difficult to answer and the problem is tricky to solve, the DT approach was investigated and adopted to frame the problem.

A framework based on the DT approach applied to food was created to answer all the proposed objectives. **Figure 9** shows the work process and how the resulting papers are interlinked. A brief description of each study is presented below.

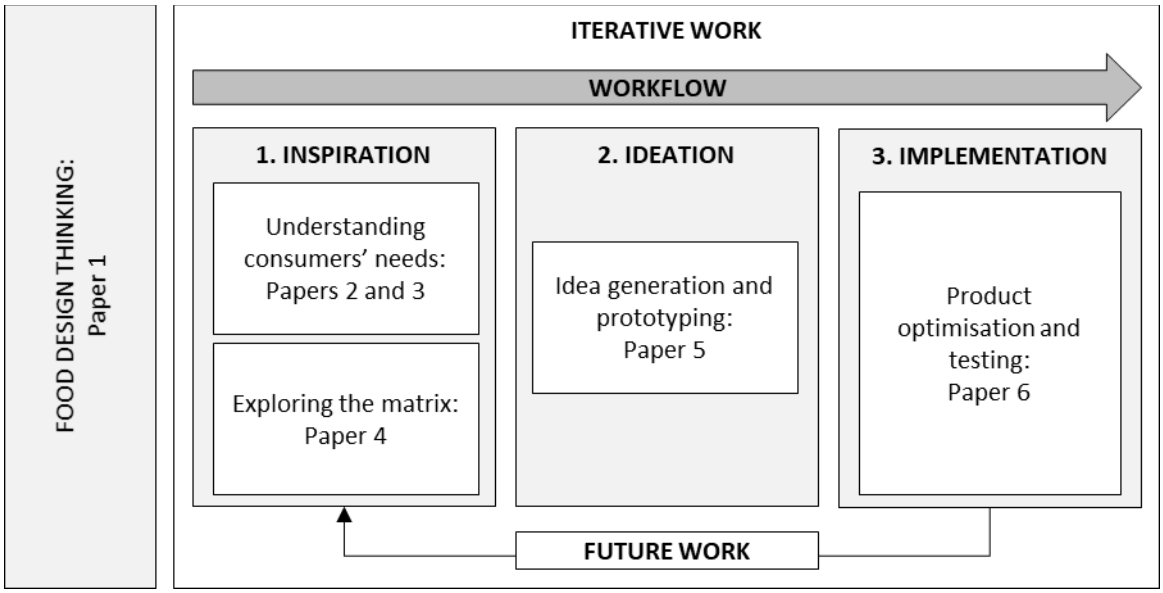


Figure 9. Thesis structure diagram.

At first, a systematic review was performed regarding FDT to understand its roots and how it can be applied to food product development (Paper 1). From there, a workflow based on the ideas of Brown (2008) was implemented: on the Inspiration phase, the FCQ was modified by using an image-based tool, which was developed in two iterations: the first consisted of a pilot study to test the image based tool (Paper 2), which was then improved, together the questionnaire development, implementation and result analysis (Paper 3). In the same phase, the food matrix was explored to understand some gaps in the literature, such as the cytotoxic and antimicrobial capacity of RB extracts containing GO (Paper 4).

In the Ideation phase, a first approach was implemented: a group of MSc students with former education in culinary arts was asked to create innovative rice-based products through a free brainstorming exercise grounded on the information gathered in the former phase. Professional chefs evaluated the concepts. A second iteration of the process, involving a brainstorming exercise based on a developed tool, was then performed (Paper 5).

A rice-based beverage, selected from the products Ideated in the former phase, was optimised to its bioactive compounds (GO and GABA) and presented to Portuguese consumers at a science fair (Paper 6).

The list of papers is presented below:

1. Castanho, A., Brites, C., Oliveira, J.C., & Cunha, L. M. Food Design thinking, a systematic review from an evolutionary perspective *(under submission)*
2. Castanho, A., Cunha, L. M., Oliveira, J. C., Guerra, M., & Brites, C. (2018). Understanding rice consumption and encouraging consumer empathy through design thinking. In Experiencing Food, Designing Dialogues. (Eds) Bonacho, R., Sousa, A.P., Viegas, C., Martins, J.P., Pires, M.J., Estêvão S. V., (pp. 109-116). CRC Press.
3. Castanho, A., Brites, C., Rocha, C., Oliveira, J.C., & Cunha, L. M. (2023). Adaptation and application of the food choice questionnaire to rice consumption: a design thinking approach. Food Quality and Preference. 110, 104951. doi: 10.1016/j.foodqual.2023.104951
4. Castanho, A., Guerra, M., Brites, C., Oliveira, J. C. & Cunha, L. M., (2023) Design thinking for food: remote association as a creative tool in the context of the ideation of new rice-based meals. International Journal of Gastronomy and Food Science. 31, 100664. doi:10.1016/j.ijgfs.2023.100664
5. Castanho, A, Lageiro, M, Calhelha, RC, Ferreira, ICFR, Sokovic, M, Cunha, L., & Brites, C (2019). Exploiting the bioactive properties of γ-oryzanol from bran of different exotic rice varieties. Food and Function. 10, 2382-2389. doi:10.1039/c8fo02596g
6. Castanho, A., Pereira C., Lageiro, M., Oliveira, J.C., Cunha, L. M., & Brites, C., Optimisation of a rice beverage to its bioactive compounds through germination and fermentation (2023). Foods. 12, 1476. Doi:10.3390/foods12071476

Chapter 4. **PAPER 1. FOOD DESIGN THINKING, A SYSTEMATIC REVIEW FROM AN EVOLUTIONARY PERSPECTIVE**

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foods

MDPI

Review

Food Design Thinking, a systematic review from an evolutionary perspective

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Abstract: Design Thinking (DT) has been a subject of extensive debate and application across diverse knowledge domains, including the food realm; nonetheless, its precise definition remains unclear. This systematic review comprises two components. Firstly, it examines the evolving understanding of DT by aggregating pertinent studies selected based on their representativeness, determined by the volume of citations. This process was facilitated through the utilisation of citation mapping software, complemented by an analysis of the most pertinent reviews within this domain. Secondly, it investigates the Food Design Thinking (FDT) approach. The review encompasses a total of 22 references and reviews in the first segment and 27 studies in the second segment. In Part 1, the results reveal the emergence of two principal areas of investigation, namely education and management, stemming from the foundational DT theory. Furthermore, the findings highlight that DT has assimilated the knowledge gathered from these domains. In Part 2, the outcomes illustrate the utilisation of FDT to address a multitude of food-related issues, including education, sustainability, health and wellbeing, and food product development. From this analysis, it becomes notable that this approach presents contextual variations while emphasising the notion of consumer integration throughout the FDT process.

Keywords: Food Design Thinking; Design Theory; Design Thinking Application; PRISMA

1. Introduction

The expression "Design Thinking" (DT) has been increasingly referred to in the literature. When searching for the expression in the most relevant academic databases, such as Scopus or Web of Science, between 2005 and 2022, it is possible to verify that the published works show a positive growth rate. Furthermore, when analysing the search results, it is possible to confirm that the expression is commonly used in various research areas, such as engineering, computer science, education, economics, social sciences or healthcare. Although in food studies and respective knowledge fields (e.g., nutrition or food engineering), the expression is not so present as in the knowledge areas mentioned above, some authors [1,2] noted that DT could also be useful for food innovation.

As already exposed by others [3-5], the expression DT is used in divergent ways: as a transdisciplinary and user-centred method directed to innovation and popularised by IDEO and Stanford d.School [6,7], or a part of the designers' activity discussed by design theorists authors such as [8-11].

While this discussion regarding DT is relatively recent, the Design concept, and in particular the ways of thinking about design and design problems, was also discussed before [12], while for Alexander [13], Design is about doing physical things (giving form, organisation and order, working on the CONCRETE realm); for Simon [11] it is the

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"knowledge" that allows human action to respond to problems, working on the ABSTRACT realm. Traditionally, the designer was seen as an artefact maker and the Design and the making co-occurred; as the concept evolved, the artefact-making and the DT separated into different realities, where the making is usually be completed after the thinking process [14].

While some divergence may contribute to a healthy discussion and the concept evolution, the DT concept, particularly the simplistic way it is used and what it promises, is seen by others as a fad, as McCausland [15] reported. In her speech at the Adobe 991 Conference, the designer Jen [16] criticised DT, pointed out the simplistic way the design practice is summarised in a 5-step linear diagram, and how the design theory authors are excluded from the current DT approach [16]. In his blog, the designer Ricardo Martins expressed his idea on why DT is a fad based on a work by Miller, Hartwick, *et al.* [17], who define a fad as a series of statements that propose a quick fix for a problem and have a typical life cycle: become popular quickly, stay popular for a few years and have an abrupt decline in interest. For Miller, Hartwick, *et al.* [17], there are also common characteristics of management fads, which Martins [18] correlated with DT: it is simple, promises too much and can be applied to any context; it can be implemented incompletely, which allows managers to believe they are being modern without a final evaluation on the DT strategy success; the author refers DT only reformulates old ideas more appealingly, in accordance to the zeitgeist, and although it was created by theorists, a well-known company popularised it. Bruce Nussbaum, one of the advocates of DT, considers "the success rate for Design Thinking processes was very low", and the expectations about how DT could be a linear methodology that could deliver innovation did not meet reality [19]. Michael Hendrix, an IDEO partner, states that many people use DT in "superficial ways", turning it into a "theatre of innovation", and argues DT is not a formula but instead, a set of "milestones in the creative process", and its success depends on the company culture [20].

The use of DT in food studies is relatively new; however, some authors advoke the use of the Food Design Thinking (FDT) approach can benefit innovation in the field by integrating the consumer not only as a validator but as a point of departure for innovation; furthermore, FDT also presents other advantages in this domain, as it is claimed to promote faster results through rapid prototyping and a more hands-on approach [2,21].

Citing Liedtka [22], "bringing rigorous empirical scrutiny to the design-thinking process could itself be construed as a wicked problem: the problem can be defined in many different ways". Considering the difficulties inherent to the definition of the DT concept, this review aims to identify the roots of DT from a historical perspective based on its academic citation network. It also focuses on FDT and its discussion and application.

2. Methodology

The research methodology was divided into two parts: 1) a review of the roots of DT and 2) a review of the FDT approach.

In the first part (Figure 1), the research was based on the most cited works and is divided into two research branches. The first branch aimed to identify the most cited works in the DT literature. To determine the most cited works, a research based on the expression "design think*" was conducted using the Web of Science (WOS) search engine, considering its presence in the title, abstract or keyword fields. The references were extracted as "full reference", which included citations; thus, the retrieved database consisted of the original text and cited works. Both original and cited works references presented some inconsistencies in some fields; for instance, some author names had different spellings (e.g. Simon AH., Simon H. or Simon H.A.); therefore, entrances for those fields were standardised by using Visual Studio Code v. 1.8 as database code editor to find, replace or correct the inconsistent data. The standardised data was explored using the citation network manager CitNetExplorer V1.0.0 (Leiden University). The most cited references (> 100 citations) were used as data sources for the review.

The second branch of the first part consisted of selecting relevant review works to complement and validate the data found in the first branch. The research and selection for review papers regarding the DT was performed by using the Prisma 2020 Statement method [23] by retrieving the works on WOS and Scopus databases, parting from the expression "design think*" AND "review*" OR "overview*" (in the title, keywords and abstract). 118 review papers were screened after carefully reading the title and abstract. Several works (n = 92) were removed in the screening phase due to several factors, such as being out of scope, as the expression only appeared as keywords, or, in other cases, DT was only used superficially, not being the central theme of the review. After joining the two branches, 23 studies were selected for review in Part 1.

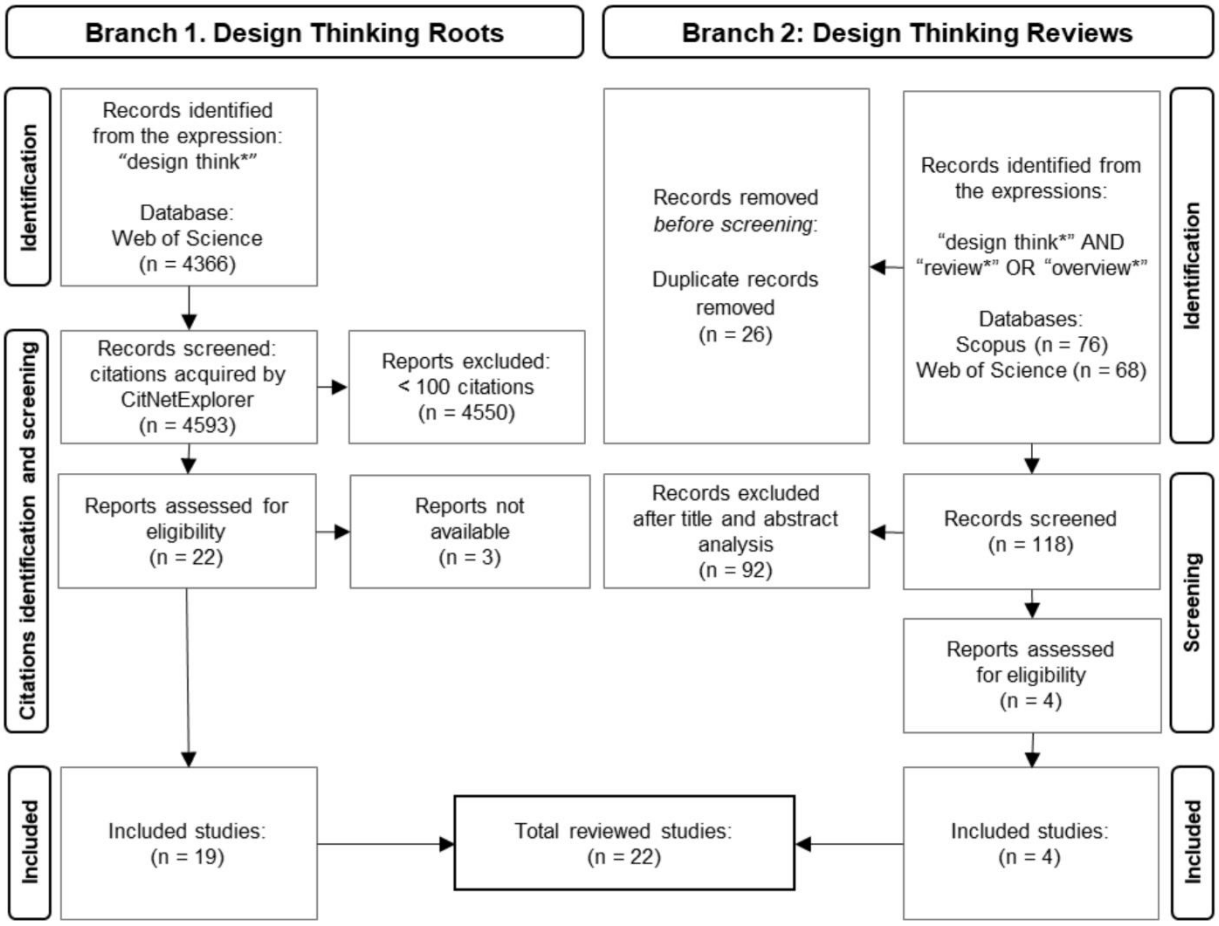


Figure 1. Schematic view of the methodology used to identify and screen the most cited works regarding Design Thinking (Branch 1) and PRISMA methodology used to obtain the most relevant reviews.

For Part 2, a search for "design think*" AND "food" (in the title, keywords and abstract) was performed in WOS and Scopus. The Prisma 2020 Statement method [23] was used to screen the references. The refinement of the obtained works is shown in Figure 2. From the 116 original papers, 56 were excluded in the first phase, as the abstract did not contain the expression "Design Thinking" (n = 17), were not in English (n = 2), were not research papers (n = 9) or were not accessible (n = 28). From the remaining documents (n = 60), 33 were removed after a second screening: the abstract was carefully read, and 33 papers were excluded due to FDT not being the paper's central theme. The 27 remaining papers were grouped according to the subject and content analysed.

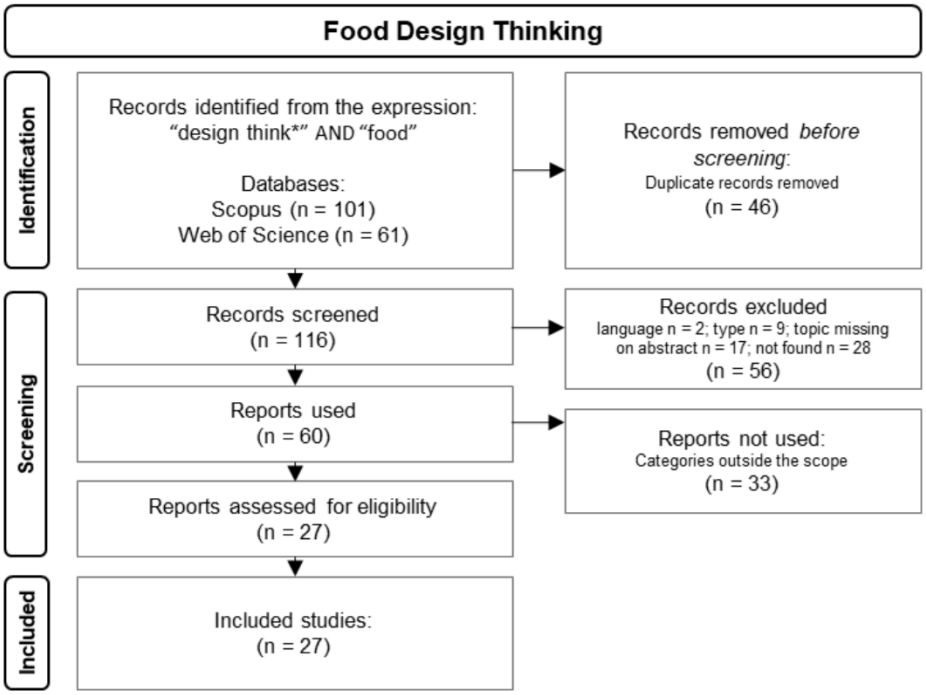


Figure 2. Schematic view of the PRISMA methodology used to obtain the data for Part 2.

3. Results and discussion

3.1 Methodological notes

Due to the incredible popularity of DT and its inclusion in many areas as an "umbrella concept" [4], works on the theme abound. Considering this particularity, the approach to the first phase is intended to capture the essence and the evolutive course of *what DT is*. Due to the intense discussion on the subject, with some designers arguing against the "management DT approach", labelling it as a *fad* [15], the applied paper identification and screening methodology for the branch of the first part intended to minimise the researcher bias by including the most referred works used in the theme with little human intervention, being guided by a citation network manager (CitNetExplorer). Although the CitNetExplorer only worked with references from WOS, due to technological limitations, the advantages of being a simple and objective tool were considered more important in this scenario; furthermore, this approach allowed to explore relevant works that, despite not being indexed to scientific databases, consisted of the most essential works on the theme (considering Design academic works, and moreover the older ones, are based on books with no experimental data). Since the method could present limitations, such as missing essential pieces or concepts, a collection of reviews was analysed to complement the work.

The second part of the study revealed how the DT expression is used by many authors to promote the studies, taking advantage of the DT trend. This can be observed by the number of studies collected that passed the first screening phase and were discarded. Many of the studies used "Design Thinking" as a keyword or in the title, even though the theme would not be the focus of the work and, in some cases, the exact wording did not appear in the whole paper. This might be one of the causes of DT being considered a *fad*.

3.2 Part 1. Design Thinking Roots

The references included in the citation analysis and the selected reviews are presented in Table 1, grouped by chronological order and theme, representing the order of this review.

Table 1. Reviewed documents grouped by theme, including publication date, citation count and main subject discussed

Author (date)	Publication date	Citation count	Main contribution
Design Thinking			
Simon [11]	1969	195	The Science of Design
Rittel and Webber [24]	1973	192	The nature of design problems
Schön [25]	1983	199	Reflection in practice
Rowe [26]	1987	164	The episodic structure
Buchanan [8]	1992	312	Design as a liberal art
Brown [6]	2008	582	The human-centred Design
Dorst [27]	2011	280	Design process and logic
Education and experiments			
Dorst and Cross [28]	2001	146	The surprise element
Dym, Agogino, *et al.* [29]	2005	228	Design in engineering education
Cross [30]	2007	152	Novice vs. Expert designers
Razzouk and Shute [31]	2012	179	Novice vs. Expert designers
Seidel and Fixson [32]	2013	112	Brainstorming in education
Design Thinking and management			
Dunne and Martin [7]	2006	190	User-centred approach on DT
Brown [33]	2009	307	DT applied to business
Martin [34]	2009	228	Traditional/DT-based companies
Brown and Wyatt [35]	2010	173	DT in management
Design as a process			
Beckman and Barry [36]	2007	144	DT as a learning process
Carlgren, Rauth, *et al.* [37]	2016	117	DT process in companies
REVIEWS			
Liedtka [22]	2015		Biases on DT
Kimbell [12]	2011		The three types of DT
Micheli, Wilner, *et al.* [4]	2019		Defining DT
Waidelich, Richter, *et al.* [38]	2018		The DT processes

As some concepts are common in the reviewed references (Table 1), before further exploring the results, those concepts are presented below.

- Analysis and synthesis: The concepts of analysis and synthesis have been discussed since Plato as methods of inquiry. Plato distinguished two forms of inquiry: division (διαίρεσις) and bringing together (συναγωγέ); thus, analysis stands for Platos' division, which means proceeding from whole to parts, and synthesis, from Platos' bringing together, means arranging the parts in wholes [39].
- Divergent and convergent thinking: The concepts of divergent and convergent thinking were established by Guilford [40] in his research on creativity theory. Divergent thinking is a major component of creativity. It is characterised mainly by the ability to produce many solutions to a problem. Contrarily, convergent thinking is the ability to synthesise all the alternatives into a single solution.
- Wicked problems: Sometimes designated by ill-defined problems, wicked problems, as proposed by Rittel and Webber [24], can be identified by ten characteristics: 1) having an unclear definition, as the understanding of the problem depends on the

idea to solve it, therefore the formulation of the problem is a problem itself; 2) having an unclear end, as there are no criteria for when the work is complete; 3) the solutions are "good or bad" not "true or false", as the evaluation is not objective but subjective, depending on the interests, ideologies or values of a community or individual; 4) there is no immediate or ultimate test for the solution; 5) the solution have consequences, and this applies in the particular case of planning in a large-scale as every implemented decision is irreversible; 6) the solutions for the problem are unlimited; 7) every problem is unique; 8) the problems can be interlinked with others, causing another problems; 9) the problem can be represented in varied ways; and 10) the planner has no right to be wrong, as the actions have real consequences.

- Human-centred DT vs User-centred DT: Human-centred DT, as proposed by Brown [6], includes the insights from people from outside the design project; user-centred design DT, as proposed by Dunne and Martin [7] is focused particularly in the users, how to understand them and include them in the process of DT.
- Deductive, inductive and abductive reasoning are based on Aristotelian logic. Deductive reasoning is a "way of thinking that relates ideas to one another in reaching conclusions". In contrast, inductive reasoning "uses a specific observation to reach a general conclusion" [39]. According to Peirce's theory [41], abduction is "the process of forming explanatory hypotheses". It includes "all the operations by which theories and conceptions are engendered". To better understand these concepts, Dorst [27] exposed them visually (Figure 3).

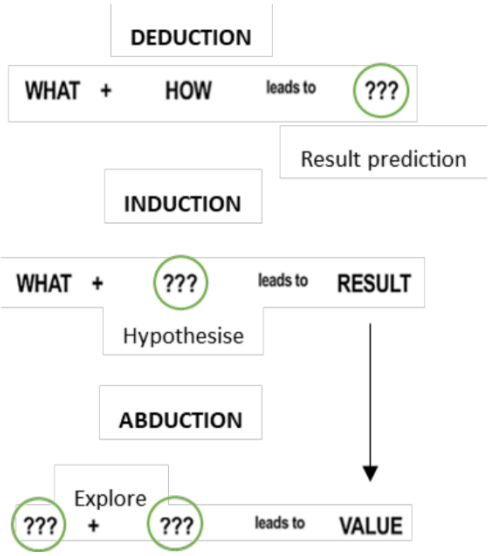


Figure 3. Inductive, deductive and abductive reasoning based on Aristotelian logic. Adapted from Dorst (2011).

3.2.1 Design Thinking

The Sciences of the Artificial, by Simon [11], significantly impacted the literature in different knowledge areas, being considered "one of the most influential texts in the 50-year history of the development of design theory" [42] and has been reviewed by authors since it was first published [42-44]. The Sciences of the Artificial was later updated by Simon and republished in 1981 and 1996.

To better understand The Sciences of the Artificial and its impact, it is essential to state that it was first published at the beginning of the third industrial revolution when there was a fascination with computers and automation; therefore, there was a desire to also "scientise" Design, which led to "the design methods movement" in the 60s [42].

Simon [11] describes Design through the concept of artificial. Artificial things are material (or conceptual) things created by men in opposition to natural things. There is, therefore, a distinction between science and engineering as disciplines. While science is interested in observing and analysing what things are, engineering is concerned with creating the artificial or achieving a specific goal and function. For Simon [11], the natural and the artificial interact and influence each other as a system, as the artificial things are made of natural materials, and the artificial influences the natural. This interaction is mediated by the artefact, which is the interface between this system's interior and exterior. Thus, the designer's role is to draw the limit between the interior and exterior, which functions as a homeostatic mechanism.

This theorisation led to the idea of Design as "The Science of the Artificial", the same way there are "Natural Sciences". Additionally, a designer is seen as someone who changes "existing situations into preferred ones", which presupposes a problem-solving approach, a broader definition of what a designer is, bringing professions such as engineering, architecture, business, education, law and medicine to the design field.

While Simon [11] proposes a "scientifisation" of Design, the author believes a set of problems cannot be solved linearly. Regardless of sharing Simon's view [11] on the distinction between natural and artificial, Rittel and Webber [24] focused on the question of problems. In "Dilemmas in a General Theory of Planning", Rittel and Webber [24] define Design problems as "wicked" and cannot be solved in the linear way science proposes. For Rittel and Webber [24], natural sciences' problems are well-defined, separable and have findable solutions. In contrast, the design problems need to find the problem definition (the difference between the observed and the desired) and problem location (where the problem is), therefore being "wicked".

Schön [25] continues defining Design by comparing it with natural sciences in his book *The Reflective Practitioner: How Professionals Think in Action*. However, the author focuses on how designers think while criticising how technical rationality sees Design. While earlier authors (e.g. Simon [11], focused on the solution, the decision-making process, the objectives to meet and the means to reach them), Schön [25] introduced the Design process as a process of reflecting in action. Reflection in action requires a constant reframing of the problem and a continuous understanding of the interactions between the means and the end (needing to adapt to the situation as the unexpected results emerge), as evident in professions such as clinical psychology, Design and architecture.

While for Schön [25], the design process is based on a dialogue between the designer and the situation, Rowe [26] approaches it to a more structured process, such as the scientific method [45]. Based on their experience with architecture students, the author wrote about DT as a decision-making process, denying, however, the idea of an ideal step-by-step sequence; instead, for the author, Design follows an episodic structure, described as a "movement back and forth between areas of concern" with periods of speculation and contemplation. Rowe [26] tries to identify a generic problem-solving procedure and to understand the source of the concepts that construct the frameworks. For Rowe [26], the answer is not only in the problem-solving methods but in the frames applied to them.

For Rowe [26], the constant reframing of problem-solving leads to uncertainty, which is both frustrating and joyful for the designer. Despite these rapid changes being essential to the design process, as the conflicts often stimulate creativity [30], it requires the designer to have some specific personality traits, such as being aware and sensitive to nuances of environments, noticing coincidences, recognising opportunities, identifying favourable conjectures, becoming profoundly involved or being optimistic. However, although personality and personal motivations are important, designers can exercise their skills [26], which have been studied by other authors (Section 3.9).

Dorst [27] describes the DT framework using formal logic (induction, deduction and abduction) and compares the framing application by novice or expert designers. While students generate proposals for the 'how' and the 'what' and match them, experts develop

'frames'. However, when the problem is a paradox, even an expert needs to keep reframing the problem. Experienced designers only start working on a solution once the core paradox has been established; thus, they search for clues by broadening the problem context. To create new frames, expert designers deal with analysis, creating 'themes', or "a sense-making tool". Despite 'themes', which can be seen as outside the core of the problem, they become the triggers for creating new frames and finally finding a solution. Thus, personal traits, skill training, and experience contribute to how designers solve problems.

3.2.2 Design Thinking as a liberal art

Although Simon [11] already expanded the discourse of Design to other areas, Buchanan [8] popularised it, referring to Design as "the new liberal art" or a flexible area that could expand and integrate very different knowledge fields, being also present in daily lives, leading to a productive end. The idea of the expansion to other areas, as proposed by Buchanan [8], materialised as DT was integrated into design education and management.

Dym, Agogino, *et al.* [29] discussed the importance of Design in engineering education, as engineering leads with "processes whose form and function have to achieve clients' objectives or users' needs while satisfying a specified set of constraints". DT should be, therefore, included in the engineering context by a) including divergent-convergent thinking to deal with wicked problems; b) applying the framing process to decision-making; c) promoting teamwork and user-centred Design; e) using both the language of Design and engineering by mixing verbal, graphic and formal and representation and numbers or analytic models.

Dorst and Cross [28] experimentally studied the creative process in the education context, describing Design as a matter of developing and refining in an iterative process of analysis, synthesis and evaluation occurring in two design spaces: problem and solution. This idea of co-evolution of the design process was also referred to by other authors [25,26]; the dialogue between the problem and the solution ends when a "problem-solution pair" or "problem framing" is created. The authors introduced the notions of "default" and "surprise" being the "default" questions given by constraints and the "surprise" by the designers, leading to a process of a "burst of development" instead of a gradual change. Cross [30] also explored the differences between novice and expert designers, concluding that novice designers usually identify a problem aspect and immediately begin exploring its solution in depth. In contrast, expert designers move quickly to early solution conjectures and use these conjectures to explore and define problems and solutions together. The change of focus from the problem to the solution appears to be a feature of design expertise that develops with education and experience in designing [30].

Seidel and Fixson [32] studied the use of brainstorming in multidisciplinary teams, concluding that it resulted successfully during the whole process and the integration of new members to the team. Based on experimental studies, Razzouk and Shute [31] conclude that including DT in education may better prepare students for real life by teaching them to solve complex problems and develop critical thinking skills.

DT was also employed in the management field. The reviewed works on the theme are similar, as the authors oppose the traditional management model to a new one. For Brown [33], the need for this new approach derives from the new societal challenges, where "products" and "services" are being merged, the complexity of problems is increasing and sustainability is a real issue to be worked on. As a human-centred approach, DT can help deal with that complexity, inspiring solutions with global potential and being part of global activism. The author emphasises the collaborative nature of DT not as a way of integrating all the participants in the process but also to improve lives in an empathic way, where there is no "us vs. them" but "us with them".

For Martin [34], the core of the innovation dilemma relies on the tension between reliability and validity, where the goal of reliability is to produce consistent and predicta-

ble outcomes, and the goal of validity is to produce outcomes that meet the desired objective; in this dynamic, most companies choose reliability over validity, as it seems safer [35]. The DT lies between reliability and validity, art and science, intuition and analysis, and exploration and exploitation by applying abductive reasoning and deductive and inductive logic.

In the new management approach, companies should work as designer shops, working on projects collaboratively and iteratively (as a human-centred approach), using abductive reasoning and seeing constraints as an opportunity. This new approach should be incorporated from the top of organisations and taught in management schools [7,33]. Brown [33] and Martin [34] suggest the employment of designers' tools, such as observation, brainstorming, visual expression (through sketching or post-its), storytelling and prototyping. Prototypes are viewed as essential in the process and have been needed since the beginning to accelerate the exploration of ideas and to set goals; storytelling is also important as it inserts the time dimension in the project, working in two ways: it helps to visualise the idea through time, being helpful to designers, while can also help communicate the value of an idea to the client at the end of the project.

Martin [34] describes the design process as a knowledge funnel with three phases: 1) exploration of the problem, starting with intuition; 2) the heuristic, which transforms the intuition into language; and 3) the algorithm, where the heuristic is transformed in a step-by-step procedure. This process of refinement occurs as a dynamic interplay between innovation and efficiency. For Brown and Wyatt [35], the process starts with a brief, which helps the project team to begin. However, to the authors, it is essential to observe peoples' experiences. The ideation phase relies on divergent thinking, a process usually carried out by brainstorming in a multidisciplinary and interdisciplinary team; in idea generation, the use of visual means should be encouraged.

3.2.3 The human-centred Design

Brown [6] describes DT as a human-centred design methodology, where the innovation is powered by the direct observation of the end user's needs; the process is described as a system of spaces: inspiration, ideation, and implementation, which are used iteratively. In the inspiration phase, the problem (or opportunity) is explored; the ideation is the phase of idea generation, development, and testing; and the implementation phase is the project delivery to the consumers [35].

The author describes DT as a team-based approach to innovation and defines DT as "a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity", referring some aspects to take in consideration for the process to succeed: involving DT since the beginning, taking a human-centred approach, using experimentation and prototype in early stages, use co-creation, blend big and small projects, adjust the budget to the speed of the project, look for an interdisciplinary team, and Design by cycles. Collaboration and integration are also essential for the Design's success so everyone can participate.

3.2.4 Design Thinking as a Process

Beckman and Barry [36] intended to integrate the innovation and learning processes in a way that could be employed across disciplines. The authors rely on the model of Owen [46], who views Design as a process of knowledge development that operates in the analytic and synthetic realms and the theoretical and practical realms and is intended to fit all fields once the proper tools are employed. The authors also explore the learning theories, citing the experimental theory of Kolb [47], where four steps in learning (experiencing, reflecting, thinking and acting) work iteratively. The Kolb model also involves two approaches to grasping experience (concrete experience and abstract conceptualisation) and two others to transform experience (reflective and active experimentation). Thus, the authors establish a parallel in the theories of Kolb and Owen, creating a new

model. Although the process is not linear, the authors establish four stages for generating observations, frameworks, imperatives and solutions.

Each of the steps of the model involves a different kind of reasoning and skills: 1) the observation quarter involves the understanding of the context (consumers' needs) through concrete analytical means (by observation, market research or direct interaction with the users); 2) in the frameworks quarter, where the designers move to the abstract realm, coming up with new solutions (by identifying interesting stories or behaviours and creating matrices or timelines); 3) in the imperatives step, where the designers synthesise the imperatives to be met; 4) in the solutions step there is a return to the concrete realm to generate the solution that best meets the imperatives and test it.

Carlgren, Rauth, *et al.* [37] approach the DT process by interviewing six companies that use it. The authors found five common characteristics: 1) user focus, 2) problem framing, 3) visualisation techniques, 4) experimentation and 5) diversity. Despite these common characteristics, how each company uses DT depends on their needs, sources of knowledge and organisational context.

Waidelich, Richter, *et al.* [38] reviewed the models used by DT literature, finding similarities between them: the ideation phase is the most mentioned, followed by the prototype, and most models start with the understanding phase. As the author states, DT methods are applied to achieve the best results, and therefore, there is no standardisation; however, the similarities are related to the popularity of the IDEO model (3I) and Stanford d.School [6,7,48].

3.2.5 Design Thinking Reviews

The most relevant reviews on DT make a clear cut between DT as part of the design theory and the management concept [3,12,22]. Kimbell [12] attributes the change in the designers' role to the natural evolution of times, namely the way capitalism has changed and is now seen as dynamic rather than bureaucratic; the new global economy of signs that is product-saturated; the rise of the creative class, who find meaning in work; and the request for answers after the 2008 crisis. Johansson-Skoldberg, Woodilla, *et al.* [3] point out the differences between both discourses: while the "designers" DT presupposes the creation of artefacts, a reflexive practice, a problem-solving, a practice-based activity of making sense of things and creation of meaning (rather than artefacts); the "management" DT includes the IDEO's way of working, a way to approach indeterminate organisational problems and part of management theory. Johansson-Skoldberg, Woodilla, *et al.* [3] conclude that both concepts are so different that they cannot be merged.

Micheli, Wilner, *et al.* [4] define DT as an "umbrella construct" and describe its characteristics through a literature review complemented by an exercise with designers. The authors identified ten attributes of DT: 1) Creativity and Innovation, 2) User-centeredness and involvement; 3) Problem-solving; 4) Iteration and experimentation, 5) Interdisciplinary collaboration, 6) Ability to visualise; 7) Gestalt view, 8) Abductive reasoning; 9) Tolerance of ambiguity and failure; and 10) Blending rationality and intuition. The authors also found the eight most used tools and methods reported in the literature: prototyping, visualisation, ethnography, experiments, brainstorming, journey maps, personas and mind maps. From the cluster analysis, the authors got five perspectives on DT: 1) DT as interdisciplinary collaboration; 2) DT as belonging to the design field (abductive reasoning; the ability to visualise; interdisciplinary collaboration; and tolerance for ambiguity and failure); 3) DT as problem-solving and resilience (tolerance for ambiguity and failure, and interdisciplinary collaboration); 4) DT as reflecting upon the whole (ability to visualise and a gestalt view of problems), and cluster 5) Learning to think as a designer (gestalt and the role of blending analysis and intuition).

In their review, Micheli, Wilner, *et al.* [4] include concepts of both "designers" and "managers", meaning both discourses can be merged, contrary to the previously mentioned by Johansson-Skoldberg, Woodilla, *et al.* [3]. As an example, Lawson [10], who is a designer, considers the client or the user as constraint generators; or, in the case of well-

known methodologies such as the proposed by Brown [6], it is evident the presence of the synthesis/analysis and convergent/divergent thinking, and the way that the author views the process as iterative, denying the step by step procedure, approaching his point of view from the one of Rowe [26].

3.3 Main remarks on the Design Think concept evolution

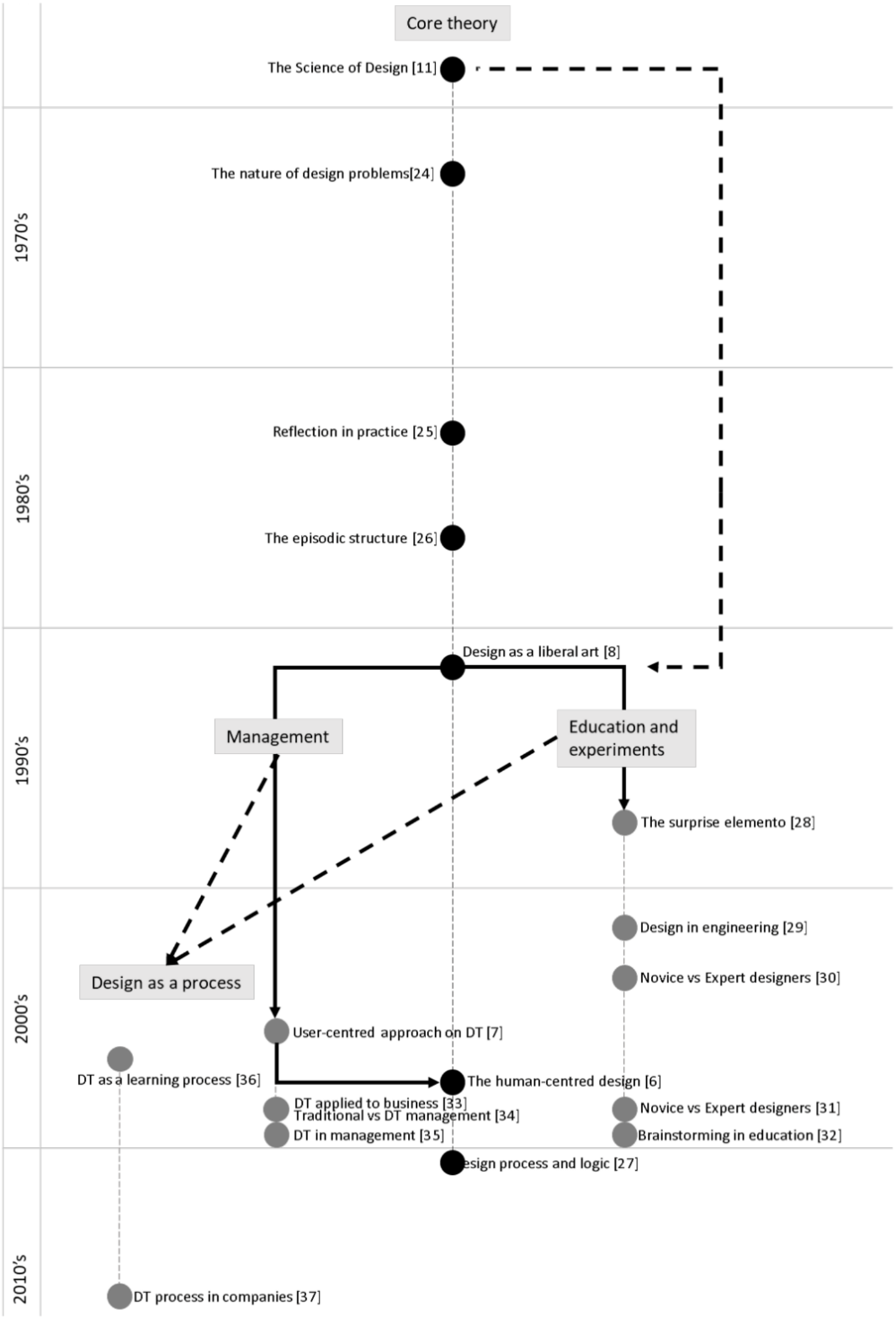


Figure 4. Interactions between the themes discussed by the authors. The titles and numbers represent the authors reviewed works found in Table 1. The lines represent the interactions.

Figure 4 visually represents the relationships between the different works, helping to understand the historical progression and sub-divisions within the DT field [6,8,11]. The figure reveals that Buchanan [8] work in 1992 serves as a critical breakpoint, leading to subsequent themes related to the applications of education and management. It also demonstrates the linkage between Buchanan's work [8] and Simons' ideas [11], as well as the contributions from the management field to Brown's work [6]. The interactions between these themes are represented by the lines in the figure.

This view eliminates the gap mentioned earlier. Hence, Brown's work [6], although initially considered outside the design domain and more aligned with management, is now considered part of the design theory. Despite the lack of citations in Brown's work [6], it encompasses the core principles of design theory, also adding the management perspective; furthermore, Brown's work [6] consists of an easy-reading article and presents DT as a framework that can be used easily by the industry, thus gaining more and more popularity.

Despite not explicitly mentioning the term "Design Thinking" in his book "The Sciences of the Artificial," Simon, regarded as the father of DT, conceptualised Design as the underlying knowledge behind the creation of objects [11]. The author transformed the traditional notion of the designer as a mere "doer" into that of a "thinker" as, according to Simon, all human creations are considered "artificial" and can be designed [11]. Although some review articles propose a division between academic Design and other perspectives on DT, considering Simon's standpoint [11] eliminates this gap. Thus, DT should integrate the discourse of design theory and other perspectives derived from the concept of evolution.

3.4 Part 2. Design Thinking in Food Studies

After grouping, there can be found two main groups: one related to the theoretical background, comprising general FDT theory and models (n = 7) and the other group covered FDT applications in various areas, namely sustainability (n = 6), health and wellbeing (n = 5), education (n = 5) and food product development (n = 4). The results are summarised in Table 3.

As many of the works were based on existing DT methods, making a small synthesis of the ones used in this context is relevant (Table 2).

3.4.1 Food Design Thinking theory and models

The relationship between design and food studies becomes clear given the context presented in Part 1. Olsen [2] was one of the first authors to discuss DT applied to Food. The author emphasises the importance of consumer empathy, and consumers, traditionally viewed as product validators, at the end of the process, should be integrated in the beginning as a point of departure. Olsen [2] also refers to important DT steps such as prototyping, consumer testing and collaboration, suggesting an open innovation system where research, industry and users could work together. In the same sense, Shimek [21] discusses the advantages of integrating DT in the innovation process, connecting qualitative consumer studies and tangible product design; the author considers food consumer behaviour to be more emotional than rational, and, therefore, the opportunity is not to *correct* the consumers but to follow their beliefs. The author highlights the five characteristics of DT that can be useful to new product development in the cereal industry: 1) Multidisciplinary collaboration, 2) Building empathy with consumers, customers, and key stakeholders, 3) Idea development including the consumer, 4) Rapid prototyping and 5) Human-Cantered Storytelling.

Zampollo and Peacock [49] describe FDT as "creating food products, food services, or food systems, where the design methods and tools are designed specifically to facilitate reflection on the eating experience", integrating many Food-related aspects. The authors developed methods and tools dedicated to FDT, creating two new tools specifically designed for FDT: Themes for Eating Design (TED) and Thoughts for Food. TED was created based on a set of food-related images and implemented to generate and describe food

experience regarding product, room, meeting, atmosphere, and management control system. Thoughts for Food appeared as a new iteration of TED and consisted of cards with an icon, a word on the front, and a description on the back. It was intended to be used the same way as TED, with the advantage of being easier to handle. The authors tested TED and Thoughts for Food with great results, concluding they opened the doors to creating the FDT discipline.

Table 2. Design Thinking models used in the reviewed works.

Popular designation	Phases
Double Diamond [50]	Discover Define Develop Deliver
HPI model [51]	Understanding Observing Point of View Finding Ideas Prototyping Testing
3I (IDEO) Brown [6]	Inspiration Ideation Implementation
Stanford d.School [52]	Empathise Define Ideate Prototype Test

Franchini, Dosi, *et al.* [53] discuss how design processes can shape innovation and propose the integration of Stage-Gate Stage-Gate [54], one of the most used frameworks for food product development with DT, bringing together the advantages of Stage-Gate (e.g. increase of the development speed) with the creativity of DT. The authors employed both approaches in a company (DT to get ideas and Stage-Gate [54] to process them), concluding that the model "fails to balance exploration and exploitation", creating internal problems regarding employees and resources management. Despite these results, the authors conclude that the integration of those approaches should be further researched.

Despite the existence of varied DT models, other authors Sijtsema, Fogliano, *et al.* [55], Batat and Addis [56] and Massari, Principato, *et al.* [57] developed their own models directed to varied food issues.

Sijtsema, Fogliano, *et al.* [55] proposed a FDT model for food product development, departing from Olsen's (2015) perspective. The Circular Food Design model represents the iterative process of FDT and combines the Double Diamond model [50] with sustainability elements. This user-centered and flexible model serves as a collaborative tool. It aims to structure and integrate different perspectives and innovation phases within the food system, promoting creativity and increasing the likelihood of success in healthy and sustainable food development. Massari, Principato, *et al.* [57] also proposed a proposed a model related to sustainability. The CEASE (Communities, Engagement, Actions, Shareability, Ecosystems) model focuses on the issue of food waste and intends to maintain and consolidate the emerging food-management strategies and behaviour styles developed within the Covid-19 pandemic lockdown. The authors used the Stanford d.School [52] DT as a base, considering: Empathise with the communities; Define, by analysing the solu-

tions adopted by consumers to solve similar problems; Ideate through co-design; Prototype, by creating suitable conditions and scenarios to develop collaboration and collective action; and Testing the impacts of the proposal.

Table 3. Food Design Thinking reviewed works grouped by theme, their theoretical implications, the problem or product worked on, and the method used.

	Main contributions/ objectives	DT method
	Theory and models	
Olsen [2]	Integrate the consumers from the beginning	N.a.
Zampollo and Peacock [49]	Describe the concept of FDT and generating new tools	N.a.
Franchini, Dosi, *et al.* [53]	Employ Stage-Gate and FDT simultaneously	N.a.
Shimek [21]	Characterise FDT for product development	N.a.
Sijtsema, Fogliano, *et al.* [55]	Design a non-linear FDT model directed to sustainability	Double Diamond
Batat and Addis [56]	Design a FDT model to improve food experience	New model
Massari, Principato, *et al.* [57]	Design a FDT model directed to prevent food waste	Stanford d.school
	Food Design Thinking and Education	
Mitchell, Woodhouse, *et al.* [58]	Implement FDT	Double Diamond
Frost [59]	Integrate science and culinary arts	N.a
Derler, Berner, *et al.* [60]	Compare FDT with traditional food development	3I/IDEO
Kaygan [61]	Integrate industrial design with food engineering	Stanford d.school
Pärli, Stauffacher, *et al.* [62]	Shift food practices towards sustainability	New model
	Designing for Sustainability	
Nguyen, Nguyen, *et al.* [63]	Develop an interactive fridge to prevent food waste	HPI
Bonaccorsi, Betti, *et al.* [64]	Develop a smart freezer	3I/IDEO
Kamil, Hua, *et al.* [65]	Develop a technological system to prevent food waste	New model
Purnomo, Bunyamin, *et al.* [66]	Solve the problem of excess taro production	New model
Adebayo, Emuoyibofarhe, *et al.* [67]	Improve farm productivity	Stanford d.School
Asawadechsakdi and Chavalkul [68]	Develop a sustainable single-use package	New model
	Design Thinking for Health and Wellbeing	
Mummah, King, *et al.* [69]	Develop an app to motivate healthy eating	New model
Bogomolova, Carins, *et al.* [70]	Develop a plan to encourage healthier food purchases	New model
Fernhaber, Wada, *et al.* [71]	Develop a plan to deal with food deserts	New model
Kalita, Das, *et al.* [72]	Develop a plan to improve street food vending hygiene	New model
Rejikumar, Aswathy, *et al.* [73]	Enhance dining experience	Stanford d.school
	Design Thinking for Food Product Development	
Bunyamin, Purnomo, *et al.* [74]	Develop foods with Tengkawang oil	New model
Hastie, Ashman, *et al.* [75]	Develop foods to promote aged meat consumption	New model
Tkaczewska, Kulawik, *et al.* [76]	Develop food products with functional properties	New model
Gallen, Pantin-Sohier, *et al.* [77]	Develop insect base foods and their packaging to improve the consumer experience	3I/IDEO

Batat and Addis [56] have developed a framework oriented explicitly towards food experience and wellbeing. To create the model, the authors compare the concepts of DT, Food Design, and Food Experience Design regarding their orientation, focus, actors involved, types of innovation, outcomes, creativity level, and competitive advantage, concluding the concepts fail to capture the experiential aspects of food consumption and neglect to integrate consumer wellbeing throughout the various stages of the food journey. The authors also discuss how the perspectives of producers and consumers regarding FDT differ, and the factors that influence consumers' experiences (physical, social, and technological environments) and their overall wellbeing (life satisfaction, affect, and sense of purpose), creating an integrative model.

3.4.3 Food Design Thinking and Education

Similarly to what happens in the DT, FDT was also implemented in the educational context.

Mitchell, Woodhouse, *et al.* [58] explored the implementation of DT in Otago Polytechnic's Bachelor of Culinary Arts (OPBCA) program, aiming to foster "designerly ways of knowing" in graduates. The core methodology employed in this program is based on the Double Diamond approach [50]. Students engaged in project-based learning, where they receive a project brief outlining the requirements and constraints of the problem to solve. Throughout the learning process, the students prototyped and tested dishes, documented their progress, and delivered the final outcomes to clients. This approach allowed students to bridge their personal experiences and interests with the professional culinary world, promoting acquiring fundamental cookery techniques while encouraging critical thinking and problem-solving skills.

Similarly, Frost [59] described the work performed at the Nordic Food Lab, a research and development institution that operated between 2008 and 2018. The lab was a collaborative space for chefs and researchers to explore various aspects of gastronomy, particularly molecular gastronomy. The project contributed to the knowledge in the field by sharing the research findings with the community. It highlighted the potential for cross-pollination between chefs and scientists, where chefs could incorporate sensory science techniques in their restaurants, and scientists could leverage Design and prototyping to expedite food innovation.

Derler, Berner, *et al.* [60] conducted a case study using the DT approach to examine transdisciplinarity's role in enhancing secondary school students' food literacy. The study included nutrition and agriculture-focused secondary school students and a polytechnic school. The students were asked to develop sustainable food products for their peers. The research process encompassed four phases: exploration, ideation, prototyping, and optimisation. During the exploration phase, workshops were conducted, and students' food consumption behaviours and perceptions were assessed using surveys, photovoice, and food diaries. In the ideation phase, the collected data were analysed, and food product ideas were generated based on personas representing typical users. The students then voted on the best ideas and created product specification sheets. In the prototyping and optimisation phase, students conducted experiments to refine their prototypes, documented their learning process, and iteratively improved their food products. The authors emphasised the motivational aspects of the DT approach and highlighted the positive influence of researcher involvement from the project's inception.

Kaygan [61] examined team development within the context of a collaborative design course that integrated industrial design and food engineering students. The author underscored the significance of collaboration in addressing complex societal issues, noting the growing interest in interdisciplinary programs. The course focused on "food away from home," and students engaged in a DT methodology. The initial week fostered open debates on design strategy, allowing students to identify commonalities and differences between their fields of knowledge. Subsequently, lectures were conducted to introduce

students to the theory of DT, emphasising problem-solving skills and mindset. The process was based on Stanford d.School [52] DT model, along with key concepts such as wicked problems, user-centeredness, and the characteristics of a design thinker. Students employed design tools like mind maps and role-playing in the following weeks to brainstorm ideas and generate potential solutions. A brainstorming card tool facilitated idea generation, and the selected ones were sketched. As the project progressed, students were encouraged to independently prototype their ideas, with reduced assistance from teachers. The author highlighted the value of DT in introducing engineering students to a fresh perspective on Design while providing design students with a simplified version of the design process.

Pärli, Stauffacher, *et al.* [62] presented a case study demonstrating the application of DT in creating interventions for real-world food practices within a master's course. The project aimed to address academic and societal needs, specifically focusing on shifting residents' food practices towards sustainability and testing the effectiveness of the interventions. The students followed a three-stage process to achieve these objectives. In the initial stage, they conducted a thorough literature review, performed site observations, and conducted interviews to clarify and focus on the topic. In the subsequent stage, the students designed the interventions by combining data sources, identifying insights, and explaining the underlying reasons and methodologies behind their observations. The proposed interventions were then discussed with the community for feedback. Finally, the students implemented the interventions and assessed their effects, closing the DT cycle.

3.4.4 Designing for Sustainability

There were found six works related to sustainability. Three of them developed technological improvements to increase people's awareness of the Food they buy or store [63-65].

Nguyen, Nguyen, *et al.* [63] employed the DT approach to design an interactive fridge prototype to promote food waste prevention. The authors used the HPI model [51] supported by various tools and techniques. In the understanding and ideation phases, the authors conducted surveys and semi-structured interviews to investigate users' behaviours and habits regarding food storage. The research revealed three main concerns: consumers' lack of awareness of the Food in their fridge, the lack of awareness of food quality, and the lack of interest in eating leftovers. To address these concerns, the authors prototyped objects such as stickers (for categorising food types), sliders with timers (for categorising food states), and an LCD display that reacted to the state of the Food, making the fridge more engaging and encouraging cooking. The prototype was tested with 10 participants through semi-structured interviews, indicating its effectiveness in helping users categorise Food, making the fridge more interesting to use, raising awareness of food quality, and motivating users to reduce food waste. Bonaccorsi, Betti, *et al.* [64] developed an innovative smart freezer using an industrial DT approach focused on user involvement. The authors collaborated with 11 users to recreate typical domestic freezer use conditions and evaluate existing fridge models. Contextual inquiry, observation, and thinking aloud were employed in a heuristic approach. The outcomes of the assessment phases and user involvement stage provided insights into user-product interaction and user needs, which informed the prototype's design proposal and technological developments.

Kamil, Hua, *et al.* [65] utilised a DT approach to develop a system (reader and app) to address the food waste problem. Through interviews with 52 users, the authors identified five elements of solutions. The idea generation phase involved brainstorming sessions to establish design criteria, including simplicity, user-friendliness, interactivity, emotional appeal through aesthetics, and the use of quality materials. Various solutions were depicted through the object and user interface sketches, and a 3D design was created to visualise the selected solution. A prototype was developed using a 3D printer. The *Pebble* system was implemented in supermarkets, allowing users to test it to acquire Food-related data and expiration dates, raising their awareness of the Food they bought and its quality.

On a more large scale, Purnomo, Bunyamin, *et al.* [66] and Adebayo, Emuoyibofarhe, *et al.* [67] worked with farmers helping them to deal with food production imbalances regarding excess or lack of production. Purnomo, Bunyamin, *et al.* [66] conducted a participatory action research using a DT approach to address the issue of excess taro production in an Indonesian village. The researchers followed their own six-stage process: meeting with community leaders, visiting gardens, empathising with the community and identifying the challenges related to Taro processing and commercialisation. Based on their findings, the researchers developed a business model focusing on Taro flour as a derivative product. The ideal business model involved key partners such as farmers, local non-governmental organisations, and local governments. This model aimed to establish a structured and clear pathway for the business to thrive.

Adebayo, Emuoyibofarhe, *et al.* [67] studied the needs of African farmers and employed a DT method to improve farm productivity. The authors implemented the Stanford d.School model [52] supported by semi-structured interviews and observation, brainstorming sessions with farmers, sketches, scenarios, and mini-prototypes. The proposed solution involved placing sensors on farm fields connected to social media platforms to monitor environmental changes such as temperature, relative humidity, soil moisture, pH, and pest levels. The solution was evaluated and demonstrated its effectiveness in helping farmers improve crop yields.

In another approach to Food-related sustainability issues, Asawadechsakdi, et al. [67] employed a DT-based approach to create single-use packaging from leaves to reduce plastic bag waste. The authors followed their own 4-phase model (problem identification, understanding consumer needs, creativity, and prototyping) supported by interviews with vendors and consumers, observations of package sizes, cooking methods, carrying behaviours, container opening behaviours, and eating methods. The creativity process was based on brainstorming sessions and morphological analysis to separate attributes and functions of the packaging, inspiring different concepts. The authors focused on moulding leaves and stabilising the package, experimenting with various techniques. Two design types were developed: the fresh leaf package with a hard frame and the dried leaf package with a soft frame. After evaluating the designs through interviews with voluntary package users, the fresh leaf package was selected due to its ability to support food weight, carry dry and moist Food, and be held with one hand.

These studies illustrate the application of DT in addressing food waste and environmental concerns through the Design of innovative prototypes and systems. By involving users in the design process and considering their needs and behaviours, these approaches contribute to reducing food waste, promoting sustainable practices, and improving the overall efficiency of food-related systems.

3.4.5 Design thinking for health and wellbeing

This section comprises five studies. Mummah, King, *et al.* [69] and Bogomolova, Carins, *et al.* [70] employ the DT approach to motivate healthy eating; Fernhaber, Wada, *et al.* [71] and Kalita, Das, *et al.* [72] worked on problems external problems that could compromise healthy eating, namely the case of food access and the case of food hygiene. Finally, Rejikumar, Aswathy, *et al.* [73] worked on improving food wellbeing during restaurant service.

Mummah, King, *et al.* [69] developed an app to motivate healthy eating among overweight adults using the DT approach. The IDEAS framework guided the iterative process, consisting of eight phases. In the empathise phase, the authors conducted semi-structured interviews to understand the target users' struggles with meal planning and their goals of building a healthier lifestyle. The target behaviour phase involved reviewing the literature to identify eating behaviours with health benefits, such as increasing fruit and vegetable consumption. Grounding in behavioural theory, the authors reviewed relevant literature to inform the design process. In the ideate phase, brainstorming sessions were held in a

multidisciplinary environment to generate potential mobile app features. Prototype potential products were sketched and discussed, resulting in two prototypes. User feedback on the prototypes was gathered through interviews, which helped refine the Design. The minimum viable product was then built, focusing on user experience, visual Design, logic, and content. The potential efficacy and usability of the app were evaluated through a questionnaire, measuring usability and user satisfaction. The resulting app, Vegethon, is a standalone mobile app that allows users to self-monitor their vegetable consumption, incorporating gamification elements to reward the behaviour change process. Users can set personalised goals, log their vegetable consumption, and receive challenges, points, and notifications to reinforce their goals. The app also provides advice, tips, and a personalised weekly report.

Bogomolova, Carins, *et al.* [70] developed a program called "A Healthy Choice" to encourage healthier food purchases in an Australian supermarket. The research consisted of two parts. In the first part, co-design sessions were conducted with consumers and supermarket staff. These sessions followed a co-design process, including word association tasks, group discussions, reviews of former programs, idea generation, and idea pitching. The participants collaboratively created proposals and pitched their ideas. In the second part, the proposals from the co-design sessions were evaluated by supermarket management for feasibility. The "A Healthy Choice" program was developed, implemented, and evaluated. The program involved strategies suggested by consumers and addressed the product, physical evidence, and place dimensions of the marketing mix. Shelf talkers with the "A Healthy Choice" logo and descriptions were placed on selected healthy products in the store. The program was evaluated based on consumption data collected through surveys and sales of healthy items, showing positive results.

Fernhaber, Wada, *et al.* [71] employed a participatory design process based on the DT framework community INNOVATE to address the issue of food deserts in the USA. The process involved engaging various stakeholders to co-create solutions for improving access to healthy and affordable Food. The process was divided into four phases. In the Inquire phase, the authors interacted with the community through conversations, workshops, and an online platform to understand the root problems and prioritise the major areas of concern. The Ideate phase focused on generating ideas for addressing the identified goals through brainstorming sessions with the community, then narrowing down ideas based on their quality. In the Investigate phase, community members developed solutions to shape the ideas. Finally, doers could pitch their initiatives in the Impact phase and network for grants to implement the selected ideas. The community INNOVATE process facilitated collaborative problem-solving and empowered community members to play an active role in finding solutions to food access challenges.

Kalita, Das, *et al.* [72] applied the DT approach to improve livelihood and hygiene for street food vending in India. A team of management and design students employed visual ethnographic narratives to study user behaviour and vending issues through marketing research. Sketches and simple prototypes were used to generate and address specific design problems. The product detailing was modelled in 3D, and a 1:1 scale prototype was developed. Various materials and forms of edible packaging and serving were explored. The prototypes underwent usability and feasibility testing, including focus group discussions.

Rejikumar, Aswathy, *et al.* [73] proposed a methodology to create a service design that enhances the dining experience in a restaurant in India. The authors combined the Stanford d.School DT model [52] with the Taguchi Method to identify optimal settings for selected design attributes contributing to Food Wellbeing. Customers' objections and concerns in restaurant dining experiences were collected in the empathise stage. The customer's needs were defined, and brainstorming sessions were conducted with experts to generate ideas and create multiple options for the selected attributes of the service design. Scenario-based narrations of the prototype designs were used to facilitate customer eval-

uations. The robustness of the prototype designs was tested through a Taguchi experiment. The research revealed that hygiene perceptions and service design are critical in Food Wellbeing. Consumers valued information about ingredients and recipe transparency, which enhanced their food wellbeing.

These studies demonstrate the application of the DT approach in promoting health and wellbeing, addressing issues such as healthy eating motivation, access to healthy Food, and improvement of dining experiences. Through user involvement, collaborative problem-solving, and iterative design processes, these approaches enhance individuals' health behaviours and overall wellbeing.

3.4.6 Design Thinking for Food Product Development

Bunyamin, Purnomo, *et al.* [74] employed the DT approach to develop food products in collaboration with the community. The study focused on the Pikul Pengajid Indigenous Forest, known for its high productivity in Tengkawang fruit oil. However, the consumption of green butter derived from the oil was low due to a lack of awareness and dislike for its pungent smell. The researchers conducted Participatory Action Research with the community, employing various tools and instruments for data collection, processing, and analysis. They followed the stages of DT, including direct observation of the green butter-making process to identify pain points and gains. Based on these observations and using criteria constraints, they designed food products such as Soft Ginger cookies, Tengkawang sticks, Tengkawang doughnuts, Tengkawang noodles, and Tengkawang Pie. The products were named in collaboration with naming experts to promote the region and highlight the quality and taste. An action plan was created, considering production capacity, diversification of derivative products, development of business groups, and establishment of Tengkawang processed product centres.

Hastie, Ashman, *et al.* [75] employed the DT approach to promote the consumption of aged Cull Ewe meat in Australia, which tends to become tougher as animals age. The methodology consisted of four stages. In the problem definition stage, stakeholders, including consumers, producers, and food service representatives, were consulted to understand their needs. In the dish ideation and prototype development stage, 15 food service professionals received the collected information, creating 17 stimuli as images or prototypes. In phase three, two panels of participants discussed the stimuli, leading to a perceptual mapping with axes representing economy/premium and familiar/traditional concepts. The final stage involved serving eight selected dishes to a consumer panel, who rated the dishes in terms of liking, premiumness, frequency of consumption, and suitability for food service outlets. The results indicated that consumers liked the meals and considered them premium, demonstrating the success of the DT approach in addressing the problem.

Tkaczewska, Kulawik, *et al.* [76] proposed a protocol for designing food products with functional properties using the DT approach, focusing on developing an antioxidant-rich snack. The protocol consisted of multiple steps, including identifying the target consumer group, diagnosing the problem, identifying its cause, creating a food product concept, proposing food products, preparing preliminary prototypes, creating a product description sheet, developing the detailed recipe and production process, testing and modifying the prototype, determining nutritional value and storage conditions, and finalising the product characteristics and necessary documentation (GMP/GHP and HACCP guidelines). The authors acknowledged that the protocol should be adapted as the DT process is not linear.

Gallen, Pantin-Sohier, *et al.* [77] applied the DT method to improve the experiences associated with insect-based foods. Their multidisciplinary team, including design students and specialists in various knowledge areas, followed a three-step approach: exploration, ideation, and experimentation. In the exploration phase, data on consumption trends, acceptance of different insect species, and shape acceptance were collected from existing literature on consumer behaviour. In the ideation phase, the team generated 12

prototypes through brainstorming, with each group representing a persona based on emerging trends. Visual representations of the product concepts were created. The concepts were tested through recipe prototypes in the experimentation phase, and packaging designs were developed accordingly. The team presented the products to 30 consumers in guided interviews, allowing for product refinement based on consumer feedback.

These examples highlight the application of the DT approach in practical food product development, involving community collaboration, addressing consumer preferences, and incorporating iterative design processes. By employing DT methodologies, researchers could generate innovative food products, overcome consumption barriers, and create solutions catering to consumer needs and preferences.

3.5 Main remarks on the Food Design Thinking concept

DT has emerged as a valuable approach in food studies, offering innovative and user-centred solutions to various challenges. In this sense, all the practical applications of DT start with a problem, suggesting the creation of artefacts to solve it. This common objective of FDT is consistent with the theory of DT, which dates back to Simon's description of Design as the creation of artefacts to solve problems [11]. Additionally, Rittel and Webber [24] proposed the concept of design problems, further aligning with the objectives of FDT.

The application of this approach in different food-related contexts, including product development, sustainability, education, and health and wellbeing, suggests that DT can be applied to a diverse range of Food related problems. This parallels Simon's ideas [11] and Buchanan's concept of DT as a problem-solving approach that can be employed across various domains and subdomains [8].

Another common aspect found in the various theories and applications of FDT is using a step-by-step process and, in some cases, mentioning iterations. These references can be attributed to the works of Schön [25] and Rowe [26], as they define the design process as driven by episodes and iterative steps. The step-by-step logic is also evident in works related to DT methods, which primarily divide the process into three main phases: inspiration, ideation, and implementation (3I) [6]. While these phases can be expanded indefinitely, they form the foundation of the FDT process.

Furthermore, consumer involvement through empathy, understanding, and co-creation is emphasised, which is related to the most recent literature on DT, which considers the entire human-centred process. This human-centeredness is evident in all areas of food design application, whether the user is a consumer, a client, or a society. The involvement of the end-users and stakeholders is crucial to creating solutions that address their needs effectively. Prototyping and testing are also commonly used in the studied works, as they allow for the exploration and refinement of ideas. Despite these overall commonalities, the differences between FDT approaches can be defined by the specific problems they address, which may require alternative methodologies to the typical well-defined step-by-step process. Socioeconomic context and cultural influences are also important factors when implementing FDT. As shown in Table 3, many authors adapted the typical DT methods and generated completely new approaches based on the existent ones, showing DT is an adaptable to the problem and the context, contributing to the uniqueness of the DT process even though there are commonalities among different approaches.

4. Conclusions

The Design Thinking approach is an evolving concept emerging from various perspectives, such as the design process itself. This concept has been shaped by numerous authors and their contributions. These perspectives have expanded the boundaries of design thinking, recognising it as a versatile approach applicable in various domains.

The evolutionary perspective of design thinking has been reinforced by its integration into different fields, including management and education, by combining analytical

and intuitive thinking in a human-centred way. Moreover, the iterative and adaptive nature of design thinking has been recognised through models that emphasise observation, framework development, and solution generation.

Design Thinking was also applied to the food area. The practical examples employ the approach differently regarding the scope, which is desirable, as different problems and contexts require different approaches; however, there is a common ground in all of them: the user-centred approach, collaboration and use of prototypes.

Although there may be differing views on the boundaries and applications of design thinking, its evolutionary trajectory is characterised by the integration of diverse perspectives, the acknowledgment of complexity, and the emphasis on collaboration, empathy, and interdisciplinary approaches. Design Thinking continues to evolve as a valuable approach for addressing complex and ill-defined problems in various domains. As scholars and practitioners further explore and refine Design Thinking, its evolution is likely to continue, incorporating new insights and approaches to meet the challenges of the future.

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Chapter 5. **PAPER 2. UNDERSTANDING RICE CONSUMPTION AND ENCOURAGING CONSUMER EMPATHY THROUGH DESIGN THINKING**

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Understanding rice consumption and encouraging consumer empathy through design thinking

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ABSTRACT: Portugal is the European country with the highest rice consumption per capita. However, consumption of the most produced type in the country - *Carolino* rice, has decreased. To invert this tendency it is important to understand the consumers. The Food Choice Questionnaire (FCQ) is a relevant tool that can be used to access food choice motives, but requires a necessary adaptation to better approach the purpose.

While some authors have based on the existing literature to modify the questionnaire, the method proposed in this study considered a human center approach based on techniques of a Design Thinking Methodology. The items of the FCQ were previously crossed with Food Drink Europe trend categories, and further were discussed, using images, within 3 focus groups.

The method that was used enabled the inclusion of new items (concerning innovation, authenticity and local production), which were in accordance to users' language and culture, and may serve as support to understand new trends in the food market and to develop new products accordingly.

1 INTRODUCTION

Rice is one of the most important staple foods all across the world for about half of the population (FAO, 2016). There are two sub-species of rice grain, *Indica* (long grain and non-sicky texture when cooked) and *Japonica* rice (short grain and more sticky when cooked).

Traditionally, the European population consumes mostly *japonica* rice (Ferrero, 2004). Nonetheless, the consumption of *indica* rice has increased in recent years, having surpassed *japonica* rice consumption since 1999/2000. To respond to the market needs, Europe imports husked rice from the US, Thailand, India and Pakistan (Ferrero, 2004).

According to GPP (2016) Portugal has the highest consumption of rice in Europe. However, a consumption decrease was also observed over the past decade, especially with the most cultivated varieties in the country: *Carolino* rice, from the sub-specie *japonica*. This accounted for 72% of 2012 production, with a growth of 27% between the years 2010 and 2012. The apparent consumption of that rice represents only 44% (GPP, 2016), which leads to large-scale imports of *Indica* rice, commonly known in Portugal as *agulha* rice.

DIS!ArrozPortugês (Design innovation and health, promotion of Portuguese rice) (Castanho, 2017) is a transdisciplinary project aiming to encourage the consumption of rice produced in Portugal, through the use of the *Food Design Thinking* techniques.

1.1 *Human centered design*

Food Design Thinking (FDT) is considered a human-centered approach once it perceives consumer insight as the starting point of the whole

product development process that advocates rapid experimentation and stimulates individuals' creative potential through consumer empathy, visualization and rapid prototyping, and collaboration (Olsen, 2015). Although the FDT is a more commonly used concept, the phenomenon of user-driven innovation is not a new: it was first reported in the 70's by von Hippel (1976), where costumers started to adapt or modify scientific instruments from the industry as they didn't respond to their needs. In addition, consumer-driven innovation is defined by Grunert et al., (2010) as a process in which an analysis and understanding of the consumers' needs and preference formation plays a key role.

The development and introduction of new products in the market is known to be risky, since about 76% of the new products tend to fail after one year in the market (Dijksterhuis, 2016; Stewart-Knox & Mitchell, 2003). One of the main reasons pointed as a cause to that failure is the lack of understanding of consumers' behavior (Ryynanen & Hakatie, 2014). Apparently, innovation in the food industry is based in experts' opinions rather than on consumers' (Olsen, 2015). Also, R&D departments don't even work with consumer behavior experts, but rather with scientists having a technological background (Dijksterhuis, 2016).

As the success of a food product depends not only on the product itself but also on the consumer and the environment (Babicz-Zielinska, 2006) it is essential to listen to consumers' needs from the beginning of the New Product Development process (as early as possible), and keep listening to them along all the stages (Halagarda, 2017; Kühne et al., 2010).

1.2 *The food choice questionnaire*

To access the motives behind consumers' food choice is one of the most important steps in the initial phase of a new food product development. The Food Choice Questionnaire (FCQ) is a multidimensional measure developed by Steptoe et al., (1995) to access food choice motivation. The questionnaire measures the importance of 9 factors (health, mood, convenience, sensory appeal, natural contents, price, weight control, familiarity, and ethical concern) by asking the participants 36 questions. All the questions start by "It is important to me that the food I eat on a typical day" followed by an item. The respondents answer the questions on a four-point Likert scale ranging from "not at all important" to "very important".

Although many authors use the questionnaire in its original version, others modified the question items, the question itself, the scale, or even the grouping factors. To be applied to countries other than English speaking, the questionnaire was also translated in several languages such as Turkish (Dikmen, et al, 2016) or Portuguese (Alves, 2005). As the FCQ was initially developed in the UK, its ability to be extended to either cultural backgrounds is limited since it doesn't take into account motives that may be relevant to other cultures (Freedman, 2016). However, when (Markovina et al., 2015) applied the FCQ in 9 European countries, they obtained satisfactory indicators of validity and reliability, therefore the authors recommend the use of the original FCQ version to European countries.

The FCQ has also been used to access the motivation to choose a specific food product. In this way, to apply the questionnaire, authors were forced to modify some items, since the original FCQ was not adapted to a single product. Several authors used different methods to modify the original questionnaire:

Lindeman & Vaananen (2000), adapted the FCQ to measure ethical food choice motives, based on the literature and previous studies regarding how ideology or religion may affect food choice. This adaptation was also later used by M.-F. Chen (2007), M.F. Chen (2011) and Dowd & Burke (2013) to access food choice motives regarding organic and GM foods and ethical values. Asma, Nawalyah, Rokiah, and Mohd Nasir (2010) added a new factor (religion) to adapt the questionnaire to Malaysian cultural differences. Johansen et al., (2011) added two motives that "were expected to be important" and removed a grouping factor in order to adjust the FCQ to access motivation for choice of calorie-reduced dairy products. Roos, et al (2012) also modified the FCQ reducing it to 7 factor groups and 30 question items to understand the effect of a recessionary economy on food choice. Roos et al., (2012) adapted the FCQ to the plurality of family food choices by only using 27 items and modifying the question to "For my family it is important that the food we eat in a normal day is…". Konttinen et al., (2013) measured Socioeconomic disparities in the consumption of vegetables, fruit and energy-dense foods using a short version of the questionnaire. Oellingrath et al (2013) also reduced the original FCQ after considering the importance of the items in the study to compare parental food choice motives and eating patterns of children. Russell et al, (2014) made modifications to the original questionnaire was in a way to associate parent's food choice motives with children's food preferences based on a previous study of parents' reasons for serving foods. With that purpose they changed the question to 'It is important to me that the food I choose for my child for a typical snack or evening meal…'. Finnaly, Ooi et al., (2015) added four factors (religion,

parents, peers and media) based on the literature, to access the food choice motives of adolescents.

1.3 *Food design thinking*

The concept of design thinking not only involves listening to the consumers, but also bringing them to the center of the creative process. Zampollo & Peacock (2016) created methods of approaching the initial phase of the *Food Design Thinking* process. They called one of these methods the *Themes for Eating Design* (TED) being based on the idea that creativity is stored and needs a trigger to come out. The method consists of using a tool called the "Visual Explorer" – a collection of hundreds of food related images –, to answer questions related to the ideal eating situation. The participants are divided in groups and are meant to pick an image that answers the question. These dialog between participants intends to produce innovative ideas (Zampollo & Peacock, 2016). From that point, the same authors developed the *Thoughts For Food* tool, similar to TED. The visual explorer was substituted by cards divided in groups representing general ideas, each card has an image on the front and an explanation on the back. This method is easier to use than TED's, due to the portability of the cards.

The use of images may be useful to reduce the complexity of information processing, storage and retrieval, working as a precursor or gatekeeper to more extensive elaboration. Recurring to images may be especially useful in areas in which judgments or decisions have to be made on the basis of very complex, conflicting and/or incomplete information, on the basis of a very large amount of data (Poiesz, 1989).

The aim of this paper is to describe the methodology of the adaption of the Food Choice Questionnaire to rice consumption through a Design Thinking methodology that involves the consumer since the beginning of the process. This adapation also includes an attempt to reduce the questionnaires items and prepares it to be used it as an online survey.

2 METHODS

The categories of the Food Choice Questionnaire (Steptoe et al., 1995) were confronted with Food and Drink Europe trends (FoodDrinkEurope, 2016) in order to reduce the number of categories. The translation to Portuguese was based on (Alves, 2005).

The determination of the items within each category was developed using 3 focus groups with 6 participants each: individuals over 35 years of age, with and without higher education, and young people under the age of 35. All individuals were recruited by direct contact, from Quinta do Marquês research campus in the Oeiras area (Portugal) and reported to consume rice at least twice a week.

In the focus group sessions, the individuals were asked about their rice consumption habits, specifically on the type of rice they consumed the most.

An exercise based on the *Thoughts for Food* method (Zampollo & Peacock, 2016) was then carried out. Participants were presented with two types of cards: one with a logo and a slogan representing the five categories previously defined (Figure 1), and the other with images collected online based on the original FCQ items. In a first phase, the individuals were asked to distribute the images by categories until there was a consensus (Figure 2). In the second phase the group was asked to describe what those images could represent, completing the phrase "for a rice to have this slogan it would have to be…". In the third phase the group was asked to synthesize the items to a maximum of 4 characteristics to each category (Figure 3).

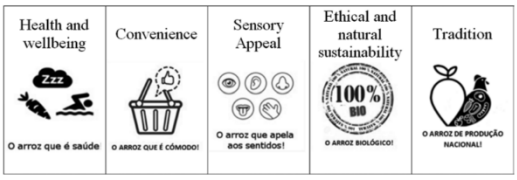


Figure 1. Symbols and slogans of the different grouping cards according to the obtained on Table 1. Image by the authors.



Figure 2. Focus group 1 working on the first phase. Photography by the authors.



Figure 3. Focus group 2 working on the third stage. Photography by the authors.

The questionnaire will be applied as an online survey, in Portuguese and English, recurring to a 7-point Likert scale.

3 RESULTS AND DISCUSSION

3.1 *Category definition*

In order to reduce the questionnaire's length and to adapt it to the motives for rice consumption, the FCQ grouping factors were confronted with FDE (FoodDrinkEurope, 2016) food trend categories. It was possible to observe that the categories from both sources fit in many ways (Table 1). Some of the original FCQ categories were excluded or merged with others, considering the FDE categories: Mood was excluded as it has no correspondence to a FDE category; Weight Control and Health were merged as a new category, Health and wellbeing; Familiarity, even though it was absent from the FDE items, was maintained as it is related with the global theme of the DIS project (promotion of Portuguese rice); Natural Content could be merged with Health or with Ethics. However it was decided to be joined to Ethics and add the word sustainability.

Although the Price category was considered very important it was not considered to the focus group discussion as it may cause some inhibition to creative thinking. The Price category was then added from the original FCQ.

3.2 *Focus group results*

Focus group 1 was composed by 6 individuals with ages over 35 and with higher education. When asked about their rice consumption, all the group replied that rice is preferred over pasta (not referring another dish component such as potatoes or beans). When questioned about what kind of rice they prefer, the group preferences depended on the dish to prepare (including basmati, thai, and other types of rice), except one person that preferred *carolino* rice over the other types and who prepares all the dishes with *carolino* rice.

Table 1. Definition of new categories for the FCQ.

Food choice questionnaire	Food drink europe	New categories
Health	Health: Natural Medical Vegetal	Health and Wellbeing
Mood	–	–
Convenience	Convenience: Easy to handle Nomadism Time saving	Convenience
Sensory Appeal	Pleasure: Sophistication Variety of senses Exoticism Fun	Sensory Appeal
Natural Content	–	–
Price	–	Price*
Weight Control	Physical: Energy Wellbeing Slimness Cosmetics	Health and Wellbeing
Familiarity	–	Tradition
Ethical Concern	Ethics: Ecology Solidarity	Ethical and Natural Sustainability

In focus group 2 the participants had no superior education and their age was over 35. All the participants revealed to use rice more often than pasta (also not referring to potatoes or any other ingredients). Most of the participants mentioned the usage of *carolino* rice only for preparing "arroz doce" (Portuguese rice pudding) and *agulha* for all the other dishes. This even includes "arroz malandrinho", a Portuguese way of cooking rice dishes where the *carolino* rice is cooked in excess of water, usually a flavorful broth, made with fish, meat and/or vegetables, resulting in a creamy but runny rice dish. One of the participants only used *agulha* rice for all the dishes, and another participant used *agulha* or *carolino* rice depending on the dish.

Focus group 3, with younger participants (under 35 years), had different responses regarding the cooking and consumption of rice. All the participants except one, affirmed to only use *agulha* rice and only as a side dish for fish, meat or vegetarian dishes. The participants prefer the rice to be loose and fast to cook, and reported to rarely cook *malandrinho* rice. One of the participants mentioned to use *carolino* or *agulha* depending on the dish.

Table 2. Results of the focus group discussion and development of new items.

	Focus group 1:	Focus group 2:	Focus group 3:	
	age >35, with higher education	age >35, without high education	age <35	
	58,33 ± 4,7 years old 100% of women	49,6 ± 8,0 years old 100% of women	24,6 ± 4,38 years old 66,7% of women 83,3% higher education	Items derived from focus group after merging
Health and wellbeing	Easy digestion* Fat free and gluten free* Provides energy* Light Healthy Without additives Nutritional information Wellbeing	Nutritious* Energetic* Health promoter* Functional* Facilitates digestion Satiety Healthier composition Wellbeing Rich in vitamins	Healthy* Nutritious* Functional* Complements the diet* Regime Force Energy Freedom Joy Wellbeing Lightness Balance Easy digestion Alternative to non healthy foods	Healthy A complement to the diet Nutritious
Convenience	Practical* Fast* Diversified* Already with seasoning Ready to consume	Practical* Fast* Easy to cook* Easy to consume* Ready to consume	Fast* Convenient* Effective* Innovation* Multitasking Variety of choice Accessible Practical Less effort	Quick and easy to prepare and consume Ready-to-eat rice contains different ingredients Innovative
Sensory Appeal	Versatile* Aromatic* Tasty* Texture Which absorbs aromas Appetizing	Visual appeal* Sensory appeal* Exotic* New experiences	Pleasure* Different* Innovation* Flavor Texture Variety Choice Creamy Dense Tasty	It is appealing Tasty Source of pleasure Aromatic
Ethical and natural sustainability	Without chemicals* Not GMOs* Sustainable	Without additives* Healthy product* Quality assurance* Quality control Natural pesticides	Without pesticides* Sustainable* Authentic taste* Quality* Fresh Local production Home production Kitchen garden Healthier Quality Appealing Natural taste Color	Comes from sustainable agriculture chemicals and contaminants free Authentic tasting GMOs free

(*Continued*)

Table 2. (*Continued*).

	Focus group 1:	Focus group 2:	Focus group 3:	
	age >35, with higher education	age >35, without high education	age <35	
	58,33 ± 4,7 years old 100% of women	49,6 ± 8,0 years old 100% of women	24,6 ± 4,38 years old 66,7% of women 83,3% higher education	Items derived from focus group after merging
Tradition	National economy* Quality* Confidence* Marketing Guarantee certificate	Traditional* Quality* Appeals to national sentiment* Quality assurance Traditional gastronomy Support to national companies	Tradition* Confidence* Familiarity* Safety Local	From a trusted brand Quality certified and from a known origin Comes from local production Familiar, traditional and appeals to national sentiment

* Items considered important by the group.

These results are aligned with the global tendencies of rice consumption reported by (GPP, 2016). Rice was referred as the most consumed staple food in every focus group, and *agulha* rice is more consumed than *carolino.* The tendency to consume *indica* rice was already reported by Son et al., (2014). In their study, authors compared the effect of culture in the choice of rice. They reported an increase of rice consumption in European countries, which may be influenced by the interest in Asian cuisine or derived of health concerns. At the same time they concluded that the non sticky-rice is preferred in France as well as in the UK and Spain (Son et al., 2014).

3.2.1 *Focus group exercise*

The participants' motivation when presented with the exercise was high. In the first phase the participants distributed the cards almost in silence, just by adjusting the positions and creating a consensus very quickly.

The second phase, where the participants had to give verbal and written expressions for the images, generated a long discussion about image meanings.

Analyzing the words and expressions written by the participants to complete the statement "for a rice to have this slogan it would have to be …" group 3, with younger people, had more ideas in how to describe rice regarding all the categories except Tradition. Another difference from this group to the others is the fact they relate innovation with Convenience and Sensory Appeal. The participants of group 3 also gave different answers to the category Ethical and Natural Sustainability, where they use terms related to health and sensory properties.

When comparing the items chosen by all the focus group participants with the original ones from the FCQ, it is possible to observe that in spite of the images used had been adopted based in the original items, the terms and the position of images per focus FCQ group were very different, which means the interpretation of images and its conceptual meaning varies among the participants, which can promote discussion and encourage the creative thinking.

The participation of consumers in the conceptualization of the FCQ items contributed to the addition and removal of items present in the original questionnaire as well as altering the language, adapting it to the consumer's language of the region were the questionnaire will be used and adjusting it to new tendencies.

3.3 *Questionnaire development*

Data obtained was crossed with the items used in the original Food Choice Questionnaire. The items chosen by the participants had a great correspondence with the ones of the FCQ. The category "Price" was also added from the original FCQ.

One of the objectives of this FCQ modification was to reduce the items of the questionnaire, following the tendency of other authors, in order to reduce the expended time when answering to it (Konttinen et al., 2013; Roos et al., 2012; Oellingrath, et al., 2013). The questionnaire obtained

Table 3. Final FCQ questionnaire. *"For me it is important that the rice that I eat…"*.

Item	Proposed factor
Is healthy	Health and wellbeing
Is a complement to the diet	
Is nutritious	
Is nutrient enriched	
Is quick and easy to prepare	Convenience
Contains additional ingredients[a]	
Is innovative[a]	
Is appealing[a]	Sensory Appeal
Is tasty	
Is a source of pleasure	
Is aromatic	
Comes from sustainable agriculture	Natural sustainability
Is free of chemicals and contaminants	
Has authentic taste[a]	
Is GMOs free	
Is familiar	Tradition
Is traditional	
It appeals to national sentiment	
Is from a trusted brand[a]	
Is quality certified and of known origin	
Comes from local production[a]	
Is not expensive*	Price*
Is cheap*	
Has the right price*	

*Added from the original FCQ.
[a]Items added from the focus group without any relation with those from FCQ.

(Table 3) has 24 items distributed by 6 proposed categories.

The initial part of the statement was also modified to "For me it is important that the rice that I eat…" in order to adapt the statement to the theme focused.

The questionnaire will be developed as an online survey. In spite of not all the individuals having access to the Internet—which, obviously, excludes some groups, online surveys are used to acquire a large numbers of responses at a very low cost, and also due to how easily the data can be handled (McDonald & Vangelder 1998).

4 CONCLUSIONS AND FURTHER RESEARCH

The Food Choice Questionnaire, in spite of having been created in 1995, still is a widely used tool to access consumer's food choice motives. But the FCQ is not a static tool, as proven by the number of modified questionnaires in use.

The modifications made by other authors are based on the literature or experts opinion. In this experimental method the consumer was included in the FCQ item modification stage through an image brainstorming exercise within a *focus group* approach, which enabled the inclusion of new items according to the user' language and culture where the questionnaire is going to be used. The role of the consumer was visible particularly on questions regarding food innovation, authenticity and trust in local production.

The use of images allowed an open focus group discussion without external interferences. The recourse to the consumer also allowed to understand some patterns to be confirmed with the questionnaire results.

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Chapter 6. PAPER 3. ADAPTATION AND APPLICATION OF THE FOOD CHOICE QUESTIONNAIRE TO RICE CONSUMPTION: A DESIGN THINKING APPROACH

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Adaptation of the food choice questionnaire using a design thinking approach and application to rice consumption by the major European consumers

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ABSTRACT

Portugal, the largest rice consumer in Europe, is witnessing an increase in imported rice, prompting a need to understand the underlying reasons for this rise. The Food Choice Questionnaire (FCQ) has been adapted to particular cases, however, the procedure isn't standardized. A method based on Design Thinking—a user-centred problem-solving approach—and the use of images in the association technique, was developed and presented to Portuguese rice consumers, comprised of three phases. In the Inspiration phase, the FCQ items and others retrieved from interviews were converted into images through an online survey. In the Ideation phase, eight Portuguese rice consumer *consensus-groups* performed card-sorting and word association exercises based on these images and an evoked context regarding rice. In the Implementation phase, the generated words were compared to the original FCQ items. The method was revealed to be valuable in adapting the FCQ in a structured manner that can be employed to other realities. The adapted FCQ consisted of 33 items (including 12 new) and was presented to 371 Portuguese rice consumers. An exploratory factorial analysis revealed six factors, where Sensory Appeal, followed by Convenience, and Health & Nutrition were the most relevant. A cluster analysis based on consumption patterns, when compared to the rice choice determinants, revealed three consumer groups: "Nationals" – mainly consumed Portuguese rice, "Varied" – consumed different rice types, and "Imported" – predominantly consumed Basmati rice. The findings indicate that the changes in lifestyle contribute to the preference for more convenient rice, regardless of price, aligning Portuguese consumer patterns with those of other European countries.

1. Introduction

Rice is a staple food in many countries, with significant differences in rice consumption levels. According to FAO (FAO, 2022), in Asia, rice consumption in 2020 was 115 kg *per capita*, while in European countries, it only corresponded to 7 kg *per capita*. In the European context, there are also significant differences, with Portugal showing the highest yearly estimated consumption with 19 kg *per capita*, which is *circa* twice as much as the next highest; these high consumption values were confirmed by the National Food Consumption Survey (IAN-AF) performed in 2015–2016 (Lopes et al., 2017), where Portuguese consumers self-reported a consumption of 23 kg per capita. Despite the significant consumption, Portuguese rice production only accounts for 13 kg *per capita*, of which 87 % corresponds to the traditional *japonica* rice (most of which being the commercial type *Carolino*, which is a long grain) and 8 % to the *indica* rice type (most of which commercialised as the type *Agulha*, also a long grain) (GPP, 2019). The production does not cover demand, with imports sharply increasing in recent years, where in 2020

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imports were near double of the production (FAO, 2022). Rice can be found in the market as brown rice (after removing the husk, but still with the bran), milled (which corresponds to rice after removing the husk and bran), and parboiled (parboiling being a post-treatment given to brown rice before milling, where steam is used to pre-gelatinise the starch, modifying its cooking behaviour). While brown or parboiled rice can correspond to any variety, those on the market come essentially from *indica* types.

The commercial type *Carolino* was the market leader for many years, however, as the market has shifted in the last decade, the *Agulha* type is now the market leader (45 % of sales according to the most recent Nielsen data, almost twice the sales of *Carolino* by quantity), with most being imported *indica* from South America. Short and medium grain types are barely used (GPP, 2019). The presence of other fully imported commercial rice types, such as the aromatics (Basmati and Jasmin) and varieties for risotto (mainly *Arborio* and *Carnaroli*), have also been growing in presence in the market, indicating an increasing demand for novelty. Basmati sales are currently even slightly higher than *Carolino* in value (21 % versus 20 % of market sales value in the most recent Nielsen data).

In order to help the promotion of Portuguese rice production, there is a need to preserve the gastronomic tradition of *Carolino* rice consumption in very different ways (e.g. by preserving the traditional *malandrinho* rice, the many different ways of cooking it or its association with conviviality (Cabral et al., 2022)), together with the development of new rice based products which include Portuguese rice as the main ingredient. This purpose also contributes to the ecological footprint reduction associated with imported rice from outside Europe (Wiedmann & Lenzen, 2018), while helping the Portuguese rice farmers to maintain their businesses (Trobe, 2001). Thus, to promote Portuguese rice consumption it is important to understand the motives behind rice consumption choices by Portuguese consumers (Cabral et al., 2022). However, food choice is a complex behaviour, and it is influenced by many interrelated factors (Chen & Antonelli, 2020). These factors may be categorized as those related to: i) the food (its internal and external attributes), which has been studied by e.g. Boesveldt and de Graaf (2017) or Larson and Story (2009); ii) the individual factors (biological, physiological and psychological factors) as reported by e.g Leng et al. (2017), Esposito et al. (2021) or Cuevas et al. (2017), and iii) the external economical and sociocultural factors (such as culture, economy and political environments) as Larson and Story (2009) or Mozaffarian et al. (2018) reported.

Despite rice being considered a staple food in many countries, cultural differences in the preference for rice and its preparation across cultures have also been studied by others (Son et al., 2013; Son et al., 2014). The authors studied the perceptions of participants from four different countries (France, Korea, Japan and Thailand) regarding rice, by using word association, concluding how the different cultural backgrounds contributed to different perceptions towards rice. The most evident differences were attributed to the geographic location and the influence of the Confucianism philosophy in the Asian countries, as all those countries related rice with the utilitarian dimension, while French participants related rice to a symbolic one. Despite the similarities, there are also differences between Asian countries, as for instance, despite the common affective and cognitive constructs found, Japanese and Korean participants perceived rice differently, as Japanese related it with a more sensorial dimension and Koreans to a more utilitarian one (Son et al., 2014).

As the differences regarding consumer motivations (such as the above mentioned ones) can be further studied, Steptoe et al. (1995) developed a tool to assess them. The Food Choice Questionnaire (FCQ), in its original version, is a well-known tool that measures the importance of 36 items grouped into nine factors (Health, Mood, Convenience, Sensory appeal, Natural contents, Price, Weight control, Familiarity, and Ethical concern) for a typical day. The FCQ has been applied to various countries from all continents, and several cross-cultural studies based on the FCQ have been developed (Cunha et al., 2018). For this, many different approaches were applied to identify relevant items and factors to add or remove from the FCQ, namely bibliographic research, the use of *focus groups* or other qualitative research, or considering more culturally immersive studies, as different cultures may interpret the concepts in different ways (Ares, 2018). However, to the best of the authors' knowledge, there is no standard common method to adapt it.

One potential approach for such adaptation could be the use of a Design Thinking (DT) approach. DT is mainly known as a user-centred method for problem-solving using design methods and tools, that can be used in any area of knowledge to respond to difficult problems that often need creative approaches (Brown, 2008; Buchanan, 1992; Micheli et al., 2019). The DT concept evolved from the idea of design as the science of the artificial (which includes all *things* created by humankind), as opposed to natural sciences (Simon, 1969). Design problems, considered as ill-defined or wicked, and the way designers think to solve them (by using their own kind of reasoning), have been discussed by theorists since the 1960′s (Cross, 1982; Lawson, 2005; Rittel & Webber, 1973; Schön, 1983; Simon, 1969). Later on, based on the concept of design as the science of the artificial (design being considered a liberal art), since the ways designers used to solve problems could be applied to other areas of knowledge; those liberal views of design became even more evident after the popularisation of the method used by the design company IDEO, presenting it as a user-centred method (Brown, 2008), which has gained popularity in several areas, such as in management (Dunne & Martin, 2006).

Despite the lack of a universal definition or even conceptualization of the DT method, the examples in literature present a series of iterative phases, mainly based on the IDEO (Inspiration, Ideation, Implementation) approach to DT (Micheli et al., 2019; Waidelich et al., 2018). Considering the IDEO approach, in the first phase (Inspiration), it is common to resource to ethnographic techniques, allowing designers to better understand user's needs, although other approaches may be used (Micheli et al. 2019). The second phase (Ideation) uses resources or techniques that promote idea generation, such as brainstorming. Finally, the third phase (Implementation) uses prototypes to test the generated ideas (Liedtka, 2015; Micheli et al., 2019).

Food science can benefit from the application of DT (Olsen, 2015), however, this approach has hardly been employed in food related issues. Bunyamin et al. (2020) used the DT approach to develop food products with community collaboration, and Hastie et al. (2021) to promote the consumption of aged lamb meat.

Zampollo and Peacock (2016) created the *Themes for Eating Design* (TED), an image-based tool created through the generation of important questions based on the various aspects of a meal. The authors converted the images to cards with symbols and their representative phrases, and used the tool as a trigger to answer questions about the ideal eating situations in a focus group context. Apart from the DT context, images have been used in the food space in many ways, including helping to understand food consumption patterns (Martin et al., 2009), and as a way to classify foods (Farinella et al., 2016; He et al., 2014), improving creativity (Salvador et al., 2019), and helping understand consumer emotions and predict their behaviours toward food (Chi et al., 2013; Vu et al., 2016).

Based on Zampollo and Peacock (2016), Castanho et al. (2023) developed and tested a tool based on words generated by chefs, through the use of word association, directed to the conceptualization of rice based meals by aspiring chefs. The authors grouped the words into three categories: meals, concepts, and ingredients, and created a card–game brainstorming exercise based on the association of word cards from the different categories. The results of the card-game exercise were compared to those of a traditional brainstorming session, concluding that the tool helped aspiring chefs to improve their creativity (Castanho et al., 2023). Association is a technique often used by designers to promote creativity, and is considered as one of the keys for idea generation, (Guilford, 1967; Mednick, 1962). Association related tools can be applied by using any stimuli, including words, logotypes, or images.

However, signs may be more interesting as a stimulus, as its interpretation may reveal cultural differences, considering they transmit a world interpretation, including stereotypes and beliefs (Eco, 1975; Rania et al., 2015). Thus, the use of images as stimuli can trigger individual responses related to the inner mental state (Reavey, 2012), but also be used to simplify complex information (Poiesz, 1989).

Given the former context, this work intends to: i) adapt the FCQ to a specific cultural context -Portugal- and food category -rice; ii) develop an image-based tool inspired on a DT approach, to support the adaptation of the FCQ, by using images as a vehicle to promote the emergence of new items, iii) implement the resulting FCQ questionnaire (further referred as the FCQ-DT) to assess rice choice determinants, and iv) to compare the importance of such determinants between different consumer groups, based on their rice consumption profile.

2. Materials and methods

This method of adaptation of the FCQ, aiming to better understand the determinants of food choice associated with rice consumption by Portuguese consumers, as well as its implementation, is depicted in Fig. 1.

The first part comprised of the adaptation of the FCQ through the DT method, divided into three phases:

(1) The Inspiration phase consisted in the preparation of the materials for the idea generation phase and has resourced to three different elements (see Fig. 1): a) the original 36-item FCQ (Steptoe et al, 1995) and a previous study on Portuguese consumers conceptualization of rice consumption (Cabral et al., 2022), b) a set of alternative images, chosen for their potential to convey each of the different items, and further selected through a consumer questionnaire. The final set of images was built into the image cards, and c) a set of concept images designed by the first author, based on the Zampollo and Peacock (2016) approach, included in six grouping cards, mainly conveying the underlying constructs from food choice, combining a logo and a short sentence.

(2) The Ideation phase, consisted of a consensus group (List, 2001), that included two exercises: a) a card sorting exercise, where participants were asked to associate each of the image cards with one of the grouping cards. This activity was developed following an evoked context, as participants were told by the moderator to consider that the logos and sentences were present on a rice package or used in the advertisement for rice or rice products, and b) a conceptualization phase, where, after the moderator restated the evoked context, the participants were asked to discuss to a consensus, a word or expression to convey each of the image cards.

(3) The Implementation phase consisted of the analysis of the words/expressions generated during the ideation phase and confronting the results with the original FCQ items. From this, a new list of items emerged, leading to the adapted FCQ, following a DT approach, the FCQ-DT.

The second part was comprised of the application of the FCQ-DT within a larger set of Portuguese consumers, where participants were asked to evaluate each of the items on a 7-point scale (from 1 – non important to 7 – very important), answering the question: "*For me it is important that the rice I consume is …?*".

Resulting data were analysed and organised into factors characterising the rice choice. Participants were further grouped into different rice consumption behaviour clusters, and their determinants of rice choice were further explored, by cluster.

Details of the different parts, phases and steps are further presented

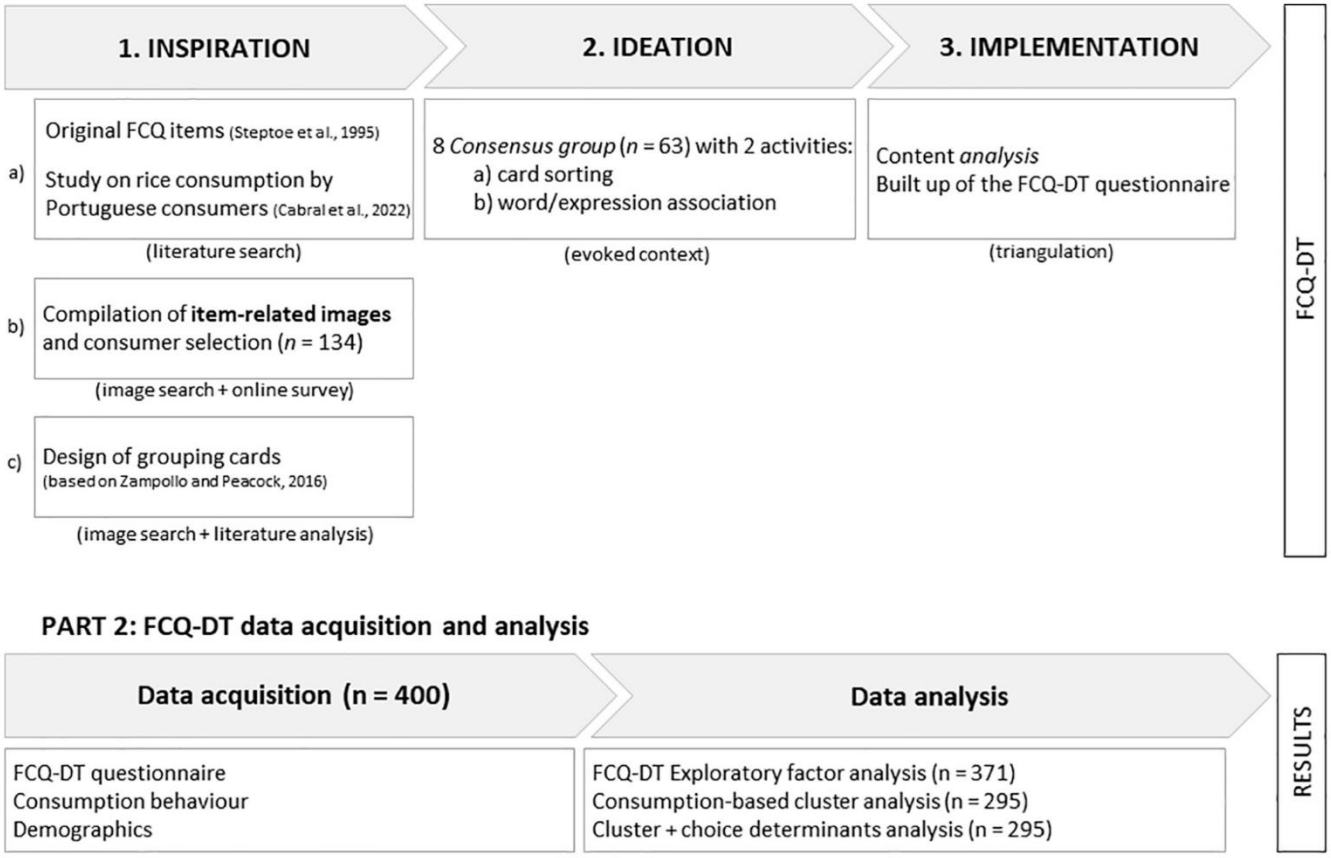


Fig. 1. Schematic view of the methodology.

in the following sub-sections.

2.1. PART 1 - adapting the FCQ through the Design Thinking approach

Based on the IDEO approach (Brown, 2008), three phases were considered in the process of adapting the FCQ to the choice of rice by Portuguese consumers, as follows in each subsection.

2.1.1. Inspiration

For the Inspiration phase (Fig. 2), the authors have resourced to a broad combination of methods.

2.1.1.1. FCQ-based item selection. Starting from the original 36 items of the FCQ (Steptoe et al., 1995), the list was revised, excluding the three items from the Price factor. Despite data on overall food choice determinants by Portuguese consumers, showing that the factor Price is the most important (Markovina et al., 2015), price was considered a minor issue by Portuguese consumers when referring to rice (Cabral et al., 2022). Moreover, the authors wanted to focus on food choice factors other than price; thus, 33 items from the FCQ were considered. Nevertheless, these price related items were later recovered in the questionnaire for Part 2.

Based on previously reported individual interviews with Portuguese rice consumers (Cabral et al., 2022; Cabral et al., 2019), five relevant statements were considered as items to include: "The package is easy to open and store", "It has an appealing package", "It is indicated for special occasions", "It is national" and "It is on sale").

Based on previous work developed by the research team, and combining this with the original FCQ list, a new set of 37 items was selected.

2.1.1.2. Choice of item related images. For each of the 37 selected items, the first researcher choose three images by searching Google free images, and inputting the item terms/expressions or their synonyms (Krishnan & Jawahar, 2013). The sets of three chosen images were incorporated into an online survey using LimeSurvey®, with the respective item (e.g. "Is nutritious"), and presented in a randomized order. A total of 134 adult participants (65 % female and 35 % male; 63 % under 40 years old and 37 % above that age; and 83 % with higher education versus 17 % with no higher education) were recruited from informal networks and social media (Maya et al., 2022; Ribeiro et al., 2022), following a convenience sample, and for each set were asked to pick the image that best suited the item representation and to rate the extent to which the image fitted the item, on a 7-scale point, from "1 – Does not fit the concept at all" and "7 – It completely fits the concept". Items with an average score lower than 3.5 were discarded, as such evaluation means that none of the selected images adequately fit the related item (please refer to Supplementary material S1 for a full detail of this data).

Following the item selection procedure presented in section 2.1.1.1, a set of six factors was considered by the authors (by merging Health and Wellbeing, and Familiarity and Tradition without removing any item). The six factors - Health and wellbeing, Convenience, Sensory appeal, Familiarity and tradition, Mood, and Ethical concern and Sustainability - were then transformed into icons and slogans, based on the *Themes for Eating Design* (Zampollo & Peacock, 2016) and on an earlier pilot study (Castanho et al., 2017). These were then presented as grouping cards, to be used in the card sorting exercise (please refer to Supplementary material S2).

The selected items images and factors were printed onto 10x15 cm (size A6) cards to be used during the Ideation phase.

2.1.2. Ideation

The selected printed cards were presented to eight *consensus groups* (List, 2001) (with seven to eight participants each, in a total of 63 participants). Participants were regular rice consumers, purposively divided into homogeneous groups, based on their education level (lower and higher education), age group (under and above 35 years old) and sex (male, female), as these variables were identified as influencing rice consumption (Cabral et al., 2022). The participants were recruited from the Sense Test database (a sensory evaluation and consumer tests company located in Northern Portugal, which is the strongest rice consumer region of the country). The company ensures the protection and confidentiality of data through the authorisation 2063/2009 of the National Data Protection Commission and following the EU General Data Protection Regulation (EU 2016/679), as well as a longstanding internal code of conduct, assuring informed consent.

The *consensus groups* were assisted by a moderator (the first researcher). After an initial icebreaker introduction, the moderator emphasized that although consensus is being looked for, it must not be

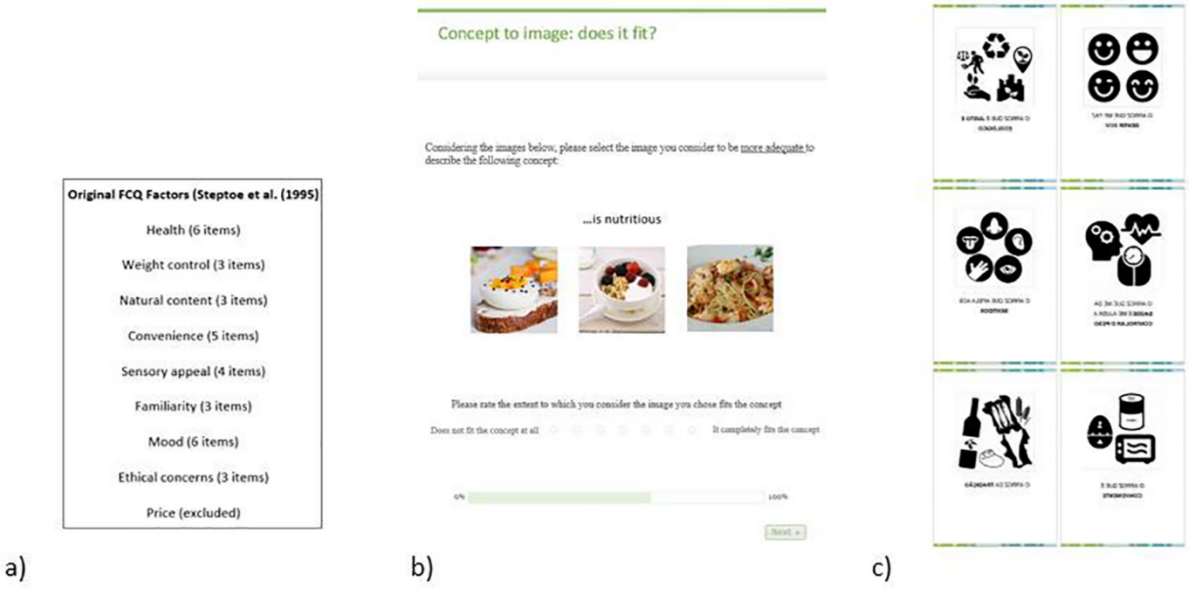


Fig. 2. Schematic view of the Inspiration phase: a) Choice of initial FCQ-related items; b) Online survey for item-related image selection; and c) Grouping cards design following the Zampollo and Peacock (2016) approach (translation of expressions into English).

forced and that participants should speak their minds, and not worry about others' opinions. The participants were then introduced to the context of the exercises. An evoked context was given during the presentation of the grouping cards by the moderator: "Please imagine how the icons and slogans could be applied to a package of rice, or an advertisement for rice or rice products". After this introduction, the participants were asked to complete two exercises, one at a time: 1) a card sorting, consisting of combining the item related image cards with one of the grouping cards; and 2) an *image-word* association exercise, where the participants were asked to say and write the words that best describe each image, while considering the previously evoked context (Fig. 3). The participants were allowed to discuss, to reach a consensus, by voting until a majority of > 75 % was reached (List, 2001).

2.1.3. Implementation

The words/expressions generated during the Inspiration phase were submitted to lemmatisation (Rojas-Rivas et al., 2019), grouped and selected according to the majority rule (Kowalska-Styczeń & Sznajd-Weron, 2016), which comprises only the inclusion of the words/expressions that were generated by the majority (>50% of the consumers). The generated words/expressions were compared with the items from the original FCQ to identify the ones to be excluded, added or retained (see Table 2).

A new version of the FCQ, for the evaluation of choice of rice products by Portuguese consumers was built, based on the described DT approach, thus further referred as the FCQ-DT.

2.2. PART 2 – Determinants of rice choice – Application of the adapted food choice questionnaire (FCQ-DT)

A total of 400 participants were recruited through a consumers' database and were stratified by sex (male, female), education level (lower and higher education) and age (18–34, 35–49 and 50–64 years old), with a single exclusion criterion: participants had to be rice consumers, consuming at least one rice meal per month. Participants were recruited within the consumer database of Sense Test.

The survey, implemented through LimeSurvey®, included questions regarding rice consumption, such as frequency of consumption, rice cooking and shopping habits (Supplementary materials S3). The participants who reported buying or cooking rice were also asked about the frequency of using or buying specific commercial designation types frequently found on the market (*Agulha*, *Carolino*, Basmati, Thai, Brown and Parboiled commercial varieties, and rice used for Risotto). The answers were initially responded on an 8-point scale (never, in special occasions, 1 to 3 meals/month, 1 meal/week, 2 to 4 meals/week, 5 to 6 meals/week, 1 meal a day, and 2 or more meals a day), being later standardised to number of meals/week.

Table 1
Number of identified dimensions and categories and different concepts by grouping factor (without repetitions) and word examples.

Concept Category	Example of words
Health and nutrition (27)	Nutritive, healthy, easy to digest Energy, vitamins, whole grain
Familiarity and tradition (26)	Celebration, versatility, portions conviviality, familiar, typical dishes
Convenience and accessibility (16)	Cooks rapidly, practical, pre-cooked Easily accessible, preservation, transportation
Ethics and environmental concerns (16)	Certified, Portuguese Natural, basic, without additives Organic, ecologic, environmentally friendly package
Mood (12)	Comfort, satiating, satisfying
Sensory Appeal (12)	Aromatic, appealing, tasty
Price (8)	Cheap, economical, large packings

The final version of the FCQ-DT, with 33 items is presented in Table 4.

After discarding the outliers, a total of 371 responses were considered for the FCQ-DT analysis. From those responses, the ones from the participants that cooked or bought rice (n = 295) were included in a cluster analysis.

2.3. Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics, v. 26.0 at

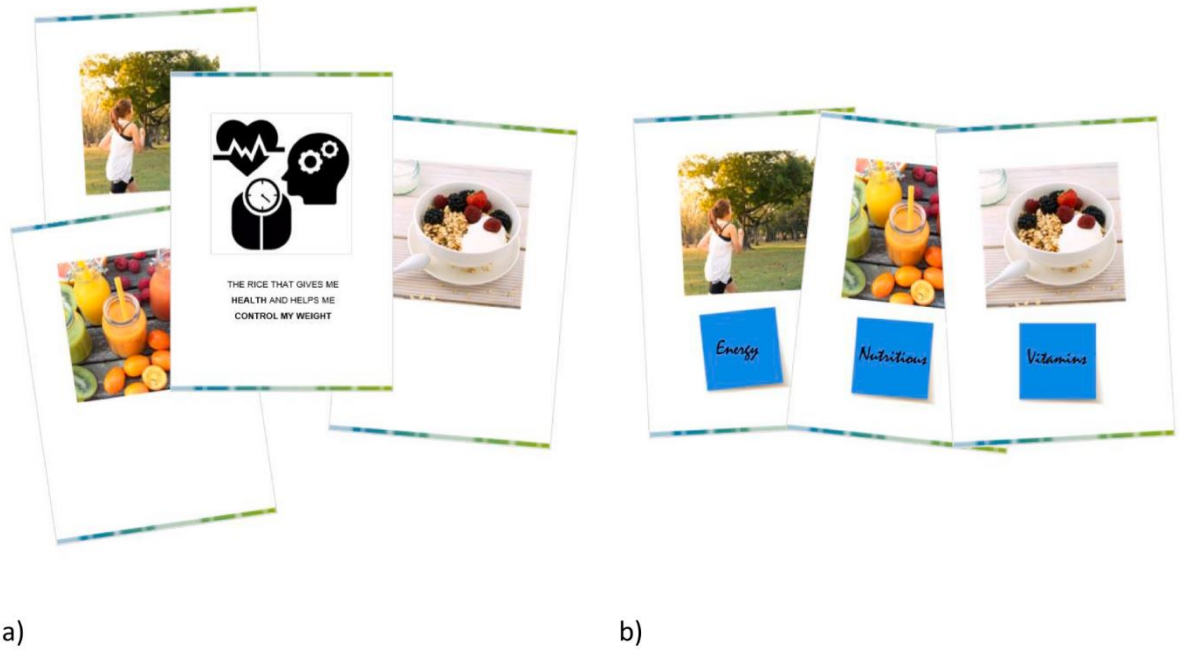


Fig. 3. Schematic view of the Ideation phase a) Card sorting exercise, b) Word/expression association.

Table 2
Modification of the FCQ: discarded and retained items from the original FCQ (Steptoe et al., 1995, items in italic), new items generated from consumers' consensus group, also containing retained items from those adapted from the work of Cabral et al., 2022; Cabral et al., 2019) (*).

	Discarded	Retained	Generated
Health and Nutrition	n = 7	n = 5	n = 3
Is high in protein	x		
Is good for my skin/teeth/hair/nails etc.	x		
Is low in calories	x		
Helps me control my weight	x		
Is low in fat	x		
Contains no additives	x		
Contains no artificial ingredients	x		
Is high in fibre and roughage		x	
Contains a lot of vitamins and minerals		x	
Keeps me healthy		x	
Is nutritious		x	
Contains natural ingredients		x	
Gives energy			x
Is in portions			x
Is easily digestible			x
Convenience and Accessibility	n = 0	n = 5	n = 2
Is easy to prepare		x	
Can be cooked very simply		x	
Takes no time to prepare		x	
Can be bought in shops close to where I live or work		x	
Is easily available in shops and supermarkets		x	
Is versatile			x
Is easy to preserve			x
Mood	n = 3	n = 3	n = 1
Helps me to cope with stress	x		
Helps me to cope with life	x		
Keeps me awake/alert	x		
Helps me relax		x	
Cheers me up		x	
Makes me feel good		x	
Comforts me			x
Ethical and Environmental concerns	n = 3	n = 0	n = 2
Comes from countries I approve politically	x		
Has the country of origin clearly marked	x		
Is packaged in an environmentally friendly way	x		
Is national/Portuguese*			x
Is organic			x
Tradition and Familiarity	n = 2	n = 1	n = 2
Is what I usually eat	x		
Is like the food I ate when I was a child	x		
Is familiar		x	
Is suitable for celebrations and important moments*			x
Promotes conviviality/socialization			x
Price	n = 0	n = 3	n = 1
Is not expensive		x	
Is cheap		x	
Is good value for money		x	
Is on sale/promotion*			x
Sensory Appeal	n = 0	n = 4	n = 0
Smells nice		x	
Looks nice		x	
Has a pleasant texture		x	
Tastes good		x	
Is ideal to complete my meal	n = 0	n = 0	n = 1

a 95 % confidence level. Nonparametric tests, Kruskal-Wallis and Chi-square tests, as well as one-way ANOVA, followed by the Tukey post-hoc multiple comparison test, where applicable, were used. Multivariate outliers were removed based on the Mahalanobis distance. An exploratory factor analysis, with Varimax rotation, was used to determine the factor structure of the FCQ-DT. The internal consistency of each extracted factor was tested using Cronbach's Alpha. Participants were also grouped into different clusters based on their reported behaviour regarding the consumption of different types of rice. A hierarchical cluster analysis was used to determine the number of clusters, followed by a K-means cluster analysis, to group the participants by cluster (Malhotra et al., 2006).

Table 3
Demographics and total rice consumption of the respondents divided by clusters, obtained after a K-means cluster analysis at 95 % confidence.

Sociodemographics	Total n = 371 **n** (%)	"Nationals" n = 130	"Varied" n = 74	"Imported" n = 80
Sex*		ab	a	b
Female	215 (58 %)	83 (63.8 %)	41 (53.9 %)	61 (76.3 %)
Male	156 (42 %)	47 (36.2 %)	35 (46.1 %)	19 (23.8 %)
Education Level*		a	b	a
Without higher education	179 (48.2 %)	53 (40.8 %)	46 (60.5 %)	25 (31.3 %)
With higher education	192 (51.8 %)	77 (59.2 %)	30 (39.5 %)	55 (68.8 %)
Age group				
18–34	137 (36.9 %)	52 (40.0 %)	25 (32.9 %)	33 (41.3 %)
35–49	138 (37.2 %)	46 (35.4 %)	30 (39.5 %)	34 (42.5 %)
50–64	96 (25.9 %)	32 (24.6 %)	21 (27.6 %)	13 (16.3 %)
Household size* (no. of people)		ab	a	b
1	40 (10.8 %)	15 (11.5 %)	6 (7.9 %)	14 (17.5 %)
2	103 (27.8 %)	34 (26.2 %)	21 (27.6 %)	27 (33.8 %)
3	106 (28.6 %)	41 (31.2 %)	19 (25.0 %)	21 (26.3 %)
4	98 (26.4 %)	34 (26.2 %)	26 (34.2 %)	14 (17.5 %)
5+	24 (6.5 %)	6 (4.6 %)	4 (5.3 %)	4 (5.0 %)
Household net monthly income* (children included)		ab	b	a
≤600€ per capita	196 (52.8 %)	66 (50.8 %)	50 (65.8 %)	33 (41.3 %)
>600€ per capita	163 (43.9 %)	60 (46.2 %)	24 (31.6 %)	45 (56.3 %)
Mean rice consumption # (meals per week)	**Mean** (±SD) 3.7 (±2.3)	3.4 (±1.7) a	4.1 (±1.6) b	2.9 (±1.5) a

* Significant differences between clusters, according to the chi-square, at 95% confidence level.
# Significant differences between clusters, according to the Kruskal-Wallis' test, at 95% confidence level.

3. Results and discussion

3.1. PART 1 – Adapting the FCQ through the Design Thinking approach

3.1.1. Inspiration

3.1.1.1. FCQ-based item selection. Item selection and grouping allowed the inclusion of five items collected from interviews with Portuguese consumers ("the package is easy to open and store", "it has an appealing package", "It is indicated for special occasions", "It is national" and "it is in sale"), which consisted of a first step of the cultural adaptation. In

Table 4
Factorial structure of the FCQ-DT data, with explained variance and α-Cronbach for each factor (n = 371). Main factor loadings for each retained item and mean ± SD scores for both factors and individual items. Different letters reflect statistical differences between mean factor scores, according to the Wilcoxon test ($p < 0.05$).

Dimensions/Items	Loadings	Mean ± SD
Health and Nutrition (Expl. Var. = 15.06 %; α-Cronbach = 0.907)		**5.40[b] ± 0.4**
Is high in fibre and roughage	0.782	4.99 ± 1.6
Contains a lot of vitamins and minerals	0.739	5.11 ± 1.6
Is nutritious	0.718	5.67 ± 1.3
Keeps me healthy	0.643	5.94 ± 1.2
Gives energy	0.637	5.25 ± 1.5
Contains natural ingredients	0.619	5.12 ± 1.8
Is easily digestible	0.585	5.71 ± 1.4
Mood (Expl. Var. = 12.91 %; α-Cronbach = 0.880)		**4.69[d] ± 0.6**
Cheers me up	0.797	4.65 ± 2.0
Helps me relax	0.757	4.10 ± 2.0
Makes me feel good	0.697	5.58 ± 1.6
Comforts me	0.694	5.07 ± 1.7
Promotes conviviality/socialization	0.609	4.05 ± 2.0
Price (Expl. Var. = 11.42 %; α-Cronbach = 0.883)		**5.15[c] ± 0.4**
Is not expensive	0.868	5.31 ± 1.5
Is cheap	0.862	4.89 ± 1.6
Is good value for money	0.810	5.59 ± 1.4
Is on sale/promotion	0.753	4.83 ± 1.7
Convenience (Expl. Var. = 9.61 %; α-Cronbach = 0.903)		**5.58[b] ± 0.1**
Is easy to prepare	0.850	5.61 ± 1.3
Can be cooked very simply	0.836	5.67 ± 1.3
Takes no time to prepare	0.771	5.44 ± 1.3
Sensory Appeal (Expl. Var. = 9.49 %; α-Cronbach = 0.765)		**6.07[a] ± 0.5**
Tastes good	0.794	6.60 ± 0.7
Has a pleasant texture	0.713	6.21 ± 1.0
Looks nice	0.561	5.99 ± 1.2
Smells nice	0.519	5.46 ± 1.6
Familiarity and Tradition (Expl. Var. = 6.62 %; α-Cronbach = 0.629)		**3.93[f] ± 1.1**
Is in portions	0.755	2.91 ± 1.9
Is familiar	0.565	5.07 ± 1.6
Is suitable for celebrations and important moments	0.556	3.81 ± 2.0
Ethical and Environmental Concerns (Expl. Var. = 6.37 %; α-Cronbach = 0.657)		**4.27[e] ± 1.0**
Is national/Portuguese	0.829	4.97 ± 1.7
Is organic	0.684	3.58 ± 2.0

fact, several authors added items to the original FCQ to adapt it to the objective of the study, as for example Carrillo et al. (2011), who added the "is low in sugar" item to the FCQ to better understand the opinion of consumers on low-sugar foods and their influence on food choice; or Rojas-Rivas et al. (2019) who adapted the FCQ to assess the motives of amaranth consumption.

The rearrangement of grouping items is also a common proceeding. Some examples of the questionnaire presented by Johansen et al. (2011) who removed one factor, or the work of Abdul Rahman et al. (2013), who added a risk assessment factor, or Espinoza-Ortega et al. (2016), who modified the FCQ factors and added two new ones. In this work, grouping items suffered relatively small changes. The three factors associated with *health and wellbeing* were merged, and *tradition* was added to the familiarity factor, and sustainability was added to the environmental concerns one, based on Cabral et al. (2022). The price factor was excluded from the items to be presented to the later consensus group exercise, as it might compromise the consumers' discussion. In a cross-cultural study performed by Markovina et al. (2015), Portuguese consumers reported price as the main food choice determinant (regarding overall food choice), meaning this factor could be considered a sensitive subject. Furthermore, Cabral et al. (2022) determined price was not so important for Portuguese consumers, regarding the particular case of rice. Thus, price was removed from the consensus group discussion, not being subjected to the consumers' appreciation at this stage, however, it was later recovered and included in the implemented FCQ-DT.

3.1.1.2. Choice of item related images. The image choice survey, in which the participants were asked to pick an image out of three and rate its fitting to each of the selected items was responded by 134 Portuguese consumers (65 % female and 35 % male; 63 % adults under 40 years old and 37 % above that age; and 83 % with higher education versus 17 % with lower education). The results revealed significant difference between generations (millennials/non-millennials) regarding the choice of five images (*Is high in fibre and roughage*, *Helps me control my weight*, *Has a pleasant texture*, *Is like the food I ate when I was a child* and *Makes me feel good*), and between sex, regarding the item *Is what I usually eat* and education level regarding the item *Is high in protein*, when applying the Chi-Square test at 95 % confidence level (Supplementary materials S1). These results emphasize the idea of images as a way of triggering individual responses related to the inner mental state (Reavey, 2012), as well as reflecting how image interpretation may reveal cultural differences (Eco, 1975; Rania et al., 2015). One evident example is the case of the *Is like the food I ate when I was a child item*, as the chocolate eggs, chosen by millennials, didn't represent the childhood of non-millennials, which in this case represents market changes. In two of the of image sets, no image was considered to fit the presented concept ("*comes from countries I approve of politically*" and "*Is good for my skin/teeth/hair/nails etc*"). As those items did not represent the concept, they were removed from the card pool. The selected images were presented to the consumer *consensus groups* considering the same stratification as the one from the image selection survey, meaning that the card set used for the millennials was different to the one for the non-millennials.

3.1.1.3. Grouping cards design. Grouping cards were designed based on the Zampollo and Peacock (2016) *Themes for eating design* cards, where the images derived from the visual explorer (a picture only tool) were transformed into cards containing icons and words. In this work, the role of the grouping cards was to create an evoked environment that allows the maintenance of the FCQ structure, by including the grouping item words, all the while allowing consumers to imagine those icons and slogans applied to rice packages or advertisement campaigns, thus helping the group to generate words related to rice.

3.1.2. Ideation

Image interpretation in the *consensus group* exercise generated 117 different concepts in all groups (Table 1). The concepts were grouped into seven categories, after triangulation (Carter et al., 2014), and according to the cards grouping exercise; the category with the most associated concepts was the one regarding Health & Nutrition. Although the Price factor was not converted into images, the consumers generated some ideas related to the Price item (n = 8). However, the concepts were not very consensual, representing the fact that the Price factor had been excluded from the former image choice exercise but also the lack of relevance of the price category in the case of rice (Cabral et al., 2022).

The ambiguity of the given stimuli may vary according to its nature, as while word stimuli may be considered less open, pictures lead to broader meanings (Louvel, 2006). Words as stimuli have been used in the context of consumer research (Ares et al., 2015; Ares et al., 2008), and even to identify cultural differences in rice choice by word association (Son et al., 2014). In this study, the provided images were used to expand the concept boundary (Louvel, 2006) in the FCQ adaptation, within the frame of the original FCQ – as in the one hand, the inclusion of the original FCQ items and structure creates an artificial frame, on the other hand, images allow consumers to think independently of that frame, thus generating new concepts based on the first ones (Castanho et al., 2023; Louvel, 2006).

3.1.3. Implementation

Only the generated items common in at least 50% of the *consensus group* ($n \geq 4$) were considered, using the majority rule (Kowalska-Styczeń & Sznajd-Weron, 2016) and were compared with the original

FCQ items. After the *consensus group* exercise, 15 items/concepts from the original FCQ were removed, while 21 were retained, and the consumers' *consensus group* generated 12. The resulting FCQ-DT had 33 items (Table 2).

The FCQ-DT reveals the result of the implemented approach, assuming culture as part of human behaviour and exploring the constructs from a within-culture perspective (Ares, 2018; Helfrich, 1999). The inclusion of consumer-generated concepts reflects: a) the way consumers perceive rice is different from other foods and/or food in general, which is visible in the case of the inclusion of "is versatile", reflecting the many ways of cooking rice (Cabral et al., 2022) and the removal of the "is high in protein", which has little to no relation to rice; and b) the influence of the cultural background, reflected in items related to conviviality and socialisation, and in the inclusion of "it is national/Portuguese".

Through this approach it was possible to adapt the FCQ to the Portuguese cultural reality and the specific product by including or excluding items, while maintaining the essential structure and concept of that valuable tool. Thus, this approach may be very useful when conducing consumer research within a particular culture and/or within the scope of a specific product or product category.

3.2. PART 2 – Determinants of rice choice – Application of the adapted food choice questionnaire (FCQ-DT)

From the adapted questionnaire, presented to 400 Portuguese consumers, a total of 371 valid responses were considered for the FCQ-DT analysis. From those responses, the ones from the rice cookers or buyers ($n = 295$) were included in a cluster analysis.

Regarding consumption, the respondents reported an intake of 3.7 ± 2.3 meals per week, higher than the one found by Lopes et al. (2017), who reported the consumption of 2.9 meals per week in 2015 in Portugal, which can be explained by the panel being from the Portuguese region with highest *per capita* consumption. The overall rice consumption patterns reflect the market sales data, as the most consumed rice by the panel was *Agulha* (2 meals/week), followed by *Carolino*, Basmati and Parboiled rice types, consumed 1.5, 1.2 and 0.7 meals per week, respectively. It should be noted that at this stage, not all consumers are knowledgeable of the differences, some consumers, if they have not cooked the meal themselves, may be unaware of what type of rice they are effectively eating (exception made for brown rice). However, the results are in accordance with the most recent data collected by Nielsen (December 2022), which reveals the Portuguese sales were *Carolino* 23.2 %, *Agulha* 45.6 %, Basmati 13.3 %, Parboiled 10.9 %, Risotto 1.0 %, Brown 0.7 %, Others 5.3 %, and reinforce the concerns of the producers with the decrease of consumption of Portuguese rice varieties.

The respondents reporting cooking or buying rice were divided into 3 clusters regarding their rice type consumption (Table 3). The first cluster is composed of consumers who mainly buy and/or cook the varieties grown in Portugal, named the "Nationals"; the second cluster is composed of consumers whose consumption is more varied, therefore, can be named "Varied", and the third cluster consumers were named as "Imported" due to the greater consumption of the imported Basmati rice (Fig. 4). It important to note that the participants of the study are Portuguese consumers, therefore the reasons for the consumption of Basmati rice may be derived to those consumers being more amenable to innovation and variety and less sensitive to price, who like to experiment and appreciate new flavours. Statistically significant differences were found ($p < 0.05$) in the clusters regarding demographic data: "Nationals" and "Varied" have both bigger families and, therefore, lower income per family member; most consumers from the clusters "Nationals" and "Imported" have higher education and are women, while the "Varied" cluster have a balance between males and females, as well as with and without higher educated consumers. These differences suggest that the main demographic difference between national or imported rice consumption is related to higher income, smaller families, and higher education, which is consistent with the price differences between national and Basmati rice types.

After the factor analysis (Table 4), five items were excluded ("Is versatile", "Can be bought in shops close to where I live or work", "Is easily available in shops and supermarkets", "Is easy to preserve" and "Is ideal to complete my meal") as they presented low loadings (<0.5). Of those items, two ("Can be bought in shops close to where I live or work", "Is easily available in shops and supermarkets") were in the original FCQ. The item "Is versatile" was added following the *consensus groups'* results, and "Is ideal to complete my meal" was not theoretically included in any group as it corresponded to a one-item factor.

Although there were some changes to the initially proposed structure, the factorial analysis confirmed the hypotheses of the existence of six grouping factors. For general food consumption, the most relevant factor of choice for Portuguese consumers in 2014 was Price, followed by Sensory Appeal (Markovina et al., 2015). For rice, Price was not the most important factor, which can be confirmed by the consumption patterns, mainly regarding the high consumption of Basmati rice. Sensory characteristics, mainly texture and taste, seemed to be the most relevant factors regarding rice choice, being more important than the Price factor. Natural content, Health and Weight Loss (3rd, 4th and 5th important items for Portuguese consumers in 2015) were in the present study joined in just one factor, "Health & Nutrition", contrarily to the FCQ results for general foods. In the case of rice, Convenience seems to be more important than the Health & Nutrition factors.

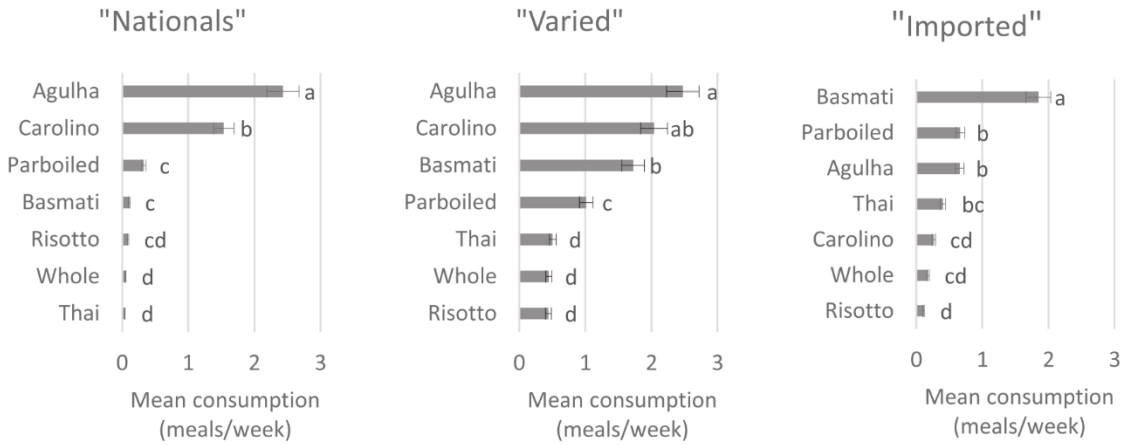


Fig. 4. Consumption patterns by cluster. Different letters in the same graphic represent different homogenous groups according to the Kruskal-Wallis' test, at 95% confidence level.

These results are consistent with the ones from an exploratory study performed by Cabral et al. (2022) regarding rice. The authors implemented a questionnaire to 256 Portuguese rice consumers; the respondents were elicited by the word "rice" and were then asked to perform a word association exercise. The authors reported that the most associated words were the ones regarding the sensory qualities of rice, mainly regarding its texture. Son et al. (2014), who studied the representation of rice across four different countries (Korea, Japan, Thailand and France) through word association, used a triadic approach, identifying utilitarian, experiential and symbolic motivations associated with rice consumption: the utilitarian dimension relates to physical and functional characteristics of the product, the symbolic dimension reflects the message and the symbolic representation, and the experiential dimension, the sensorial stimulation. Therefore, and comparing the Food Choice Questionnaire factors with the approach of Son et al. (2014), the factors related to Nutrition and Health, Price and Convenience can be considered utilitarian characteristics, the factors related to Mood, Ethics and Familiarity can be considered symbolic, while Sensory Appeal as an experiential characteristic. The authors reported that French consumers related rice consumption with more symbolic motives, such as the relation to other cultures, while the Asian countries considered it a major ingredient. All the participants associated rice with sensorial characteristics; however, Japanese people elicited more words associated with sensory properties, while Koreans associated rice with utilitarian ones. The texture was associated with "good rice" mainly by French people, who also associated it with a "non-sticky texture".

In the present study, the respondents considered experiential/sensory characteristics the most important ones, followed by utilitarian and symbolic. In their work, Cabral et al. (2022) referred to the similarity between Asian and Portuguese consumers, as both value the experiential/sensory factor, which, according to the authors, may be related to the long experience with cooking and eating rice, and the long standing historical and cultural relations between Portugal and Asia (especially India and China).

Agulha rice and Basmati rice types are considered "non-sticky", as they are both subspecies of *indica*, with low amylopectin content, and are usually consumed as a side accompanying whatever meat or fish food that goes with it. In contrast, the *japonica* subspecies used in *Carolino* are stickier, having higher amylopectin contents, and are more traditional, often cooked jointly with the protein source (meat or fish pieces), but also as a side accompanying meat or fish judged to be well accompanied by such type of rice in Portuguese gastronomy (Cabral et al., 2022) – being the elected type for traditional Portuguese gastronomy (Calingacion et al., 2014). The greater stickiness gives both a sweeter taste (from the amylopectin), and provides grains that have absorbed much more of the taste of whatever was cooked with the rice, whereas *Agulha* will give blander tastes that are better combined with some applications. Suwannaporn and Linnemann (2008) studied the impact of grain type, texture (hardness and stickiness), colour and aroma, in rice quality perception of consumers from different nationalities. The authors found remarking differences regarding eating quality perception, among consumers from different countries regarding grain type. Stickiness and hardness were both considered important factors for eating quality perception of Basmati rice, as they showed to prefer a less sticky grain. The authors reported a preference for the non-stickiness of rice as an important attribute for consumers from France, U. K. and Spain. In this way, the increased preference for *Agulha* rice, which has shifted market preferences in just over a decade, giving a non-sticky rice, approaches Portuguese towards other European consumers, meaning that while rice is still a staple food, Portuguese consumers are now approaching a more European style of eating rice.

The lower importance given to the symbolic dimension (Mood, Ethics and Familiarity), differing from the French motives reported by Son et al. (2014), may be the cause for lower *Carolino* rice consumption. It is also noted that cooking *Carolino* rice well, requires better culinary skills – *Agulha* and especially parboiled rice are more insensitive to the skills of the cook. The importance given to the utilitarian dimensions may reflect the way Portuguese consumers see rice as a staple food, which also combines with another likely reason for increased consumption of *Agulha* and decreased of *Carolino*: price. Formerly *Carolino* was cheaper, whereas today it is the reverse.

Looking at the consumption patterns of each cluster (Fig. 5), differences ($p < 0.05$) can be found in the importance given to each FCQ-DT factor regarding Health & Nutrition, Mood, Sensorial Appeal, Familiarity & Tradition and Ethics & Environmental concerns. Moreover, the order of importance differs mainly on the Health & Nutrition, Convenience and Price factors. For the "Varied" cluster, Health & Nutrition is the second most important factor (in the same homogenous group as the top factor – Sensory Appeal), suggesting that these consumers have drawn a closer relation between rice consumption and health issues, despite being the ones that present a higher overall value of rice consumption, with over 4 rice-based meals per week (Table 3). For the "Imported" group, the Convenience factor is the second most important factor, with no significant difference from Sensory Appeal, which is in agreement with the fact that these consumers tend to be from a wealthier background and a higher educational level, giving them a higher purchasing power, to look for more convenient rice-based meals, which are typically more expensive. For the "Nationals" group, Price is the third most important factor, ahead of the Health and Nutrition factor, which is in agreement with their focus on the cheaper *Agulha* and *Carolino* varieties, with almost no consumption of the other more expensive ones, such as Basmati, Risotto or Thai rice. Probably, this is related with a higher attachment to traditional rice uses, being less prone to accepting the new rice varieties. Similar results were presented in the exploratory works by Cabral et al. (2022), where they identified a group with a rice consumption profile they called "Local", presenting a high negative attachment (expressed by negative feelings and emotions) to innovative food products, such as those with a low-glycaemic index. Moreover, despite the Ethical and Environmental concerns being the second least important factor for the three clusters, there are differences between them regarding the specific item related to the origin of rice (data not shown). For the "Nationals" group, the fact that the rice is of national origin is a more important choice motive, than for the "Imported" group, which may also explain the lower attachment to the imported varieties.

4. Limitations and future work

According to Cunha et al. (2018), many different approaches may be applied to identify relevant items and dimensions to add or remove from the FCQ. The results of this research show that developing an image-based tool, inspired by a DT approach, can be applied to support the adaptation of the FCQ, by using images as a vehicle to promote the emergence of new items, minimising potential bias from researchers. Indirect measures can bring a more naturalistic view of the behaviours and choices to the research studies, explaining the intuitive and unconscious processes better (Jaeger et al., 2017). Nevertheless, the application of the DT method is cumbersome, demanding several phases and mixed methods, involving somewhat large numbers of participants (consumers).

However, even though the development of the DT approach to adapt the FCQ was focused on Portuguese rice consumers, it is possible to easily employ the methodology and direct the FCQ to other cultural realities and/or products. This derives mainly from the flexible yet structured characteristics of the methodology. Two approaches to modifying the questionnaire can be established: a) adapting it for a specific product and b) adapting it to a specific culture; or even a combination of both.

To adapt the FCQ-DT (adapted to the Portuguese culture) to other food products or categories, the selected item cards can be used, only changing the slogans on the grouping (factors) cards and the evoked context explicitly referring to the food product or category. This means

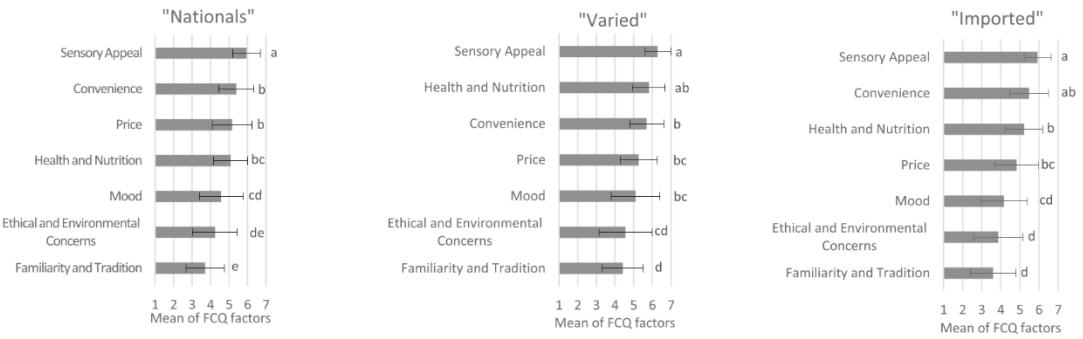


Fig. 5. Mean importance of the FCQ constructs by cluster. Different letters in the same graphic represent different homogenous groups according to the Kruskal-Wallis' test, at 95% confidence level.

that overall, the process would only have to be rerun from the Ideation phase onwards. In the case of having identified – from previous exploratory studies – the emergence of additional potentially relevant items, a preliminary step should be implemented. This would be based on the Inspiration phase, encompassing the selection of the best images to represent such items and to add them to the deck of item cards.

To adapt the FCQ to a different culture, following the DT approach, it is essential to start with the transformation of the items into images, considering that culture plays an important role in image interpretation. This means that the process must be taken full-on, from the Inspiration phase, either by using the same set of image triplets or new ones, if considered necessary, depending on how far the new country would be culturally away from Portuguese consumers. Nevertheless, one major advantage would emerge, as once the method is implemented in that specific culture, it may easily be adapted to different food products and categories.

Future work may focus on the development of a quicker and easier adaptation, which is considered the most important limitation of the study, as some steps might be condensed. Namely, at the Inspiration phase, future research could evaluate the impact of directly using images collected from published research, instead of having a consumer selection step on the number and variation of words/expressions elicited at the Ideation phase. Moreover, at the Ideation phase, the research could aim at evaluating the impact of replacing Consensus groups with Focus groups, as the latter tend to be of shorter duration and overcome the difficulty that may arise from the need of reaching a consensus, even if partial. Alternatively, Consensus groups could also be replaced by individual interviews or even individual online sessions/questionnaires, where participants would be asked to perform the card sorting (physically or online), and thence, a free-word association task would be implemented.

5. Conclusion

Design Thinking is a user-centred approach used in several knowledge areas, and consumer sciences can also benefit from its application. Overall, one can conclude that this approach allowed for a better understanding of the motives behind the choice of rice from Portuguese respondents, minimising potential bias from researchers, and helping the rice industry to understand consumers and better fit their real needs. This has also generated a tool that can be used to adapt the FCQ to different food products or categories, or within different cultures. The current research revealed three clusters of Portuguese rice consumers, based on their pattern of rice consumption: "Varied", "Nationals" and "Imported", showing differences on the motives behind rice choice. The "Imported" cluster mainly consumed imported rice, presenting a higher income, smaller families and higher education, and for whom the second main choice motive is Convenience This information, particularly the characterisation of the "Imported" cluster, may reveal that although Portuguese consumers continue to consume much more rice, when compared with other European consumers, they both respect the tradition or adhere to changes in lifestyle. The latter leads to the consumption of imported exotic varieties of rice, and of rice that is easier to cook (e.g., in ready-to-eat rice-based meals or simply ready-to-eat white rice), despite being more expensive, approaching the behaviour of other European consumers.

CRediT authorship contribution statement

Ana Castanho: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **Carla Brites:** Supervision, Writing – review & editing. **Célia Rocha:** Resources, Writing – review & editing. **Ana Pinto Moura:** Writing – original draft, Writing – review & editing. **Jorge C. Oliveira:** Funding acquisition, Writing – review & editing. **Luís M. Cunha:** Validation, Formal analysis, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2023.104951.

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Supplementary material (S1) – Item cards image selection

Selected images and significant differences between consumers' demographic data and choice of image for each concept/item. Selected images are framed in bold. All the images were collected from Google Images' search engine (https://www.google.com/imghp, during Nov-Dec 2018) under the Creative Commons Attribution (CC-BY) license, allowing images to be shared and adapted.

Concept/item	Image 1	Image 2	Image 3	Statistical differences p < 0.05
Contains a lot of vitamins and minerals				
Keeps me healthy				
Is nutritious				
Is high in protein				Higher education: Image 1 No higher education: Image 2
Is good for my skin/teeth/hair/nails etc				No image was considered relevant
Is high in fibre and roughage				Millenials: Image 1 Non-millenials: Image 2
Is low in calories				
Helps me control my weight				Millenials: Image 3 Non-millenials: Image 1

Concept/item	Image 1	Image 2	Image 3	Statistical differences p < 0.05
Is low in fat				
Contains no additives				
Contains natural ingredients				
Contains no artificial ingredients				
Is easy to prepare				
Can be cooked very simply				
Takes no time to prepare				
Can be bought in shops close to where I live or work				
Is easily available in shops and supermarkets				

Concept/item	Image 1	Image 2	Image 3	Statistical differences p < 0.05
The package is easy to open and store (Interviews)				
Smells nice				
Looks nice				
Has a pleasant texture				Millenials: Image1 Non-millenials: Image 2
Tastes good				
It has an appealing package (Interviews)				
		Familiarity and tradition		
Is what I usually eat				Females: Image 1 Males: Image 2
Is familiar				
Is like the food I ate when I was a child				Millenials: Image 3 Non-millenials: Image 2

Concept/item	Image 1	Image 2	Image 3	Statistical differences p < 0.05
I tis indicated for special occasions (Interviews)				
Helps me cope with stress				
Helps me to cope with life				
Helps me relax				
Keeps me awake/alert				
Cheers me up				
Makes me feel good				Millenials: Image 3 Non-millenials: Image 1
Comes from countries I approve of politically				No image was considered relevant
Has the country of origin clearly marked				

Concept/item	Image 1	Image 2	Image 3	Statistical differences p < 0.05
Is packaged in an environmentally friendly way				
It is national (Interviews)				
Is in sale (interviews)				

Chapter 7. **PAPER 4. EXPLOITING THE BIOACTIVE PROPERTIES OF γ-ORYZANOL FROM BRAN OF DIFFERENT EXOTIC RICE VARIETIES**

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Exploiting the bioactive properties of γ-oryzanol from bran of different exotic rice varieties

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The rice industry is one of the most significant food industries since rice is a widely consumed cereal in the world. As a result of this substantial production, the rice industry has a significant amount of side streams, including bran, representing millions of tons of raw materials mainly designated to animal feed. Rice bran is a rich source of γ-oryzanol, a bioactive compound with substantial health benefits. In this perspective, different bran rice samples from distinct germplasm origins (Philippines, Italy and Portugal) were studied for their γ-oryzanol content by HPLC-PDA, cytotoxicity in four human tumour cell lines, hepatotoxicity in a normal cell line and for their antimicrobial effects on different bacterial and fungal strains. The Ballatinao sample presented the strongest activity against all the tumour cell lines, and was also the sample showing the highest amount of γ-oryzanol, suggesting its contribution to the exhibited cytotoxic properties. Regarding the antimicrobial activity, the tested samples were able to inhibit the majority of bacterial and fungal strains, with the Portuguese Ceres sample being the one presenting the highest bacterial inhibition and the Maluit and Dinorado samples, the highest fungal inhibition. Overall, the results show that rice bran extracts may be considered as potential candidates for antimicrobial agents when incorporated into food matrices.

Introduction

Rice is one of the major staple foods consumed all over the world, with China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar and the Philippines being the countries which contribute most to the levels of rice production corresponding to 82% of the global rice production and 69% of the global rice consumption.[1]

Usually, rice is consumed after dehulling and milling, which leads to a vast amount of side streams with bioactive potential, including husk and rice bran, which are mainly used as animal feed.[2] The percentage of rice side streams is variable, which in the case of bran ranges from 10% to 13%.[3] Rice bran is considered an important underutilised nutritional resource that could be incorporated into human diets to improve health, particularly in developed nations.[4] Rice bran contains mainly oil and protein,[5] as well as dietary fibre, including cellulose and hemicellulose, which are known for their functional properties.[6] The health benefits of rice bran have been related to its potential for improving lipid profiles,[7] muscle strength after resistance training[8] and for its anti-diabetic properties.[9] These benefits arise mostly from phytochemicals existing in the rice bran lipid fraction, mainly γ-oryzanol, ferulic acid and tocotrienols.[10] Of these three compounds, γ-oryzanol is the most representative, ranging from 79.2 mg to 912 mg per 100 g in rice bran depending on the bran origin and other factors such as extraction methods.[11–16]

γ-Oryzanol is a mixture of ferulate esters of sterols and triterpene alcohols, and almost 95% of total γ-oryzanol content is represented by four major compounds: 24-methylenecycloartanyl ferulate, cycloartenyl ferulate, campesteryl ferulate and β-sitosteryl ferulate, in decreasing order of abundance.[17,18]

The health benefits of γ-oryzanol have been studied since the early 1950s in animals and humans, mainly its effect on lipid metabolism.[19,20] A recent meta-analysis including randomised clinical trials showed that rice bran oil intake resulted in a reduction of LDL-cholesterol and total cholesterol levels, hence reducing cardiovascular disease risk.[7] The cholesterol-lowering effect may be related to the triterpene alcohols (a part of γ-oryzanol) that play an important role in inhibiting cholesterol synthesis and absorption.[21] The cytotoxic pro-

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perties of rice bran, particularly the oil fraction, have also been explored in recent years, mainly in cancer cells[22] and mice.[23] The authors reported an inhibitory growth effect of γ-oryzanol on colon and lung cancer cell lines.[22,23] Most of the human studies regarding rice bran bioactivity have focused on the whole bran or the oil fraction, and individual compounds, especially ferulic acid and γ-oryzanol, were considered the main contributors to human-health improvement.[10] The isolated ferulates of triterpene alcohols and sterols, known as γ-oryzanol constituents, were tested against TPA-induced inflammation in mice[24] and against MCF-7 cells,[25] revealing anti-inflammatory activity and potential for the chemoprevention of cancer,[24,25] and synergistic effects between the compounds have also been suggested.

The purpose of this study was to extract and quantify γ-oryzanol of different rice bran varieties from different regions (Philippines, Italy and Portugal). Furthermore, we also intended to explore its bioactive potential such as the cytotoxicity, antibacterial and antifungal activities.

Materials and methods

Standards and reagents

Sulforhodamine B, trypan blue, trichloroacetic acid (TCA), Tris, ellipticine, streptomycin–ampicillin, *p*-iodonitrotetrazolium chloride (INT) and the HPLC gradient grade solvents (acetonitrile, methanol and isopropanol) were purchased from Sigma (St Louis, MO, USA). RPMI 1640 medium (HyClone), Hanks' balanced salt solution (HBSS) and all the other culture medium components were purchased from Gibco Invitrogen Life Technologies (Paisley, UK). Gamma-oryzanol (CAS number 11042-64-1) was used as a standard and purchased from TCI Europe.

The culture media Muller Hinton broth (MHB) and Tryptic Soy Broth (TSB) were obtained from Biomerieux (Marcy l'Etoile, France). Blood agar with 7% sheep blood and MacConkey agar plates were purchased from bioMérieux (Marcy l'Etoile, France). The antifungal agents bifonazole and ketoconazole were purchased from Srbolek, Belgrade, Serbia and Zorkapharma, Sabac, Serbia, respectively. All other chemicals and solvents were of analytical grade and purchased from common sources. Water was treated in a Milli-Q water purification system (TGI PureWater Systems, Greenville, SC, USA).

Rice samples

Seven different varieties of rice (Arabon, Azucena, Ballatinao, Bora, Dinorado, NSICRC9 and Maluit) were selected according to the endosperm type and the seed-coat colour (Table 1) and delivered by the International Rice Research Institute (IRRI) germplasm bank. Rice varieties were grown in greenhouse facilities and the corresponding seeds were collected during the harvest of 2015. Two Portuguese varieties (Maçarico and Ceres) obtained by INIAV/Cotarroz, Portugal, were also included. Paddy samples were dehusked in a Satake mill (THU, Satake, Taito, Japan). Rice bran samples were obtained by polishing the husked grains in a rice polishing mill (TakaYama TM-05 mini testing mill, Taiwan) and sieving the seed coat fraction in order to retain the particles of size between 250 μm and 90 μm. The samples were vacuum sealed until analysis.

Table 1 Germplasm characterisation regarding the source country, seed coat colour and endosperm type[28]

Variety name	Accession number	Source country	Seed-coat colour	Endosperm Type
Ballatinao	IRGC 44297	Philippines	Purple	Glutinous
Maluit	IRGC 55391	Philippines	Red	Glutinous
Dinorado	IRGC 96108	Philippines	Red	Non-glutinous
Arabon	IRGC 97851	Philippines	White	Non-glutinous
Bora	IRGC 113686	Italy	Beige	Non-glutinous
NSICRC9	IRGC 115128	Philippines	Beige	Non-glutinous
Azucena	IRGC 117264	Philippines	Beige	Non-glutinous
Maçarico	—	Portugal	Beige	Non-glutinous
Ceres	—	Portugal	Beige	Non-glutinous

Extraction of the bran lipid fraction

The bran lipid fraction containing γ-oryzanol was extracted with isopropanol (IsOH) as solvent according to the procedure of Massaretto but with some modifications.[26] Briefly, bran samples (0.8 g) were extracted with 20 mL IsOH, mixed by vortex (Reax 2000 Vortex; Heidoph, Schwabach, Germany) for 2 minutes and the mixture was centrifuged (2K15 centrifuge with 12139-H rotor; Sigma, Osterode am Harz, Germany) for 10 minutes at 4500*g* at room temperature. The residues were extracted two more times by the same procedure with 10 mL IsOH. The supernatants were pooled and IsOH as solvent was evaporated to dryness in a rotary vacuum evaporator system (Buchi Rotavapor R-114, Waterbath B-450 and Vacuum system B-169, Flawil, Switzerland) at 40 °C. All extractions were performed in duplicate.

Gamma-oryzanol quantification in bran lipid fraction

The γ-oryzanol quantification was performed by reverse phase (RP) high performance liquid chromatography (HPLC) coupled to a photodiode array detector (PDA), according to the method of Rogers *et al.* with minor modifications.[27] The lipid residue was dissolved in 5 ml of methanol (MeOH) and filtered through a 0.22 μm nylon syringe filter (Filter Lab, Barcelona, Spain). The HPLC system (Alliance Waters 2690, Waters 996 PDA and Waters Millenium 32 software, Milford, Massachusetts, the United States) was composed of a C18 column (Spherisorb ODS2, 150 mm × 4.6 mm, 5 μm particle size, Waters) and a C-18 precolumn (Phenomenex AQC18, 4 mm × 3 mm) operating in the isocratic mode with a mobile phase of ACN : MeOH (50 : 50 v/v) for 30 minutes at a flow rate of 1.2 mL min^{-1} and an injection volume of 20 μL. Solvents were filtered with a 0.22 μm nylon membrane and degassed by ultrasound.

γ-Oryzanol standards (10 μg mL^{-1} to 500 μg mL^{-1}) were injected to prepare a calibration curve; the obtained chromatograms at a wavelength of 325 nm presented 4 peaks whose

identification as CAF (cycloartenyl ferulate), 24MCAF (24-methylenecycloartenyl ferulate), CampF (Campesteryl ferulate) and βSF (beta-sitosteryl ferulate) has been confirmed by the compounds' spectra at the maximum wavelength and by mass spectrometry. The sum of the areas of the four peaks was calculated and correlated to the standard concentration to obtain the calibration curve with a Pearson coefficient of 0.9993, a slope of 22 238 ± 322, an intercept of −112360 ± 92 149, a detection limit (LOD) of 25 μg mL^{-1} and a quantification limit (LQD) of 75 μg mL^{-1}.

All the injections were conducted in duplicate. The γ-oryzanol data were expressed as mg per 100 g of bran.

Cytotoxicity of bran rice samples

The cytotoxic effects were evaluated in four human tumour cell lines: MCF-7 (breast adenocarcinoma), NCI-H460 (non-small cell lung cancer), HeLa (cervical carcinoma) and HepG2 (hepatocellular carcinoma) obtained from DSMZ (Leibniz-Institut DSMZ – Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH). Cells were routinely maintained as adherent cell cultures in RPMI-1640 medium containing 10% FBS and 2 mM glutamine, 100 U mL^{-1} penicillin and 100 μg mL^{-1} streptomycin at 37 °C in a humidified air incubator containing 5% CO_2. The cytotoxic potential of the rice bran lipid fraction was evaluated by the sulforhodamine B (SRB) assay, according to the procedure described by Abreu *et al.* For hepatotoxicity evaluation, a cell culture was prepared from a freshly harvested porcine liver obtained from a local slaughterhouse according to an established procedure and it was designated as PLP2 (porcine liver primary culture).[29] The cell cultivation was continued with direct monitoring every two to three days using a phase contrast microscope (Nikon Eclipse 100; Nikon, Tokyo, Japan). Before confluence was reached, cells were subcultured and plated in 96-well plates at a density of 1.0×10^4 cells per well, and cultivated in DMEM with 10% FBS, 100 U mL^{-1} penicillin and 100 μg mL^{-1} streptomycin. The rice bran samples were dissolved in DMSO : water (50 : 50 v/v) to a stock solution of 8 mg mL^{-1}. Cells were treated with different concentrations of the samples (6.25 μg mL^{-1} to 400 μg mL^{-1}) and the SRB assay was performed as previously described. The results were expressed as GI_{50} values in μg mL^{-1}, the sample concentration that inhibited 50% of net cell growth. Ellipticine was used as a positive control. Two independent experiments were performed for each compound; each one was carried out in duplicate. The results are expressed as mean ±standard deviation (SD).

Antimicrobial properties of rice bran samples

Rice bran extracts were dissolved in 30% ethanol solution and added to tryptic soy broth (TSB) medium as described by Sokovic *et al.*[30] The antibacterial activity (MICs and MBCs) was evaluated against three Gram-negative bacteria: *Escherichia coli* (ATCC 25922), resistant *Escherichia coli*, *Pseudomonas aeruginosa* (ATCC 27853), and two Gram-positive bacteria: *Staphylococcus aureus* (ATCC 11632) and MRSA (methicillin-resistant *Staphylococcus aureus*). The minimum inhibitory concentration (MIC) and the minimum bactericidal concentration (MBC) were determined by the microdilution method. Briefly, overnight bacterial cultures were adjusted using a spectrophotometer to a concentration of 10^5 CFU mL^{-1} using a spectrophotometer at 625 nm (OD 625). Extract testing was carried out at different dilutions over wells containing 100 mL of Tryptic Soy Broth (TSB) and, furthermore, 10 μL of the bacterial suspension was added to all the wells. The microplates were incubated for 24 h at 37 °C. The MICs were determined following addition of 40 mL of iodonitrotetrazolium chloride (INT) (0.2 mg mL^{-1}) and incubation at 37 °C for 30 min. The lowest concentration providing a significant inhibition (around 50%) of bacterial growth in comparison with the positive control was considered the MIC. Minimal bactericidal concentrations (MBCs) were determined by sub-cultivation of 10 mL in microplates containing 100 mL of TSB. The lowest concentration that shows no bacterial growth is considered the MBC. Standard antibiotics, namely streptomycin and ampicillin, were used as positive controls and 5% DMSO was used as the negative control.

The antifungal activity (MICs and MFCs) was evaluated against four different fungi: *Aspergillus fumigatus* (ATCC 9197), *Aspergillus niger* (ATCC 6275), *Penicillium ochrochloron* (ATCC 9112) and *Penicillium funiculosum* (ATCC 36839).[31] The bacterial MICs and MFCs were determined by the microdilution method. Briefly, the rice extracts were dissolved in a 5% solution of DMSO and added to broth malt medium with fungal inoculum. The microplates were incubated for 72 h at 28 °C. The lowest concentrations without observable growth (at the binocular microscope) were defined as MIC. The minimum fungicidal concentrations (MFCs) were determined by serial subcultivation of 2 mL in microtiter plates containing 100 mL of malt broth per well and further incubation for 72 h at 28 °C. The lowest concentration with no observable growth was defined as the MFC, indicating 99.5% killing of the original inoculum. 5% DMSO was used as a negative control, while bifonazole and ketoconazole were used as positive controls.

Statistical analysis

Statistical analysis was performed using IBM SPSS v. 25 (IBM, Armonk, NY, USA). Results were analysed by one-way ANOVA to detect significant differences ($p < 0.05$) between rice varieties and the means were classified by Duncan's comparison test.

The linear relationships between γ-oryzanol concentration and cytotoxic activity were examined by generating Spearman's correlation coefficient ($P < 0.05$).

Results and discussion

Gamma-oryzanol quantification

The mean of the total lipid content identified in the bran samples from the nine rice varieties was 13.8% (Table 2). A higher amount of lipids was obtained from the Portuguese variety Maçarico, while Bora showed the lowest lipid content.

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Table 2 Total lipid content (%) and quantification of γ-oryzanol in rice bran samples (mg per 100 g), and percentage of γ-oryzanol components

Bran rice variety	Lipid content (%)	γ-Oryzanol (mg per 100 g)	CAF (%)	24MCAF (%)	CampF (%)	βSF (%)
Ballatinao	$13.6^{c} \pm 0.5$	$329.7^{g} \pm 5.5$	36.1	35.4	12.4	12.5
Maluit	$15.9^{f} \pm 0.0$	$59.4^{a} \pm 0.5$	33.3	35.1	13.7	14.4
Dinorado	$14.2^{cd} \pm 0.0$	$281.0^{f} \pm 0.6$	37.0	33.3	12.3	13.8
Arabon	$15.4^{ef} \pm 0.4$	$219.2^{de} \pm 3.7$	40.6	36.2	11.4	9.6
Bora	$7.4^{a} \pm 0.1$	$169.1^{b} \pm 0.5$	26.3	47.2	8.0	12.6
NSICRC9	$11.4^{b} \pm 0.1$	$171.7^{b} \pm 5.0$	16.8	68.8	6.9	6.1
Azucena	$14.4^{cd} \pm 0.5$	$212.6^{d} \pm 0.3$	41.6	33.4	11.0	10.9
Maçarico	$17.4^{g} \pm 0.1$	$194.7^{c} \pm 2.0$	28.5	41.2	18.3	6.7
Ceres	$14.6^{de} \pm 0.2$	$227.5^{e} \pm 1.9$	25.5	41.2	18.2	8.4
Mean	13.8 ± 1.0	207.2 ± 25.2	31.7 ± 7.7	41.3 ± 10.6	12. ± 3.7	10.6 ± 2.9
Range	7.4–17.4	59.4–329.7	16.8–41.6	33.3–68.8	6.9–18.3	6.1–14.4

Values of lipid and γ-oryzanol are expressed as the mean ± standard deviation (n = 4). Different letters in a column indicate statistically significant differences at $p < 0.05$. CAF (cycloartenyl ferulate), 24MCAF (24-methylenocycloartenyl ferulate), CampF (campesteryl ferulate), and βSF (beta-sitosteryl ferulate).

The obtained range of γ-oryzanol variability was between (59.4 ± 0.5) mg and (329.7 ± 5.5) mg per 100 g of bran, with the highest values being those exhibited by the Ballatinao variety with a purple pericarp. However, observing the differences between Dinorado and Maluit concentrations of γ-oryzanol, the results suggest that there is no correlation between the pericarp colour and γ-oryzanol content; these results are in accordance with those found by Sing *et al.*, who analysed 53 varieties of rice, including rice with a coloured pericarp, and concluded that γ-oryzanol content is not correlated with the pericarp colour.[32]

The major compounds of γ-oryzanol in the analysed samples are 24MCAF and CampF, which amount to 73% of the whole γ-oryzanol compound. Pokkanta *et al.* found similar results on 14 samples of rice bran.[15] NSICRC9 exhibits higher predominance of 24MCAF and Maçarico and Ceres present higher amounts of CampF when compared with the remaining varieties. The concentrations obtained of γ-oryzanol are within the range found in the literature (79.2 to 912 mg per 100 g).[13,16,17,33–35] The lower concentrations obtained can be related with the extraction techniques and quantification with different temperatures and solvents, which may affect not only the lipid yield[36] but also the γ-oryzanol content.[11,12,16,37] Uttama *et al.* also investigated the relationship of γ-oryzanol concentration and different methods of extraction and no significant correlation was obtained.[37] In fact, for isopropanol selection, we undertake a preliminary study (data not shown) with different types of solvents (isopropanol, ethanol, methanol, acetonitrile, hexane and dichloromethane), temperatures and extraction times for the optimization of γ-oryzanol extraction.[38]

Other important factors affecting γ-oryzanol content may be related to the rice post harvest treatments, such as drying, storing temperature, packaging type[14] and the sample particle size.[13] On the other hand, the results can be expressed in different bases, such as rice bran oil, refined rice bran oil or rice bran itself, which may result in a difficult comparison.

Cytotoxic activity of bran rice samples

The cytotoxic properties of the rice bran extracts were tested against four human tumour cell lines (NCI-H460, HeLa, HepG2, and MCF-7) and in a non-tumour primary culture (porcine liver primary cell culture). Lower GI_{50} values indicate a more effective extract in the ability to reduce cell lines proliferation.

From Table 3 it can be observed that the rice bran extract of Ballatinao was the one that presented stronger results for all the tested tumour cell lines by presenting the lowest GI_{50} values ranging from 21.44 to 48.26 μg mL^{-1}, which may be related to the higher concentration of γ-oryzanol (329.7 mg per 100 g) found in this bran rice sample. The Arabon and Bora samples showed activity only in HeLa and MCF-7 cell lines, presenting no cytotoxic effects at the maximal tested concentration (400 μg mL^{-1}) for the NCI-H460 and HepG2 cell lines. The samples of NSICRC9 and Azucena presented moderate cytotoxic activity; however, the Azucena sample presented the most promising results for the HeLa and MCF-7 tumour cell lines with GI_{50} values of 81.23 μg mL^{-1} and 96.25 μg mL^{-1}, respectively. After Ballatinao, the Portuguese varieties Maçarico and Ceres presented stronger activity, especially against the NCI-460 tumour cell line (GI_{50} values of 74.29 μg mL^{-1} and 68.27 μg mL^{-1}, respectively). Maluit, which showed the lowest concentration of γ-oryzanol (59.4 mg per 100 g), was the least active sample, presenting only cytotoxic activity against NCI-H460 and HeLa cell lines with the highest GI_{50} values (254.08 and 314.25, respectively).

The Dinorado sample showed good activity against the HeLa and MCF-7 tumour cell lines (GI_{50} values of 82.03 μg mL^{-1} and 89.27 μg mL^{-1}, respectively) and moderate activity against the remaining tumour cell lines. For the non-tumour cell line (PLP2), the samples of Ballatinao, Dinorado, NSICRC9 and Azucena presented hepatotoxicity; however, the GI_{50} values obtained for this cell line are much higher than those obtained for tumour cell lines, which shows that its use is effective against the tumour lines studied.

Table 3 Cytotoxic activity of rice bran extracts on cancer cell lines expressed in GI_{50} values (μg mL^{-1})

	NCI-H460	HeLa	HepG2	MCF-7	PLP2
Ballatinao	$21.4^{a} \pm 1.8$	$24.1^{a} \pm 1.0$	$35.3^{a} \pm 1.1$	$48.3^{a} \pm 2.4$	$157.5^{a} \pm 8.6$
Maluit	$254.1^{d} \pm 13.0$	$314.3^{f} \pm 18.1$	$>400^{c}$	$>400^{g}$	$>400^{c}$
Dinorado	$193.2^{c} \pm 5.3$	$82.0^{b} \pm 1.6$	$151.3^{b} \pm 5.2$	$89.3^{b} \pm 3.1$	$238.5^{c} \pm 9.6$
Arabon	$>400^{e}$	$198.4^{e} \pm 3.9$	$>400^{c}$	$112.0^{d} \pm 6.2$	$>400^{c}$
Bora	$>400^{e}$	$139.3^{c} \pm 1.4$	$>400^{c}$	$98.3^{c} \pm 4.3$	$>400^{c}$
NSICRC9	$88.5^{c} \pm 3.2$	$147.1^{d} \pm 2.4$	$188.4^{b} \pm 8.1$	$149.4^{e} \pm 5.3$	$247.4^{c} \pm 10.3$
Azucena	$84.3^{c} \pm 2.1$	$81.2^{b} \pm 2.1$	$127.1^{b} \pm 9.1$	$96.3^{c} \pm 3.5$	$311.3^{c} \pm 14.3$
Maçarico	$74.3^{b} \pm 3.3$	$135.2^{c} \pm 2.4$	$185.0^{b} \pm 12.5$	$225.4^{f} \pm 8.4$	$>400^{c}$
Ceres	$68.3^{b} \pm 2.8$	$98.5^{c} \pm 2.0$	$111.3^{a} \pm 6.4$	$107.0^{d} \pm 3.6$	$>400^{c}$

GI_{50} values correspond to the extract concentration needed to achieve 50% growth inhibition in human tumour cell lines or in the liver primary culture PLP2. Ellipticine GI_{50} values: 1.21 μg mL^{-1} (MCF-7), 1.03 μg mL^{-1} (NCI-H460), 0.91 μg mL^{-1} (HeLa), 1.10 μg mL^{-1} (HepG2) and 2.29 μg mL^{-1} (PLP2). Different letters in a column indicate statistically significant differences at $p < 0.05$.

A negative correlation has been found between γ-oryzanol concentration and GI_{50} for HeLa, HepG2 and MCF-7 (−0.73, −0.76 and −0.73 respectively), which means that high concentrations of γ-oryzanol may be effective at reducing the proliferation of these cells. This correlation was also reported by Uttama *et al.*, who tested a sample of Homali 105 (*Oryza sativa*) rice bran extract against four human cancer cell lines: lung (CORL23), cervical (HeLa), prostate (PC3) and breast (MCF-7) cancer cell lines; and one normal human cell line (MRC5), using a sulphorhodamine (SRB) assay.[37]

To the best of our knowledge, there are no further reports in the literature about the cytotoxic effects of rice bran extracts in the analysed tumour cell lines.

Antibacterial and antifungal activities of the rice bran samples

The antibacterial activity data expressed as the minimum inhibitory concentration (MIC) and the minimum bactericidal concentration (MBC) are presented in Table 4. In general, the Portuguese variety Ceres has shown the strongest activity against all the tested bacterial strains by revealing the lowest MIC values. However, the NSICRC9 variety from the Philippines showed the strongest activity against *Staphylococcus aureus*, and *Escherichia coli*, and shows null MIC value for *Pseudomonas aeruginosa*.

Ballatinao, the extract with the highest content of γ-oryzanol, didn't show a significant antibacterial potential compared with the other extracts, which means that γ-oryzanol may not be the only compound responsible for the antibacterial effect of these extracts. The antifungal activity data expressed as the minimum inhibitory and fungicidal concentrations are presented in Table 5. Maluit bran rice samples showed the most promising activity against all the tested fungi samples, with lower MIC values. The Maluit extract can be considered more effective against *Penicillium ochrochloron* compared to antifungal clinical agents. The Portuguese Maçarico and Dinorado from the Philippines also reveal potential activity against *Aspergillus niger*, *Penicillium ochrochloron*, and *Penicillium funiculosum*.

Table 4 Minimum inhibitory (MIC; mg mL^{-1}) and bactericidal concentrations (MBC; mg mL^{-1}) of the rice bran lipid fraction

	S. aureus ATCC 11632		MRSA		*E. coli* ATCC 25922		Resistant *E. coli*		*P. aeruginosa* ATCC 27853	
	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC
Streptomycin	0.01	0.01	0.10	N/a	0.05	0.10	0.10	0.20	0.03	0.05
Ampicillin	0.01	0.03	N/a	N/a	0.10	0.20	0.20	N/a	0.05	0.10
Ballatinao	1.50	3.00	1.5	3.00	2.00	4.00	0.50	1.00	0.25	0.50
Maluit	4.00	8.00	4.00	8.00	4.00	8.00	4.00	8.00	1.50	3.00
Dinorado	2.00	4.00	2.00	4.00	2.00	4.00	2.00	4.00	1.00	2.00
Arabon	1.99	3.99	1.00	1.99	1.00	1.99	1.00	1.99	0.49	1.00
Bora	2.00	4.00	1.00	1.50	1.00	2.00	1.00	2.00	1.00	1.50
NSICRC9	1.00	2.00	1.00	2.00	1.00	2.00	2.00	4.00	N/a	N/a
Azucena	2.72	5.44	2.72	5.44	2.72	5.44	1.10	2.72	0.68	1.10
Maçarico	2.38	4.76	1.10	2.38	1.10	2.38	1.10	2.38	0.59	1.10
Ceres	1.10	2.12	0.53	1.10	1.10	2.12	1.10	2.12	0.53	1.10

MIC values correspond to the minimal sample concentration that inhibited the bacterial growth. MBC was defined as the lowest concentration with no visible growth, indicating 99.5% killing of the original inoculum.

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Table 5 Minimum inhibitory (MIC; mg mL^{-1}) and fungicidal concentrations (MFC; mg mL^{-1}) of the rice bran lipid fraction

	A. fumigatus ATCC 9197		*A. niger* ATCC 6275		*P. ochrochloron* ATCC 9112		*P. funiculosum* ATCC 36839	
	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC
Ketoconazole	0.20	0.50	0.20	0.50	1.00	1.50	0.20	0.50
Bifonazole	0.15	0.20	0.15	0.20	0.20	0.25	0.20	0.25
Ballatinao	16.0	>16.00	2.00	4.00	2.00	4.00	1.00	2.00
Maluit	0.50	1.00	1.00	2.00	0.50	1.00	0.50	1.00
Dinorado	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00
Arabon	3.99	7.98	1.99	3.99	1.99	3.99	1.99	3.99
Bora	1.00	2.00	2.00	4.00	1.50	3.00	1.50	3.00
NSICRC9	1.00	2.00	1.00	2.00	3.00	6.00	1.50	3.00
Azucena	2.00	4.00	4.00	8.00	2.00	4.00	2.00	4.00
Maçarico	2.38	4.76	1.10	2.38	1.10	2.38	1.10	2.38
Ceres	2.12	4.23	2.12	4.23	2.12	4.23	2.12	4.23

MIC values correspond to the minimal sample concentration that inhibited the bacterial growth. MFC was defined as the lowest concentration with no visible growth, indicating 99.5% killing of the original inoculum.

As it happens for the antibacterial activity, the antifungal activity seems to be not related with the content of γ-oryzanol, since the sample that presented the best results is the one that has the lowest amount in this compound.

To the best of our knowledge, there are no reports in the literature regarding the antimicrobial activity of the raw rice bran, in particular from these specific varieties and bacterial strains. However, several antimicrobial activities have been reported in rice bran derived healthy foods. Li *et al.* evaluated the biofilm inhibitory activities of fermented rice bran broth with effective microorganisms and found growth inhibition of *Escherichia coli* and *Pseudomonas aeruginosa.*[39]

Ferdes *et al.* studied the antimicrobial effect of *Monascus purpureus* red rice against some bacterial strains (*Bacillus subtilis*, *Pseudomonas aeruginosa* and *Escherichia coli*) and fungi (*Alternaria* and *Botrytis* genus) and confirmed the bacteriostatic and antifungal activities of the monascidin A pigment.[40] Another study performed by Arpan *et al.* assessed the antibacterial activity of rice bran oil, concluding that the intake of rice bran oil may help to prevent bacterial pathogenesis by *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureu*. The bacterial cultures were supplied with rice bran oil.[41] The studies reveal the antibacterial effect and complete inhibition of these microorganisms. More importantly, these authors also reported that the presence of these extracts also inhibited the presence of other contaminants for five consecutive days.

Conclusions

Considering the extension of rice production and their industrial side streams, such as bran, it can be an important raw material for the development of nutraceuticals and functional foods. The bran rice extracts showed cytotoxic effects on tumour cell lines, possibly related to the amount of γ-oryzanol. However, to assure the right level of the γ-oryzanol influence on cytotoxic activity, the synergistic effects with other bran oil bioactives should be accounted for.

Regarding the antimicrobial properties, the obtained results show that rice bran lipid extracts can be effective at the inhibition of the studied bacteria and fungi, mainly *Pseudomonas aeruginosa*, for which the extracts reveal lower MICs and MBCs. Since these pathogenic bacteria and fungi can be easily found in highly manipulated food products, rice bran oil may be explored as a natural additive in processed foods in order to extend their shelf life.

Overall the results show that rice extracts may be considered as potential candidates to be used as antimicrobial agents when incorporated in food matrices, helping to prevent the contamination by mycotoxins. Owing to the numerous health benefits associated with the consumption of rice bran, detailed *in vivo* studies are recommended to create a strong database.

Conflicts of interest

There are no conflicts to declare.

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Chapter 8. **PAPER 5. DESIGN THINKING FOR FOOD: REMOTE ASSOCIATION AS A CREATIVE TOOL IN THE CONTEXT OF THE IDEATION OF NEW RICE-BASED MEALS**

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Design thinking for food: Remote association as a creative tool in the context of the ideation of new rice-based meals

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ABSTRACT

Portugal is the greatest European rice consumer. Thus, incorporating whole rice and rice bran in innovative rice products is challenging. An experimental method based on the creativity association theory was applied. A group of nine students performed simple brainstorming to generate recipe ideas. Following the Design Thinking approach, a group of nine chefs received a stimulus to generate words related to rice recipes, working as a stimulus for a group of 14 students to generate recipe ideas. All ideas from both groups were evaluated by the chefs. The inclusion of stimuli led to more creative ideas from young aspiring chefs.

1. Introduction

Rice (*Oryza sativa* L.) is the staple food of most of mankind, with a World per capita consumption of about 80.6 kg/year. The European average value of consumption is more modest, just 6.7kg/capita/year, registered between 2015 and 2019. Within this region, Portugal has the highest consumption, with a per capita average of about 16.1 kg/year (FAO, 2019). The importance of rice in Portuguese gastronomy can be perceived not only by the consumption data, but also by analysing rice preparations, which comprise many rice-based dishes (Vasco et al., 2021). Such dishes span from plain white rice to more elaborate rice dishes, presented as a side dish or even as a main course, and incorporating vegetables, legumes, fish, shellfish or all types of meats (poultry, lamb, pork or beef) (Cabral et al., 2022).

Despite the benefits of whole rice (Castanho et al., 2019), traditional rice preparations are made with milled rice kernels, with the remaining rice bran being incorporated into animal feed (Esa et al., 2013). However, rice bran is known to promote several health benefits (Bhaskaragoud et al., 2018; Bumrungpert et al., 2019; Wang et al., 2017; Francisqueti et al., 2017; Kozuka et al., 2015).

Design Thinking (DT) can be considered a transdisciplinary and user-centred method directed at innovation, as popularised by IDEO and Stanford d.school (Brown, 2008; Dunne and Martin, 2006; Kelley, 2001). However, it was at first, a part of the designers' activity discussed by design theorists and mainly focused on what is design and how design is a discipline that uses different types of cognitive processes to think about ill-defined problems (Cross, 1982; Lawson, 2006; Rittel and Webber, 1973; Schön, 1983; Simon, 1969). DT as a method has been used in different ways, regarding the number of iterative process steps and their terminology (Waidelich et al., 2018); according to Micheli et al. (2019) the most employed methods are the ones from IDEO (Inspiration, Ideation, Implementation), Stanford d.school (Empathize, Define, Ideate, Prototype and Test) and IBM (Understand, Explore, Prototype, Evaluate).

Although the DT approach has been applied broadly, its use in food innovation is scarce (Olsen, 2015). Frost (2019), reported the positive role of rapid prototyping in a food DT experience where chefs and scientists worked together. Derler et al. (2020) integrated applied a DT methodology in a project-based learning experiment with students to create food products based on consumers' needs.

The brainstorming technique was first introduced by Osborn (1953), who described it as a team exercise performed in two phases: free-wheeling (idea generation), and discussion (idea integration). When describing the IDEO design methodology, Kelley (2001) emphasises the brainstorming technique as the key to idea generation and creating a list of rules to get the "perfect brainstorm".

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Creative processes and idea generation applied to gastronomy, have also been a matter of study. Horng and Hu (2008) interviewed 17 culinary chefs in order to understand their creative process. For those chefs, the process was not linear nor structured, however, they make use of well-known cognitive processes, such as association and responded to some kind of external evaluation. Similarly, Albors-Garrigós et al. (2017), who studied the innovation process in haut cuisine, stated that the chefs' idea generation process is intuitive and creativity is stimulated in a non-structured way, by contacting with art, socializing or even using past experiences.

Association is considered by Guilford (1967), founder of creativity theory, as one of the key mechanisms of idea generation, relating it with memory. Through this, Guilford (1967) developed a way of evaluating the idea generation ability: the Alternative Uses Test (AUT), consisting of asking the participants for non-obvious uses for a common object, during a fixed amount of time. Mednick (1962), who also studied creativity and its psychometric measurement, claimed that creativity can be achieved by linking remote concepts to form new relationships and describing the creative process as "the forming of associative elements into new combinations, which either meet specified requirements or are in some way useful". Based on this theory, the author (Mednick, 1968) developed a creativity test based on the capability of the subjects to associate remote stimuli words: the Remote Associates Test (RAT). This consists of a set of questions where three pre-selected remotely associated stimulus words are given to the participants, who are asked to think of a word that can be linked to the stimuli words.

Based on the former context, the aim of this work was to create a structured idea generation technique, following the DT approach, with the ideation processes combining the approaches of both the AUT and RAT, applied to the development of innovative rice-based products incorporating whole rice and rice bran.

2. Methods

To better evaluate the application of the alternative DT approach, a simple brainstorming ideation process (Kelley, 2001) was also promoted for comparison purposes.

2.1. Simple brainstorming

To incorporate whole rice and rice bran in innovative products, a group of nine Culinary Arts MSc students (five males and four females, aged between 21 and 40 years) were recruited and asked to generate creative ideas. The exercise had two steps: i) the students were given data on Portuguese consumers' rice consumption patterns and choice motives (Castanho et al., 2020) and information about the benefits of whole rice and rice bran. From these stimuli, the students were grouped three by three and asked to freely brainstorm on creative rice dishes incorporating the ingredients; ii) the students implemented their ideas in a cooking class. The ideas were later evaluated by a jury of three professional cooking chefs, based on the Dean et al. (2006) evaluation method adapted to the context, regarding its adequacy to the consumer, novelty, workability and clarity, on a 4-point scale.

2.2. Design Thinking approach

The second approach was carried out in four phases (Fig. 1), adding more complexity to the exercise, including the chefs as a creativity vehicle: i) nine professional chefs (eight males and one female with more than five years of experience) received the same information stimuli as the students undergoing the simple brainstorming exercise (1st stimuli), and based on the AUT concept (Guilford, 1967), were asked to freely write down all the ingredients, concepts and recipe types that came to mind, considering that they could be employed in rice meals. The full set of chefs' words/expressions was submitted to lemmatisation and printed onto blank game cards for students to play (2nd stimuli); ii) the information stimuli were also presented to 14 Culinary Arts MSc students (five males and nine females, aged between 21 and 40 years); iii) the students were subdivided into four groups, helped by two facilitators and were asked to pick up two concept cards, two ingredient cards and one recipe type card. They were instructed to use their card set stimuli as starting point to freely brainstorm about creative recipes incorporating brown rice and/or rice bran, following the RAT approach (Mednick, 1968). The card game was repeated for an hour with each group drawing new sets of cards. During the exercise, the students were told they could brainstorm freely as a group or to have individual ideas and then discuss them to choose the most creative one primed by each card pick; iv) at the end of the exercise, the same three chefs from the simple brainstorming exercise, also evaluated the selected recipes regarding their adequacy to the consumer, novelty, workability and clarity, on a 4-point scale.

2.3. Data analysis

Statistical analysis was performed using Microsoft Excel and XL-Stat

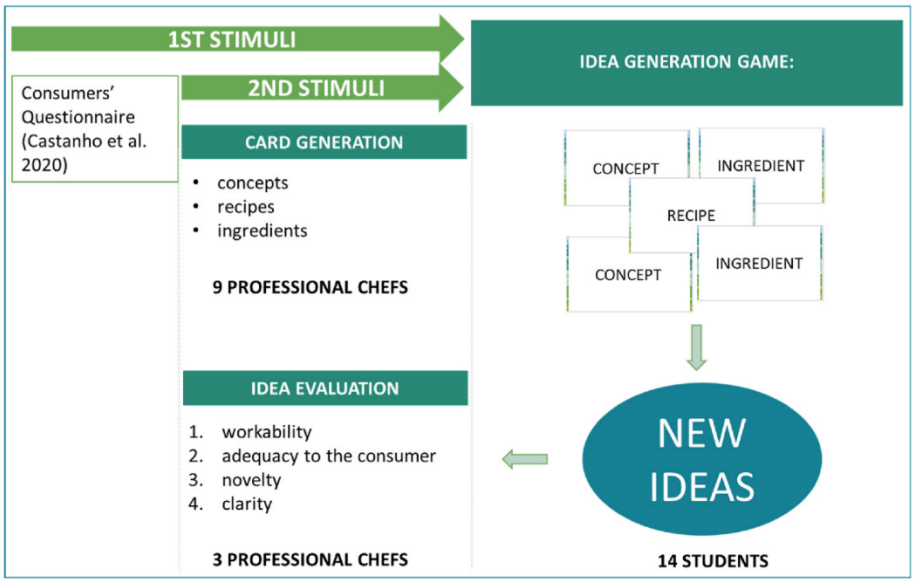


Fig. 1. Schematic view of the Design Thinking approach.

for descriptive analysis and the Mann-Whitney Test, considering $p < 0.05$, for comparison of the creativity scores of the recipe ideas.

3. Results and discussion

3.1. Simple brainstorming

The students generated three ideas: a) duck rice made with whole rice, based on a well-known and popular Portuguese dish (Rocha et al., 2015); b) oriental rice made with whole rice, based on a common recipe very popular in Portugal in ethnic restaurants; and c) petit-gateaux with the incorporation of rice bran.

The chefs' average evaluation scores were considerably low, with the novelty attribute presenting the lowest values (ranging from 1.0 to 1.7, on the 4-point scale). In general, the students did not feel very engaged with the activity and considered that it was creative enough to adapt existing recipes by replacing white rice with brown rice or by simply adding rice bran.

Fear of being judged and pressure to stay within the bounds of existing options clearly had an inhibiting effect on the performance of groups, along with a variety of intrapersonal factors affecting the commitment of individuals within brainstorming groups (Isaksen and Gaulin, 2005), which may explain the lower creativity stemming from this initial process.

3.2. Design Thinking approach

3.2.1. Designing the card tool

The nine professional chefs generated a total of 108 words/expressions, originally grouped in ingredients, concepts and recipe types. After content analysis and lemmatisation (Symoneaux et al., 2012; Rojas-Rivas et al., 2020), 89 words/expressions remained and were coded into six groups considering their content (Table 1).

The generation of cards as a design tool is not new. Aschemann-Witzel et al. (2012), used card sorting to reach a consensus about food marketing success factors; Roy and Warren (2019) identified 155 card sets and grouped them by objective and specificity, however, most of those tools, to the knowledge of the authors, are not reported in scientific literature, and therefore, there is no evidence of the results of its application.

3.2.2. Idea generation

Each of the student groups drew between five and six hands of 5-card sets, following a reshuffling of the cards between draws. From those hands (16 in total), students collected a total of 59 different cards, divided between the different categories (Table 1). After discussion within the group, at each pick, the students jointly proposed a creative idea for a recipe using brown rice and/or rice bran. Up to 62.5% of the creative ideas explicitly referred to the incorporation of one of those ingredients.

There was no obligation to directly use the cards to generate an idea, and the way they were incorporated into the creative idea varied from idea to idea (Fig. 2). Only one idea yielded no direct application of the cards, while 62.5% used one to two cards directly and the rest (31.2%) used three to four cards directly.

More detailed, verbatim use of the card's word/concept was much more frequent for the closed recipe types and for both types of ingredients (Fig. 3). Whereas for the open recipes and for the concept cards, their usage was clearly indirect. According to Vitrano et al. (2021), the stimulus type can modify the user's response. In this case, clearly, the more objective words tended to be used directly, while more diffuse concepts tended to evoke additional related words/concepts.

3.2.3. Idea evaluation

Evaluation is one of the most important steps in the creative process (Lonergan et al., 2004), being as important as the idea-generation process. The panel of three chefs evaluated all the final concepts, from both the simple brainstorming and the DT exercises (Fig. 4). No significant differences were identified for 'adequacy to consumers' and 'clarity' of the recipes. The simpler recipes proposed by the students in the simple brainstorming exercise had a high score on 'workability' and a minimum score on 'novelty'. The introduction of the DT exercise brought a significant ($p < 0.05$) decrease in 'workability', but with a significantly large increase in the 'novelty' scores (Fig. 4), meaning that a hybrid creative model may improve idea quality, as already reported by Girotra et al. (2010). The lower initial 'novelty' scores may be explained by the lower exposure to real-world (food service) situations, as many of the MSc students were coming directly from their BSc courses, with a very short professional experience.

When comparing the scoring of the recipe ideas in accordance with the number of direct cards used in the concept, no significant effect was found. This was not a surprising result, considering that the cards themselves were already the results of the creative process with a group of nine chefs.

Table 1
Card grouping, code description and its usage by students.

Initial category	CARD CODIFICATION				No. of cards picked
	Group	No. of generated cards	Description	Example	
Ingredients	Single	25	individual ingredient	peas	20
	Group	9	which includes many ingredients	pulses	5
Concepts	Objective	22	can easily access and define	low fat	19
	Subjective	5	depend on individual interpretation	tasty	2
Recipe types	Closed	9	are well defined or follow a specific recipe	lentil rice	3
	Open	19	are generic and can be adapted	cakes	10

4. Conclusions

In general, chefs' idea generation is described as an intuitive process, despite the utilization of some known techniques. Even though in the first approach the students from Culinary Arts were asked to produce innovative ideas, the results showed that the inclusion of stimuli led to more creative ideas. Carefully selected word cards and the way that they are used have proved beneficial to the creative process.

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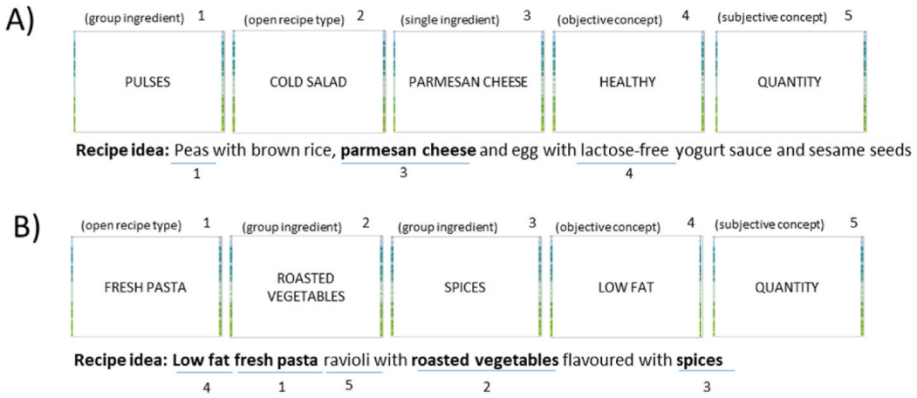


Fig. 2. Examples of card usage by the students. Underlined words in the recipe ideas denote indirect usage of the card word/concept, while bold and underline words denote direct usage of the card word/concept. A) example of recipe idea where one single card's word/concept was directly used; B) example of recipe idea where four cards' word/concept were directly used.

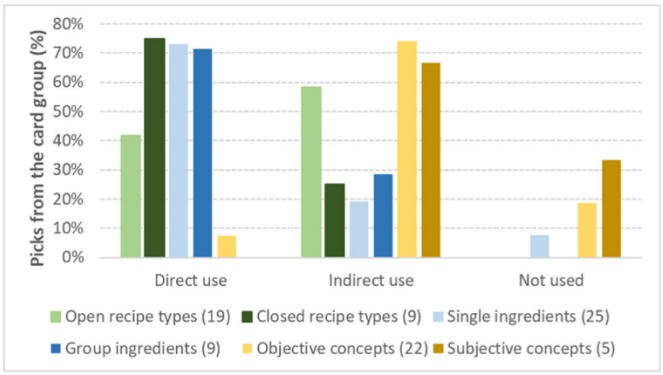


Fig. 3. Usage of picked cards according by card type (number of picks).

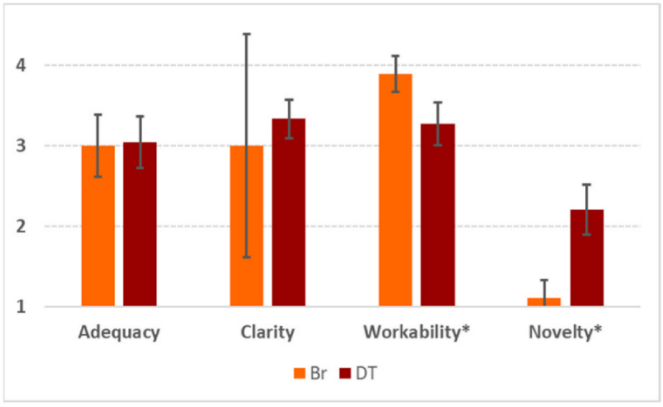


Fig. 4. Mean scores of the classifications given by the chefs' panel to the different recipes, according to the creativity process: Br – simple brainstorming; DT – Design Thinking. The whiskers represent the 95% confidence intervals.

Implications to gastronomy

Creative thinking is a relevant component of gastronomy since idea generation makes part of the innovation process. In this sense, Design Thinking can be used as a way to improve creativity in the gastronomic realm. However, as creativity is a challenging concept, it is important to know its roots to base the methods on a solid background, measure its impact and optimize it. The proposed idea generation method intends to introduce a new measurable creative method that can be used by the community, particularly in gastronomic education, opening a dialogue to improve it iteratively.

CRediT author statement

Ana Castanho: Conceptualization, Methodology, Investigation, Formal analysis, Writing- Original draft; **Manuela Guerra**: Resources, Supervision, Writing - Review & Editing Supervision; **Carla Brites:** Conceptualization, Supervision, Writing - Review & Editing Supervision; **Jorge C. Oliveira:** Funding acquisition, Writing - Review & Editing Supervision; **Luís Miguel Cunha:** Funding acquisition, Validation, Formal analysis, Visualization, Writing - Review & Editing Supervision.

Data availability

Data will be made available on request.

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Chapter 9. **PAPER 6. IMPROVING γ-ORYZANOL AND γ-AMINOBUTYRIC ACID CONTENTS OF RICE BEVERAGE 'AMAZAKE' OPTIMISED THROUGH GERMINATION AND FERMENTATION PROCESSES**

Ana Castanho | Cristiana Pereira | Manuela Lageiro | Jorge C. Oliveira | Luís M. Cunha | Carla Brites

foods

MDPI

Article

Improving γ-Oryzanol and γ-Aminobutyric Acid Contents in Rice Beverage *Amazake* Produced with Brown, Milled and Germinated Rices

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Abstract: Rice is an important source of γ-oryzanol (GO) and γ-aminobutyric acid (GABA), which are bioactive compounds that may benefit blood lipid and pressure control. Both GO and GABA can be improved by germination and fermentation. Fermentation with *A. oryzae* produces *Koji*, a rice-based starter for *Amazake*, a naturally sweet beverage. Germinated rice (brown and milled rice), were tested to improve those bioactive compounds during the fermentation process. The resulting *Koji* was optimised to GO and GABA through a response surface methodology; α-amylase activity and starch content were also assessed. The different rice matrix resulting from the germination largely impacted the biosynthesis of GABA, α-amylase and starch contents. *Amazake*, obtained by germinated rice, has increased GO and GABA contents when compared to the one obtained from milled rice (from a non-detectable value to 27.65 ± 0.23 mg/100 g for GO and from 163.95 ± 24.7 to 271.53 ± 5.7 mg/100 g for GABA). A panel of 136 Portuguese consumers tasted the beverage in a blind overall tasting test followed by an informed test, using 9-point scales. The consumer scores had a mean value of 4.67 ± 1.9 and 4.9 ± 1.8, meaning that cultural differences may play an important role with regard to liking and accepting *Amazake*.

Keywords: γ-oryzanol; γ-aminobutyric acid; α-amylase; *Koji*; *Amazake*; rice bioactives; response surface methodology

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1. Introduction

Rice is considered a staple food in many countries, particularly in Asia. Despite the low consumption rate in Europe, Portugal is the largest rice consumer, with innumerable ways of consuming rice in its gastronomic tradition. However, rice is not consumed at its full nutritional potential, since the bran and germ are discarded with the industrial processing, and rice is consumed after milling [1]. In recent years, the nutritional compounds of whole rice and rice bran have been studied to explore natural ways of increasing its content in rice-based foods. One of those compounds is γ-oryzanol (GO) [2,3]. GO is a bioactive compound known for its potential to regulate lipid metabolism, reducing the LDL (Low-Density Lipoprotein) and total cholesterol [4–7]. GO is synthesised during the maturation of the rice grain, being responsible for different regulatory functions, properties and structures; therefore, the GO content is not only affected by genetic factors but also by climate and growing conditions [8–10].

Another important compound in rice bran is γ-aminobutyric acid (GABA), a non-protein amino acid. GABA is an important neurotransmitter responsible for lowering the nervous system's activity, effectively lowering blood pressure [11–14] and treating epilepsy [15]. GABA is mainly synthesised by biochemical processes such as germination and fermentation. During those processes, the α-ketoglutarate (contained in large quantities in the bran) is transaminated to glutamic acid, which is decarboxylated to GABA through glutamic acid decarboxylase (GAD) [12,13]. Thus, increased levels of GABA can be obtained by reinforcing the germination status of the grain. The amount of GABA in rice bran ranges from 10.7–58.0 mg/100 g (before germination) and 90.0–350.0 mg/100 g (after 10–12 h of rice germination) [16].

The germination and fermentation processes have been employed empirically to increase nutritional value and enhance the assimilability and palatability of foods. The most important microorganism employed in rice fermentation is *Aspergillus oryzae*, which was named after its occurrence in rice (*Oryza sativa*) [17]. *A. oryzae* has been used in Asia, mainly in Japan, as a starter for a solid-state fermentation named *Koji*, which is the basis of many traditional products, including soy sauce, miso, sake, and *Amazake* [17,18]. Solid-state fermentation is a low moisture fermentation, providing just enough water to support the growth of filamentous fungi's penetrative and aerial hyphae, producing enzymes that would not typically be produced during other fermentation processes [19,20]. Although *A. oryzae* can ferment other products, rice is the most used food substrate for *Koji* production. The process to obtain *Koji* can be seen as a system which includes mainly (1) time, (2) temperature, and (3) moisture [21]. Ventilation, substrate type, pH, and the initial quantity of the inoculum are also essential factors in *Koji*-making [20,22]. *Amazake* is the simplest way of using *Koji*. *Amazake* is a non-alcoholic, white-coloured, sweet drink that can be made only by mixing *Koji* with water or by adding steamed rice. In the processing of *Amazake*, *Koji* acts as a starter for starch hydrolysis, where their α-amylases break the rice starch into glucose. Therefore, besides *Koji*'s unique flavour, *Amazake* is naturally sweet (without added sugars); contrary to other sweet beverages, which contain sucrose or fructose, *Amazake*'s sweetness is mainly realized through naturally produced glucose [23,24]. This is an advantage, since the final glucose content of *Amazake* can be controlled and adjusted through a longer or shorter rice *Koji* fermentation time [25].

Despite being closely related to the *Aspergillus flavus* species, *A. oryzae* is considered a safe organism by the World Health Organisation [26], if the microbiological safety of *Koji* and its products are produced with approved starter cultures, appropriate rice *Koji* fermentation processes, and storage conditions are used [20]. The safety of *A. oryzae* arises from the fact that it is unable to produce aflatoxins, as the genes responsible for its biosynthesis are absent or dysfunctional [18,20,23,24,27]. *Koji Amazake* can also be considered microbiologically safe, as starch is hydrolysed at a temperature range where harmful bacteria do not grow [24].

Few authors have studied the impact of *Amazake* intake on human health. Kurahashi and Yonei [23] studied the excess intake of *Amazake* (for four consecutive weeks) in 24 healthy subjects with high blood glucose levels. The body mass index (BMI) of the subjects did not change, but LDL cholesterol and glycated haemoglobin (HbA1c), a marker for diabetes, had a significant slight decrease, returning to the typical values after the test; the excess intake of *Amazake* led to a significant decrease in blood pressure. The authors related the hypotensive effect with the presence of GABA. Kikushima et al. [28], in a randomised, double-blind, placebo-controlled trial, evaluated the effects of *Koji Amazake*, finding that the daily intake of *Amazake* decreased systolic blood pressure. Other authors [25,29] studied the impact of *Amazake* on other health issues with positive results.

This work aimed to develop a rice-based beverage (*Amazake*) via a germination and rice *Koji* fermentation process with *A. oryzae*. As both GABA and GO can be improved naturally through biochemical processes, this work explores ways of increasing *Amazake's* GABA and GO contents, improving *Amazake's* nutritional value and evaluating its acceptability by Portuguese consumers.

2. Materials and Methods

A schematic view of the experimental methodology can be observed in Figure 1. Different rice matrices were selected for this study: milled, whole and germinated rice; germination rice was subjected to a pre-selection (through the employment of three different germination times) to obtain the greatest GABA and GO contents.

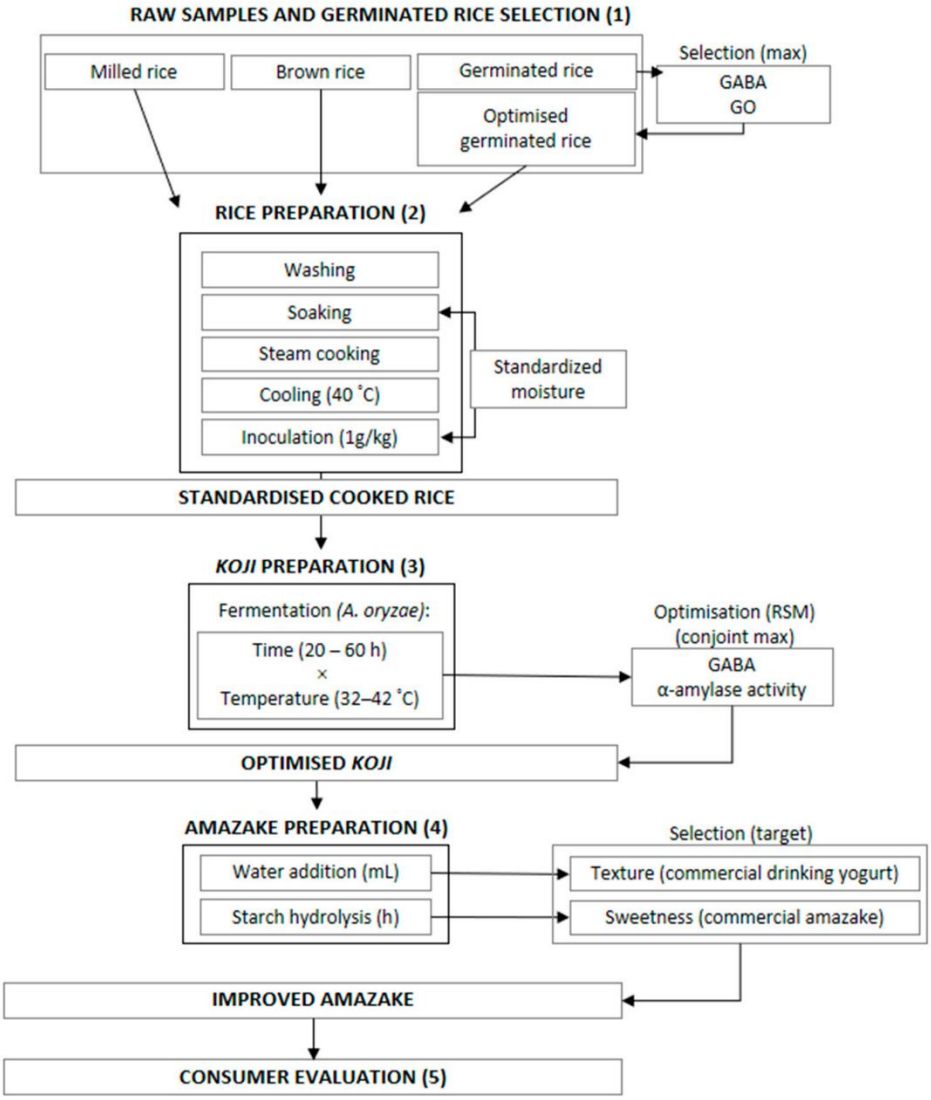


Figure 1. Schematic view of the experimental methodology, with numbers representing materials and methods, as well as discussion sections (e.g., 1 represents Sections 2.1 and 3.1).

The three raw samples were further soaked, cooked and inoculated with *A. oryzae* to produce *Koji*. The GABA content and α-amylase activity were analysed in the *Koji* preparation process to optimise the best inoculation time and temperature.

The optimised *Koji* was subjected to a starch hydrolysis process to obtain *Amazake*. The sweetness and texture parameters were monitored through the starch hydrolysis process to reach similarity with commercial *Amazake* (fermented brown rice *Amazake* from Kenshô, Spain) in terms of sweetness. For texture, the used reference was a commercial yoghurt beverage (plain liquid yoghurt from a major Portuguese retailer brand).

The improved *Amazake* was then presented to consumers to assess its overall likeability, and it was also evaluated for acceptance after elicitation with a final product prototype.

2.1. Sample Selection

Commercial milled and brown rice from the variety Ariete (from Orivarzea SA, Portugal) were acquired in the market and kept sealed at room temperature until use.

Germinated rice was prepared from brown rice, washed three times, and submerged in distilled water for 24 h; the samples were kept at 25 °C for 48 and 72 h, being washed every 4 h to avoid fermentation. Samples of 50 g were collected and freeze-dried. For comparison purposes, the raw brown rice sample was considered the control, and the subsequent samples were identified as 24 h, 48 h and 72 h germinated rice. The GABA and GO data were acquired, and the sample with greater values of those compounds was selected for further processing.

All of the samples were analysed in triplicate.

2.1.1. GABA Extraction and Quantification

GABA extraction and quantification were performed according to Jannoey et al. [30], with modifications. The freeze-dried samples were extracted with 70% ethanol. The samples were dissolved with 2 mL of ethanol, mixed in a vortex, shaken for 30 min at room temperature, and centrifuged at 4 °C for 10 min at 10,000× *g* (Laborzentrifugen 2K15, Sigma, Osterode am Harz, Germany). The supernatant was collected, and the procedure was repeated two more times, until collecting a total of 6 mL extract. The derivatisation was performed with 2-hydroxynaphthaldehyde (HN), by adding 1 mL of the extracted samples to 0.5 mL HN-methanol solution (0.3%) and 0.5 mL of borate buffer (pH 8), incubating at 80 °C during 15 min in a water-bath and cooling to room temperature. The resulting extract was filtered through a 0.22 µm nylon syringe filter (FilterTECH, Saran, France) before injection.

The quantification of GABA was performed by reverse-phase high-performance liquid chromatography (RP-HPLC) using Waters 2695 series equipment (Waters, Milford, MA, USA) connected to a diode array detector (DAD, Waters 2996, Waters, Milford, MA, USA). The amino acid HN derivative separation was performed in a C18 column (Sunfire 5 µm, 4.6 × 250 mm, Waters, Milford, MA, USA), which remained at a temperature of 40 °C (Waters column thermostat Jetstream 2 plus, Waters, Milford, MA, USA). The mobile phase used was methanol (A): water (B), with the following gradient: 0–4 min: 20–50%(A); 4–6 min: 50–80% (A); 6–8 min: 80–100% (A); 8–10 min: 100% (A) and from 10–14 min: 100–20% (A), at a flow of 0.8 mL min^{-1} and with an injection volume of 20 µL, with a total analysis time of 20 min.

The GABA-HN derivative identification was performed at 231 nm by comparison of the GABA-HN peak retention times from the GABA-HN spectra. Sample fortification with GABA standard was undertaken for all samples prior to HN derivatisation, and the results of the fortified samples were compared with non-fortified samples to validate the GABA identification. The GABA quantification was based on an external calibration curve made with GABA standard aqueous solutions (10 to 1000 mg/L). A linear regression was obtained between the GABA-HN peak area and the GABA content in mg/mL (total GABA-HN area = 144,448,962 [GABA] + 5,176,153) with a determination coefficient of 0.995. GABA quantification was measured in mg of GABA per 100 g of sample, and all samples were extracted in duplicate.

2.1.2. GO Extraction and Quantification

The γ-oryzanol (GO) quantification was performed by RP-HPLC equipped with a DAD using the same HPLC system described for GABA quantification using a Waters Spherisorb ODS 2 separation column (4.6 × 250 mm, 5 µm, Waters, Milford, MA, USA), according to the method reported by Lageiro et al. [8], with minor modifications. The extraction of GO was carried out from freeze-dried *Koji* lipid residue according to the procedures reported by Castanho, et al. [1]. The GO identification was made at 325 nm by retention times and spectra comparisons with GO standards from TCI Europe. The quantification was based on an external calibration curve with GO standard solutions

(10 to 900 mg/L). A linear regression between the total GO area (peak area sum of the different GO compounds' peak areas) and the GO content in mg/mL was obtained (total GO area = 29.10 × [GO] 58.99), with a determination coefficient of 0.9995. GO quantification was measured in mg of GO per 100 g of sample, and all samples were extracted in duplicate.

2.2. Rice Cooking and Inoculation

Rice was cooked according to Saigusa and Ohba [31], with few modifications. The milled rice (250 g) was washed three times and soaked in distilled water for 20 min. It was drained for 15 min, and the water content was adjusted to achieve 118% of the initial raw rice weight with distilled water. The rice was then steamed for 40 min in a rice cooker steamer (CKSTRC4723-050, Oster 600 mL, Sunbeam Products, Inc., Boca Raton, FL, USA), wrapped in 20 × 20 cm non-woven pads (Wells, Portugal). The cooked rice was allowed to rest for 10 min while wrapped. After removing the cloth, the rice was allowed to cool in a tray until the temperature decreased to 40 °C. For brown rice, the cooking method was slightly modified: the raw brown rice was soaked for 5 h to adjust the water content to 118% of the initial raw rice weight and cooked for 60 min. The procedure was the same for germinated rice apart from the initial water correction, as the water uptake was given by the germination time.

The water content of all samples was adjusted (133% raw weight) with distilled water to ensure process standardisation before inoculation. The cooked rice was then inoculated with *A. oryzae* spores obtained from Kenshô (Spain) according to the producer's instructions (1 g/kg of raw rice).

2.3. Koji Preparation and Optimisation

A circumscribed central composite design using rice *Koji* fermentation time and temperature as independent variables was used to obtain a surface response, with the values presented in Table 1. Ten experimental combinations were determined with two levels (−1, +1), two repetitions of the central point (0), and two levels of axial points (−α, +α) [32]. The experimental conditions were defined as between 20 and 60 h and 32 and 42 °C, according to Narahara [33]. The selected points were used for GABA, α-amylase activity, and starch content evaluation.

Table 1. Definition of the circumscribed central composite design independent variable values. The α value related to ±1 is equal to ±1.414.

	Time (h)	Temperature (°C)
Min (−α)	20	32
Max (+α)	60	42
Centre (0)	40	37
Factorial (−1)	26	34
Factorial (+1)	54	41

Before analysis, the preparation of *Koji* samples was based on Hong and Kim [34] and previous pilot studies from the research group. Fresh collected *Koji*, 20 g, was mixed with 60 mL of distilled water and homogenised in an Ultraturax (T25, IKA, Germany). From that mixture, 6 mL were diluted in 16 mL of distilled water and centrifuged at 10,000× *g*; the remaining *Koji* mixture was freeze-dried, ground to flour, passed through a 120 µm sieve, and stored in dry conditions for subsequent analysis, as *Koji* extracts. All the analyses were treated as independent triplicates.

2.3.1. α-Amylase Activity Assessment

The α-amylase activity of *Koji* extracts was measured using the Ceralpha® assay procedure (AOAC Official Method 2002.01) by using benzylidene-blocked *p*-nitrophenyl maltoheptaoside in the presence of thermostable α-glucosidase. The activity was calculated according to the Ceralpha® assay procedure using the Megazyme kit calculator for Mi-

crosoft Excel, and expressed as Ceralpha U per g *Koji*, where one Unit of enzyme activity is the amount of enzyme releasing one µmole of *p*-nitrophenol per minute under the defined assay conditions.

2.3.2. Starch Measurement

Starch data was collected using NIR transflection MPA equipment (Bruker Optics, Germany), according to Sampaio, et al. [35]. The data was obtained using the B-FING cereals calibration model (Bruker Optics, Germany).

2.4. Amazake Selection and Preparation Processes

Amazake was produced by hydrolysing the optimised *Koji* by adding water at a specific temperature and time. The suspension viscosity was measured, following each water addition, until the target value (plain liquid yoghurt, 0.285 Pa.s) was reached. As the target texture was achieved, the sweetness was determined by °Brix, through time, to achieve commercial *Amazake* sweetness (fermented brown rice *Amazake*, 21%).

The *Amazake* was mixed in a cooking robot (Thermomix TM6, Vorwerk, Germany) at the highest speed in order to homogenise the beverage.

2.4.1. Starch Hydrolysis and Viscosity Measurement

Starch hydrolysis was performed at a small scale in a Rapid Visco Analyser (RVA 4800, Perten Instruments, Sweden) at 50 °C at the constant speed of 1000 rpm for 30 min at different *Koji*:water proportions (1:1; 1:1.5; 1.75 and 1:2). The samples were cooled down to 4 °C, and the viscosity after cooling was measured at the constant speed of 1000 rpm for 2 min.

2.4.2. Brix Measurement

The sweetness of the *Amazake* was measured by its Brix (%) in a refractometer (PR-201, Atago, Japan) after filtering the suspension through a 45 µm syringe filter. The measurements were performed after 10, 15, 25 and 35 min.

2.5. Consumer Evaluation

A total of 111 consumers evaluated the *Amazake* beverage at an open science fair, which included students and families, representing a broad demographic group. In the first stage, the consumers tested the product without any information other than that it was a new and experimental rice beverage. The overall liking was evaluated using a 9-point scale, ranging from 1—"dislike extremely" to 9—"like extremely" [36].

In the second stage, after the first questionnaire, a prototype of the product was created, including a bottle full of "DIS! *Amasake*" with a label containing nutritional information, due date, ingredients, and logotype, and a flyer with information about the potential health benefits as well as information about the objectives of the project. The consumers filled out the Food Action Rating Scale (FACT) developed by Schutz [37], that was adapted for the product. The 9-point FACT scale was: 1—"I would drink this only if forced", 2—"I would drink this if there were no other food choice", 3—"I would hardly ever drink this", 4—"I do not like this but would drink this on an occasion", 5—"I would drink this if available but would not go out of my way", 6—"I like this and would drink it now and then", 7—"I would frequently drink this", 8—"I would drink this very often", 9—"I would drink this every opportunity that I have". Both the liking and FACT scales were translated into Portuguese, according to Ribeiro, et al. [38]. Demographic data (age, gender and education level) and free comments about the product were also collected with the overall liking data. Free comments have been analysed by grouping terms into categories and sub-categories derived from the content analysis [39] following a triangulation procedure [40]. All participants were aged 16 years old or above, and were willing to participate. Following the Helsinki statement, an informed consent was given, and participants were assured that all private information would remain anonymous. All minors (<18 years old) were

accompanied by their consenting parents or educators. The research team has enforced procedures to guarantee adherence to the European General Data Protection Regulations.

2.6. Statistical Analysis

To analyse data from the rice *Koji* fermentation process, following the Central Composite Design, a quadratic model (see Equation (1)) was fitted to GABA, α-amylase activity, and starch content data, where b_0 represents the constant term, b_1 and b_2 the linear terms, b_3 and b_5 the quadratic terms, and b_4 the interaction term. x_1 represents the rice *Koji* fermentation temperature (°C), and x_2 represents rice *Koji* fermentation time (h).

$$y = b_0 + b_1x_1 + b_2x_2 + b_3{x_1}^2 + b_4x_1x_2 + b_5{x_2}^2 \quad (1)$$

Raw data inspection was performed in advance, and outliers were identified among triplicates at each sampling point, following the Grubbs method (Table S1). A linear model building approach was implemented through a stepwise regression approach, minimising Akaike's AIC parameter [41]. Overall model fitting was assessed by the adjusted coefficient of determination R_{adj}^2 [32].

The comparison of processing conditions at the additional steps, such as the impact of the germination time on GO and GABA, was performed using a one-way ANOVA, followed by Tukey's post hoc multiple comparison test, if applicable. All tests were performed at a 95% confidence level using XLStat for Microsoft Excel.

3. Results and Discussion

3.1. Sample Selection

The rice bran proteins, lipids, and mineral content are considered undesirable for that specific fermentation process, and traditional rice *Koji* is produced with milled rice [21], so a milled rice sample was included as a control in the improvement of GO and GABA contents; a brown rice sample was also included for presenting a naturally richer content of those compounds due to the presence of the bran [1,42].

As GO and GABA contents also increase with germination, a previous study was conducted to select the best germination times. Figure 2 shows the contents of GO and GABA over germination time.

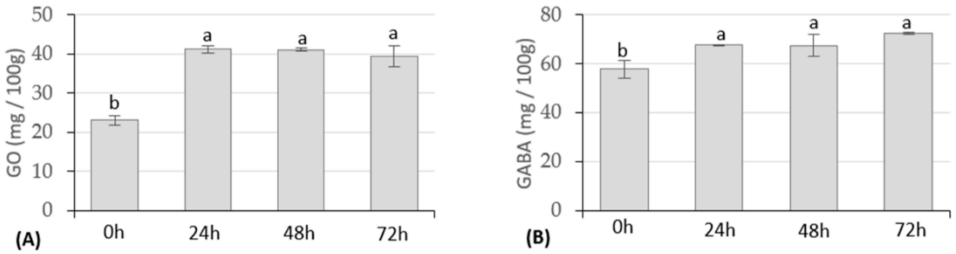


Figure 2. Effect of the germination time on the GO (**A**) and GABA (**B**) contents of brown Ariete variety rice, expressed in mg/100 g (DW). a, b—homogeneous groups according to Tukey's post hoc test at a 95% confidence level.

Both GO and GABA presented an increase in their content after 24 h of immersed germination when compared to raw rice, from 23.09 ± 1.193 to 41.17 ± 0.835 mg/100 g and 57.783 ± 3.60 to 67.73 ± 0.22 mg/100 g, respectively (Figure 2). After 24 h, the GO content lowered, and the GABA content increased; however, those changes were not statistically significant ($p < 0.05$). Wu, et al. [42] also reported an increase of the GO in the first germination stage, followed by a slight decrease; however, regarding GABA, the authors denoted a constant increase during germination. Wu, et al. [42] attributed the enhancement of GO in the first stages to the natural presence of lipases, promoting the decomposition of various lipid substances, including GO. Munarko, et al. [43] tested the effect of the germination process on the GABA content in four different rice varieties,

reporting differences in the increase rate of GABA content with the germination time; the same authors also reported differences between GO content changing rates between the four varieties along germination time. The increase of GO content with germination is also reported by other authors [44].

Considering the results obtained, a germinated brown rice sample, after 24 h of submersion, was selected for the fermentation trials to obtain rice *Koji*, in addition to the milled and brown rice samples.

3.2. Rice Preparation

As reported previously, time, temperature, and moisture are the most critical factors influencing *Koji* making [21]. GO and GABA content can be affected by the processes carried out during *Koji* making. Besides temperature and time, the system's moisture is also essential. The system's moisture combines the media's humidity and cooked rice's moisture. While initially the moisture content is about 95–98%, during the rice *Koji* fermentation process, the moisture is lost due to fungal metabolism [24], therefore being essential to cover the *Koji* with a cloth. The system's moisture was standardised by carefully monitoring the water content based on the raw weight of the rice.

The gelatinisation stage of starch, from β-starch to α-starch, is important in *Koji* making, as complete gelatinization is needed to allow the tip of the *A. oryzae* hyphae to extend forward into the rice grain and not only over the surface, thus producing more desirable compounds [24]. The gelatinisation state of the rice was also verified before inoculation.

According to Gomi [17], the optimum temperature for *Koji* making is between 32–40 °C. As *A. oryzae* cannot grow above 44 °C, the cooked rice was cooled to 40–42 °C before inoculation.

3.3. Optimisation of Koji According to GABA and α-Amylase Activity

Temperature and time were the selected variables to optimise the *Koji* making:

(1) Temperature can affect the production of metabolic compounds such as GABA, and can also dictate the type of compounds produced (e.g., temperatures up to 37 °C are reported to increase the production of protease, while higher temperatures increase amylase activity), depending on the strain specificities [21,22]; however, fermentation temperature depends not only on the external specified parameters, but also on the exothermic reaction that occurs during that stage (rising the temperature to 40–42 °C); therefore, it is necessary to mix *Koji* and to cool it and ventilate it, especially when working with large batches [24].

(2) Time is also crucial in *Koji* making, as it defines the stage of growth;

(a) spores start germinating three to five hours after attachment to the matrix;

(b) at 20 h the spores grow on the grain surface; and

(c) the hyphae grow, and the mould extends its hyphae into rice grains, spreading over the matrix at 44 h, secreting high molecular weight hydrolytic enzymes (e.g., amylase and proteases) through the process [18,24].

During this stage, GABA and α-amylase activity were selected as the target parameters to measure, as GO content is related to lipid metabolism and is not expected to change during rice *Koji* fermentation, and α-amylase will break the starch in the following hydrolysis process, therefore being essential to *Amazake* production. Starch, the main compound of rice, was measured to observe the changes occurring during the germination and fermentation processes.

Table 2 and Figure 3 present the regression models' parameters and model fit for GABA, α-amylase activity and starch content, and the contour plots for those models.

Table 2. Significant stepwise regression coefficients (±Std Error) ($p < 0.05$) and R^2_{adj}, from the fitting of Equation (1) to GABA concentration, α-amylase activity and starch content. Values for temperature (x_1) were expressed in °C and incubation time (x_2) was expressed in hours. Non-significant values ($p > 0.05$) are presented as n.s.

	b_0	b_1	b_2	b_3	b_4	b_5	AIC	R^2_{adj}
				GABA (mg/100 g)				
Brown Rice	−3120 ± 777	171 ± 39.5	n.s.	−2.47 ± 0.524	0.307 ± 0.143	−0.255 ± 0.033	197	0.679
Milled Rice	−1811 ± 387	96.7 ± 20.2	8.92 ± 1.38	−1.27 ± 0.271	n.s.	−0.102 ± 0.017	151	0.681
Germinated Rice	1900 ± 971	−98.1 ± 50.8	9.12 ± 3.48	1.21 ± 0.681	n.s.	−0.073 ± 0.043	212	0.715
				α-amylase activity (CU/g)				
Brown Rice	−3061 ± 221	153 ± 11.6	13.1 ± 0.815	−2.06 ± 0.155	n.s.	−0.159 ± 0.01	115	0.922
Milled Rice	−3490 ± 237	173 ± 12.5	16.2 ± 0.88	−2.33 ± 0.168	n.s.	−0.199 ± 0.01	114	0.939
Germinated Rice	44.0 ± 15.2	−2.31 ± 0.826	0.049 ± 0.008	0.03 ± 0.011	n.s.	n.s.	−29.3	0.618
				Starch (g/100 g)				
Brown Rice	350 ± 105	−11.9 ± 5.3	−3.66 ± 0.80	n.s.	0.048 ± 0.019	0.021 ± 0.004	74.4	0.577
Milled Rice	360 ± 75.9	−14.7 ± 3.97	−1.76 ± 0.273	0.202 ± 0.053	n.s.	0.021 ± 0.003	57.3	0.622
Germinated Rice	153 ± 16.8	−1.75 ± 0.442	−2.38 ± 0.441	n.s.	0.038 ± 0.01	0.007 ± 0.002	38.1	0.876

Germination is a process that occurs in three phases [45]:

(1) The seeds become fully hydrated;

(2) Activation of the metabolism to mobilise nutrients to grow the radicle, which emerges at the end of this phase;

(3) The seed absorbs even more water, and there is a significant mobilisation of reserve material (i.e., carbohydrates which are hydrolysed and metabolised, leading to the growing of the seed).

During the germination process, the rice matrix suffers irreversible changes: α-amylase and α-glucosidases are synthesised; thus, the starch content decreases due to the partial hydrolysis of starch [46]; the peptidase activity levels increase [47], leading to protein hydrolysis, which is not only degraded into peptides but also into free amino acids [45]. Given these changes, the GABA synthesis in the germinated rice during fermentation is carried out in a completely new matrix; if, on the one hand, the free glutamic acid present in raw rice bran was consumed as a substrate for producing GABA during the germination, on the other hand, during rice *Koji* fermentation, the enzymes produced by *A. oryzae* can break proteins leading to the existence of more free glutamic acid that is latterly synthesised to GABA. However, as *A. oryzae* produces proteases at a lower temperature, there is a need to decrease the fermentation temperature; at the same time, the time factor is also important to allow the action of the proteases, which may explain the differences between the predicted time to achieve the maximum values of GABA regarding brown and milled rice, and the germinated rice in Figure 3.

The α-amylase predicted time and temperature for maximum α-amylase activity also follows the pattern of GABA synthesis (Figure 3). In milled rice and brown rice samples, α-amylase is formed at the time/temperature suggested in the literature [21,22]; in the germinated rice matrix, α-amylase reaches its more significant activity at the lower temperature and maximum time. Here, the hypothesis presented before may also apply, and as the matrix changes, the proteases formed at lower temperatures may also change, freeing some compounds that promote the increase of α-amylase activity. Despite the differences in the initial starch amounts of milled and brown rice (82.77 ± 1.410 and 73.05 ± 0.351 g/100 g, respectively), the starch that remained after fermentation was similar in both matrices. Germinated rice predicted starch content shows a lower amount of starch at lower temperatures and maximum time, meaning that the starch structure may be responsible for those differences (Figure 3).

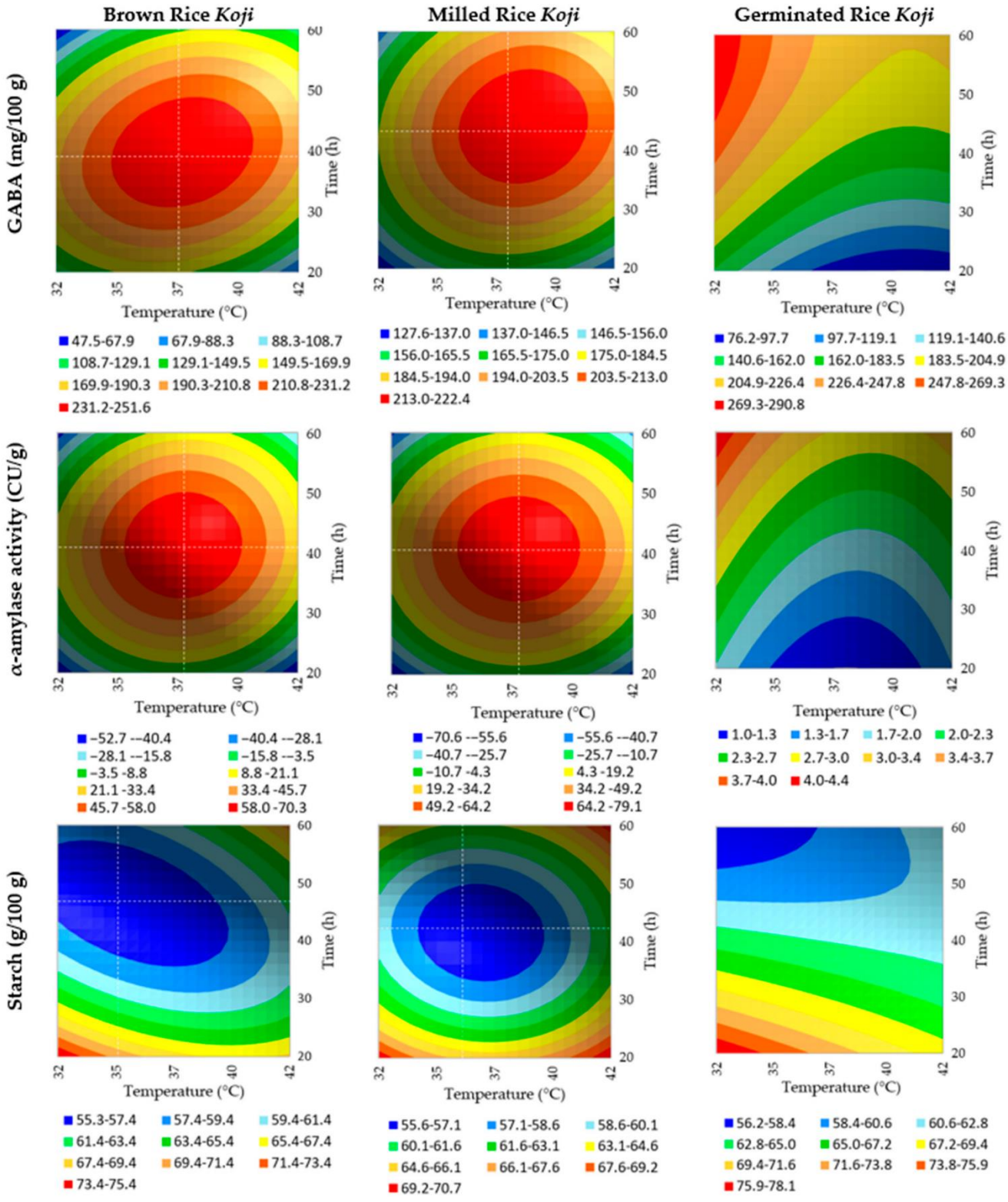


Figure 3. Contour plots of the predicted model for GABA, α-amylase activity and starch on brown, milled and germinated rice *Koji*. In GABA and α-amylase activity plots, white lines represent the temperature (°C) and time (h) targets to obtain the maximum response for GABA and α-amylase, and the minimum response for starch contents.

Table 3 shows the maximum concentrations of GABA and α-amylase activity, according to the simultaneous linear optimisation of both the GABA and α-amylase activity

models. The results show the similarities between milled and brown rice regarding time, temperature, and maximum predicted values. Germinated rice requires more time and less temperature to obtain higher values of GABA than the other matrices; however, despite the maximum α-amylase activity occurring at the same time and temperature, the values are very low compared to the other matrices. Despite the low α-amylase activity, germinated rice was selected to produce the *Amazake* beverage, as pilot studies showed that germinated rice α-amylase could produce satisfactory results on the enzymatic hydrolysis.

Table 3. Predicted maximum GABA and α-amylase activity according to the simultaneous linear optimisation of both adjusted quadratic models (Table 2).

	Temperature (°C)	Time (h)	GABA (mg/100 g)	α-Amylase Activity (CU/g)
Brown rice	37.2	40.3	251.6	70.4
Milled Rice	37.5	41.8	221.6	79.0
Germinated rice	32.0 *	60.0 *	290.5	4.0

* Within the experimental range.

The predicted results were confirmed by a GABA and α-amylase activity analysis, showing results near the expected: regarding GABA, a concentration of 251.52 ± 6.3 mg/100 g, and regarding α-amylase activity, 4.04 ± 0.07 CU/g. The starch content was also assessed in the selected *Koji*, presenting a predicted value of 55.89 g/100g, and a response of 59.11 ± 0.16 g/100 g.

3.4. Amazake Preparation

Amazake, a beverage naturally sweetened by the action of enzymes, can be produced by adding *Koji* and water and exposing it to a controlled temperature over a specific period of time. While the water addition influences texture, it will also change the concentration of α-amylase in the system, manipulating the sweetness of *Amazake*. Time is also a key factor, as sweetness can be controlled by the time the enzymes take to hydrolyse the starch to glucose [48]. The starch enzymatic hydrolysis is carried out in two stages: dextrinisation (or liquefaction) and saccharification. During dextrinisation, there is a breakdown of starch in oligosaccharides, polysaccharides, or maltodextrin with a loss in viscosity; in the saccharification phase, the maltodextrins are mainly converted into glucose [48,49]. Figure 4 shows the °Brix and viscosity values progression over time in the same *Koji*:water samples subjected to 50 °C in RVA, where the rapid decrease of viscosity represents the liquefaction phase, and the slower increase of °Brix represents the saccharification stage.

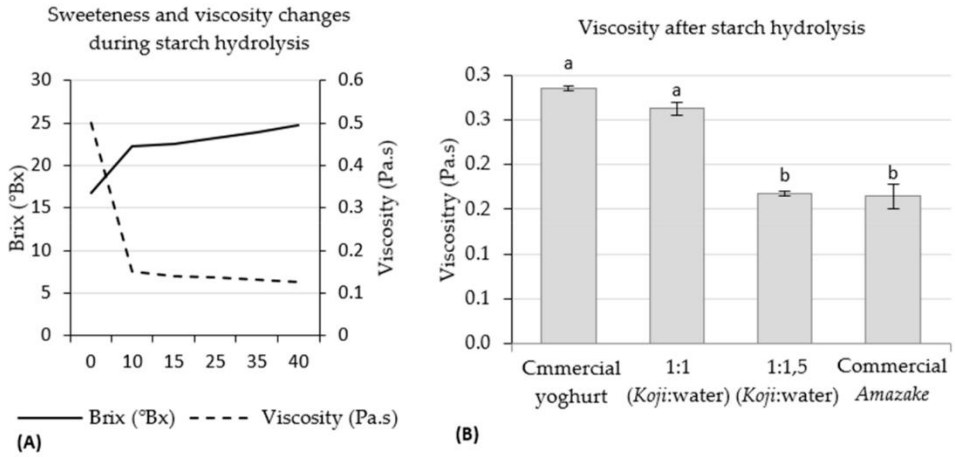


Figure 4. (**A**) Sweetness and viscosity over starch hydrolysis time. (**B**) Viscosity after hydrolysis in the selected *Koji*:water concentration and its comparison with drinking yoghurt and *Amazake*. a, b—homogeneous groups according to the Tukey's post hoc test at a 95% confidence level.

The texture and sweetness of *Amazake* were first tested on a small scale using an RVA at a constant temperature and speed. The optimum temperature for *A. oryzae* α-amylase to act on the substrate is reported to be 50–60 °C [24]; due to the reported low α-amylase activity, the system temperature was maintained at 50 °C. The texture was first improved to reach the yoghurt viscosity (0.285 Pa.s). As expected, the viscosity decreased with the water addition (Figure 4A). As the 1:1 *Koji*:water concentration showed a viscosity similar to the commercial yoghurt (Figure 4B), it was selected for the *Amazake* production at a larger scale for sensory evaluation.

The selected *Koji*:water concentration was then subjected to starch hydrolysis over time, also using the RVA, to obtain the °Brix value. Although °Brix is not a very accurate measure, in this case it was very useful, as a rapid measurement was preferred to a more accurate one due to the rapid action of α-amylase, as it could modify the results in a short amount of time. *Amazake* °Brix was set considering the reference of the commercial *Koji* °Brix, as the other compounds influence the sweet flavour in the *Amazake*, namely volatile components that are largely dependent on lipid oxidation in the *Koji* fermentation stage [50]. Therefore, instead of 14.3 °Brix of yoghurt, a 21 °Brix of commercial *Koji* was considered.

The *Amazake*, produced in the large batches (2 L) for consumers' sensory evaluation, had a relatively small change in the texture (from 0.255 ± 0.007 to 0.345 ± 0.035 Pa.s); in the large batches, the starch hydrolysis was carried out over five hours, with hourly °Brix measurements.

3.5. Effect of Germination and Rice Koji Fermentation on GO and GABA of Rice after Cooking

Figure 5 compares the effects of *Amazake*'s processing stages (cooking, germination, fermentation and starch hydrolysis) on GO and GABA contents with the traditional milled rice *Amazake*. As expected, steam cooking did not affect GO and GABA content, since both are resistant to boiling temperature [51,52]. With germination, both compounds increased, as was already reported in Figure 2; however, while for GO the value was 78.3% higher, for GABA the increase was not significant ($p > 0.05$), and represented only 17.2%.

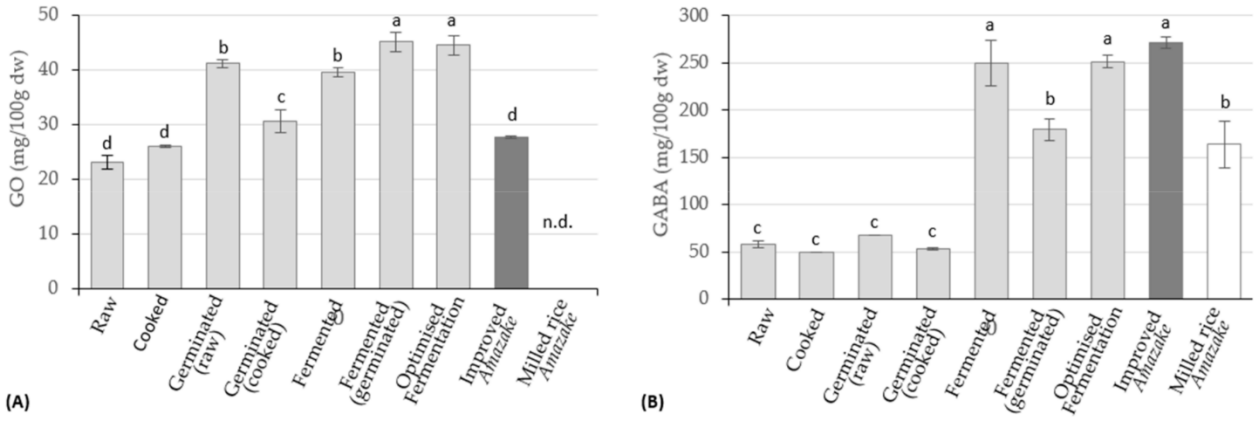


Figure 5. Effect of the various procedures on brown rice on (**A**) GO and (**B**) GABA contents. (n.d. stands for non-detectable). a, b, c, d—homogeneous groups according to the Tukey's post hoc test at a 95% confidence level. The improved *Amazake* is shown in dark grey and the traditional milled rice *Anazake* in shown in white.

Despite the higher GO content in germinated rice when raw, the amount decreased after cooking, which can be related to any leaching of the compounds; the differences between the effect of boiling in raw and germinated rice may be related to the different matrix that germination generates. GO values increased with rice *Koji* fermentation and even more when germination and fermentation were used, as well as in the optimised time × temperature samples (37 °C/20 h).

Regarding GABA, the results show that fermentation greatly impacted the concentration of the compound: non-germinated brown rice fermented at 37 °C for 40 h presents a GABA value of 249.95 ± 24.31 mg/100g; when fermented after germination, the content of GABA decreases; however, after optimisation, (32 °C for 60 h), the GABA content increased to the values of the non-germinated brown rice. The reported values may be explained by starch availability, reported in Table 2 and Figure 3, as *A. oryzae* fermentation occurs based on carbohydrate metabolism [17,18], the production of compounds may be compromised or, in this case, takes longer, derived from the changes occurred during the germination process. Wang, et al. [53] studied the effect of germination and fermentation on GO and GABA contents in rice inoculated with *Bacillus subtilis Natto.* The authors reported a significant decrease of GO and GABA after fermentation in both germinated and non-germinated rice, which is understandable as the starter cultures are different, thus having different metabolisms.

Figure 5 also shows that the GO content decreases sharply after starch hydrolysis, which may be related to the action of other enzymes (e.g., lipases that are also formed during fermentation [19,20]). Regarding GABA, there is a slight content increase after hydrolysis. When comparing the optimised *Amazake* with the one made with milled rice *Koji* under traditional conditions (37 °C/40 h), the optimisation process improved GO and GABA contents.

3.6. Consumer Evaluations

The final *Amazake* product was presented to the consumers at an open science fair. At first, no information was available about the product, and the consumer tried and evaluated the product hedonically. Secondly, the product was shown bottled under the brand DIS!Amasake with a full label and according to the EU labelling legislation for food products [54].

Although the Portuguese gastronomic tradition is rich in rice meals and even deserts [55], eating germinated or fermented rice is not a habit, and to our knowledge, there are no industries in the country producing those products. Despite this, it is possible to find *Koji* products in the market, although only in niche shops or online. Thus, the *Koji* flavour is unknown to most Portuguese consumers.

Overall liking, before elicitation, had a relatively low score, as 42.3% of the participants rated the beverage in the lower range of the scale, and only 37.8% rated the beverage in the higher range (Figure 6). The median and mode score was five, meaning that the product was neither liked nor disliked. The observed values may be related to various factors, including the novelty of the product, and/or cultural differences, as *Amazake* is a traditional drink in Japan. Various authors [56–60] have reported how cultural differences impact food preferences in a variety of cross-cultural studies. Prescott et al. [60] found that Japanese subjects had a higher preference for acidic and umami flavours at higher concentrations than Australian subjects. The Japanese beverage *Amazake* presents an acidic flavour due to the compounds formed naturally in the fermentation process.

Forty consumers filled out the optional open comments section, resulting in a total of 47 different entries. The data were grouped into four categories: taste (n = 23), texture (n = 11), aroma (n = 4), and general attributes (n = 9). The prominent taste characteristics were "bitter" (n = 5), "strong" (n = 4) and "yeast" (n = 4); however, those aspects are not correlated to the liking parameters, but rather to the individual preferences and habits. Regarding texture, the most reported characteristic was "thick" (n = 7), which may be related to the expectation of the testers given their knowledge of rice beverages in the market, which are texturally similar to milk. The aroma was described as "unpleasant" (n = 4), a preference parameter. The participants who described the beverage regarding general attributes reported it as "different/unknown/unexpected" (n = 6), and a participant commented that it "requires habituation". This last comment is interesting, as the literature reports that food preferences are acquired over time [61]; liking a substance tends to increase with familiarity and exposure.

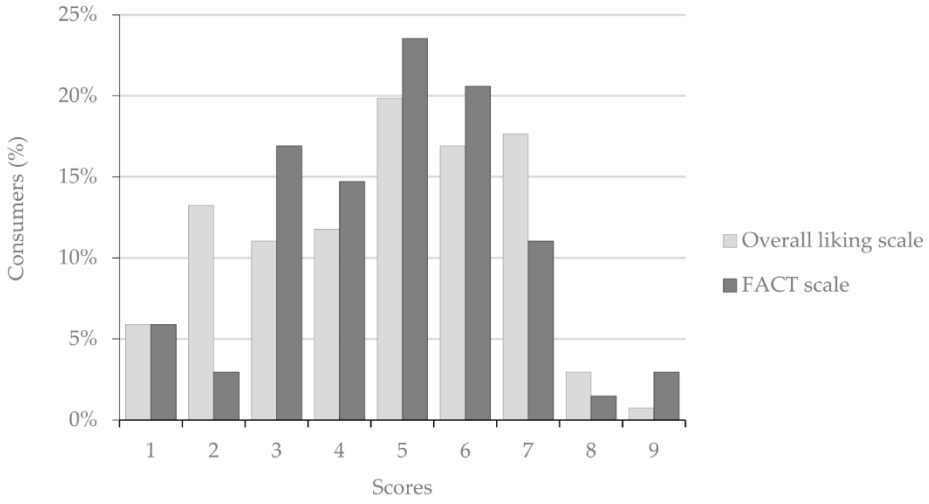


Figure 6. Distribution of consumers' responses regarding overall liking and acceptance (FACT).

Beverage acceptance after exposure to the prototype and related nutritional benefits shows a slight increase when compared with the overall liking scores (Figure 6). Thus, when comparing the differences between liking and acceptance, the participants who most disliked the product were positively impacted by the nutritional elicitation, and the participants with higher liking scores showed a more dispersed attitude; however, the overall liking scores were positively correlated with the FACT scores (R = 0.743).

As for overall liking scores, the impact of nutritional elicitation can be influenced by cultural aspects [62]. When comparing cross-cultural applications of the Food Choice Questionnaire, Cunha, et al. [63] showed that there is a visible difference between the food choice determinants of Japanese and Portuguese consumers: for the Japanese, the health and natural content are more important than sensorial traits, while for the Portuguese the sensorial traits are the most important. Therefore, Portuguese consumers may be less prone to accept unknown health-based foods with a perceived lower sensory appeal.

4. Conclusions and Future Work

The results show that all the measured compounds are affected by the rice raw material (germinated, brown or milled), particularly regarding germinated rice, and also by further fermentation. The germinated rice *Koji* was selected for the *Amazake* preparation due to its higher γ-oryzanol (GO) and γ-aminobutyric acid (GABA) contents. In the selected sample, the GO concentration increased with the germination process in raw samples (from 23.09 ± 1.19 to 41.17 ± 0.84 mg/100 g), and after fermentation (to 44.17 ± 1.8 mg/100 g); however, after the starch hydrolysis process, the values of GO decreased to 27.65 ± 0.23 mg/100 g. The use of the traditional milled rice as raw material for *Amazake* presented a non-detectable GO, while significant GO amounts can be obtained using germinated rice. The GABA content in the selected sample increased with fermentation alone from 57.783 ± 3.60 to 249.95 ± 24.31 mg/100 g, and for the predicted optimum conditions (271.53 ± 5.7 mg/100 g), maintaining the value after starch hydrolysis. Compared to the GABA content of the milled rice *Amazake* (163.95 ± 24.7 mg/100 g), it also presented a great increment. Despite the nutritional improvement associated with the bioactive compounds obtained in the *Amazake*, when presented to the consumers, the overall liking scores were low, which can be attributed to the product novelty and low familiarity with the concept of fermented rice beverages for Portuguese consumers. Nevertheless, as there is room for improvement and even adaptation of the formulation to the Portuguese consumers' habits, further sensory improvement may be sought in the future with different variants of the fermented beverage, as well as the evaluation of acceptance within different consumption contexts.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/foods12071476/s1, Table S1: Raw data used to fit the response surface design model according to Table 1, RSD (%), and Grubbs distance for the three repetitions. Numbers in bold represent the excluded outliers and criteria of exclusion. When the RSD criteria (>20%) was used, the selected outlier was identified through the highest Grubbs' distance (underlined values).

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Chapter 10. GENERAL DISCUSSION

10.1 FOOD PRODUCT DEVELOPMENT AS A DESIGN PROBLEM

Simon (1969) refers all the things created for men are artificial, and Design "is the science of the artificial"; thus, as later exposed by Buchanan (1992), Design is the "new liberal art" that can expand to all knowledge areas, as it is part of daily life. Given this context, promoting the consumption of brown rice or RB by developing a new food product is a design problem. Creating this "artefact" presupposes the study of the natural as it interacts with the artefact, framing the problem (Simon, 1969). In this particular case, it is important to study the consumers' motivations (Olsen, 2015) and the particularities of RB. However, while the rice matrix is observable and predictable, as being a part of nature, and it can be studied by natural sciences Simon (1969), consumers and their food choices are very complex, as discussed in the first part of Chapter 2. From this point of view, the problem can be described as ill-defined or wicked, which is clearly verified when compared to the wicked problems' definition by Rittel and Webber (1973) (**Table 6**).

Table 6. Rittel and Webber (1973) wicked problems definition (**Chapter 4**) and its application to the case

Wicked problems' **definition**	**Thesis problem**
• *The unclear definition* • *The solutions are not "true or false" but "good or bad"* • *There is no immediate or ultimate test for the solution*	The success of the solution depends on consumers' food choice
• *There is not a clear end* • *The problems do not have a limited set of solutions*	There are infinite ways of including rice bran in the human diet
• E*very problem is unique* • T*he problems can be interlinked with others,* • *The problem can be represented in numerous ways*	When choosing a path, unique problems will reveal
• *The planner has no right to be wrong*, as the actions have real consequences • *The implemented solution is consequential*	The solution could affect one or more stakeholders (the consumers and the rice market) or at least lead to losing time and resources.

Viewing the problem regarding the Aristotelian logic, as exposed by Dorst (2011) (**Chapter 4**), it can be seen that neither induction nor deduction can be used alone a) the *what,* which is both the RB and the consumers' motivations, b) there are infinite ways *(how)* of solving the problem, and c) the *result* was transformed as value, as it depends on the consumers.

Given this context, this design problem must be approached using DT. While there are other *step-by-step* models (working iteratively), this case was approached from three spaces system proposed by

Brown (2008): Inspiration, ideation and implementation, as its simplicity might lead to a less rigid workflow.

10.2 INSPIRATION

The inspiration phase aimed to study the consumer choice motives behind rice consumption and to better explore RB by studying existing gaps in the literature.

10.2.1 Understanding the food choice motives towards rice

Food choice is a complex problem, as stated in 2.1. The Food Choice Questionnaire was elected as a tool to study rice choice motives, as it is a well-known tool studied in varied contexts and encompasses many of the raised food choice questions (Cunha et al., 2018).

From the social sciences point of view, there are two ways of approaching phenomena: the *etic* and the *emic*: As stated in Chapter 6, "The etic approach stands for what can be directly observed, while the emic implies a deeper immersion in the problem; the etic approach is valid for cross-cultural comparisons, while the emic approach is used in culturally specific studies" (Marvin, 1976; Naroll & Naroll, 1973). In this sense, as the objective was to study a phenomenon in a particular study, the adaptation of the FCQ Developed in an *emic* way, preventing biases induced by the researcher.

Images can play a central role when working in an *emic* way. They can, in this particular context as 1) images are a form of communication, and as defined by Cross (1982), a characteristic of the design discipline, as the use of mental imagery works as a code that transforms thoughts in words; 2) images reduce the complexity of information processing, storage and retrieval, working as a precursor or gatekeeper to more extensive elaboration, as discussed by Poiesz (1989); 3) images can be included in projective techniques, triggering individual responses related to the inner mental state (Reavey, 2012) and revealing cultural differences as they transmit particular interpretations, including stereotypes and beliefs (Eco, 1975; Rania et al., 2015) and 4) the use of images is deeply related to the association technique, which is considered a search strategy in the memory structures (Mednick, 1962; Smith, 1998).

The tool developed to adapt the FCQ used images as stimuli and the association process to generate concepts the consumers indirectly related to the items and new ones elicited by words. In the second paper, a tool was implemented with images previously selected by the research team; however, even though the tool presented good results (with six new items generated by consumers, including items related to innovation, authenticity, trust and local production). The exercise was performed again, in the third paper, with some modifications: the images were previously selected by the consumers in an online survey between three images chosen by the research team, and the chosen image was rated

regarding their relatability to the item, and new items, based on interviews regarding the theme were also included (Cabral et al., 2022). This second iteration diminished the bias induced by the researcher, which is considered one of the biases compromising DT (Liedtka, 2015).

The results of the questionnaire implementation revealed that the Sensorial Appeal factor is the most important for rice choice, followed by Convenience and Health & Nutrition. These results approach the Portuguese consumers to the Asian consumers when considering the utilitarian, experiential and symbolic motivations proposed by Son et al. (2014), as verified by Cabral et al. (2022) and may be related to the cultural relations between Portugal and Asia. Agulha and Basmati rice types are considered "non-sticky" due to their high amylose content. The preference for those rice types rice is coherent with the low importance given to the symbolic dimension (Mood, Ethics & Familiarity) and may cause the low preference for the stickier Carolino rice.

10.2.2 Rice and its bioactive compounds

If the first part of ideation relied on consumer sciences, using the three types of logic reasoning (induction, deduction and abduction), being in the artificial realm, this second part is based on natural sciences methods of inquiry.

The GO content of the extracts of nine different varieties of rice was assessed, and content the cytotoxic properties of those extracts were tested for cytotoxicity against four human tumour cell lines (NCI-H460, HeLa, HepG2, and MCF -7) and a non-tumour primary culture (porcine liver primary cell culture); its antimicrobial properties were also tested.

The mean GO of all varieties was within the range of 79.2 to 912 mg/100 g on RB (Kamimura et al., 2017; Massarolo et al., 2017; Norkaew et al., 2017; Peanparkdee et al., 2018; Pokkanta et al., 2019; Wanyo et al., 2016).

A negative correlation between GO concentration and GI_{50} for three tumour cell lines (HeLa, HepG2 and MCF7) has been found, meaning high GO concentrations may effectively reduce these cells' proliferation. The cytotoxic effect against normal porcine cell lines suggests that the extracts present no hepatotoxicity. Regarding the antibacterial and antifungal activities, GO presented no correlation with their inhibition; however, the extracts can be effective in the inhibition of the studied bacteria and fungi, mainly *Pseudomonas aeruginosa*, which suggests a there may be other compounds that may interfere with the process.

10.3 IDEATION

10.3.1 Generating creative ideas through brainstorming

As Olsen (2015) expressed, the consumers must be part of the food product development from the beginning. In the ideation phase, the consumers are represented by the data acquired in the adapted FCQ. Therefore, to minimise the researcher bias from the equation (Liedtka, 2015), the idea generation phase was performed by young chefs, who had access to the results of the former adapted FCQ and information about rice and RB.

The brainstorming technique was first introduced by Osborn (1953) and later popularised as the proper technique to generate ideas (Kelley, 2001). This technique can be used alone or complemented with other techniques and tools Maaravi et al. (2021). The fifth paper reports two different forms of brainstorming implemented to generate rice-based meal ideas.

In the first iteration of the problem, a group of young chefs performed a free brainstorming exercise based only on the given information and were asked to produce innovative ideas. The results were evaluated by professional chefs regarding its adequacy to the consumer, novelty, workability and clarity, based on an evaluation tool designed by Dean et al. (2006), presenting very low scores, mainly on the novelty parameter.

Given the low scores considering novelty, the creativity concept was explored to create a new tool associated with brainstorming that could lead to creative ideas. Guilford (1967) proposed that the key factor for idea generating is based on memory; thus, to evaluate idea generation ability, the author created an association test (the Alternative Uses Test), which consisted of asking the participants non-obvious uses for an object in a fixed amount of time; the responses were evaluated by its originality, quantity, number of categories, and amount of detail (Dippo & Kudrowitz, 2013). Mednick (1962), who also studied the psychometric measurement of creativity, suggested it could be achieved by associating remote concepts to form new relationships, describing the creative process as “the forming of associative elements into new combinations”. Based on this background, the author developed a creativity test (Remote Associates Test) (Mednick, 1968), consisting of questions asking participants to link three pre-selected remotely associated stimulus words. Smith et al. (2013), who studied the semantic internal search for this test, reported that various processes contribute to the final answer, which, given the complexity of the task, approaches to it complex problem-solving. Thus, the creative tool developed for this phase makes use of stimuli generated by chefs (to diminish the researcher bias) that were randomly given to the students to link them and form a meal idea, making use of association to communicate ideas (from chefs to students) and to generate new ideas expeditiously.

The similarities with the tool designed to modify the FCQ rely on using forms of communicating indirectly by using association, which is considered a search strategy in the memory structures (Mednick, 1968), thus, being a bias remedy as proposed by Liedtka (2015).

10.4 IMPLEMENTATION

The idea elected to be optimised to the maximum concentration of bioactive compounds consisted of a rice-based beverage composed of cooked rice, RB and sugar and had a drinking yoghurt texture. To improve the beverage, previous research about the processes to increment the values of GO and GABA was first carried out. As explored by other authors (Oh et al., 2019; Pokkanta et al., 2019). Germination is one of the processes contributing to the increment of GABA. Fermentation also contributes to the increment of GABA. The most important microorganism employed in rice fermentation is *Aspergillus Oryzae*, which has been used in Asia, mainly in Japan, as a starter for a solid-state fermentation named *Koji*, which is the basis of many traditional products, including the sweet non-alcoholic beverage *Amazake*, which is a product of the hydrolysis of starch by the α-amylases produced during fermentation (Chang et al., 2014; Gomi, 2014).

The *Amazake* optimisation followed the traditional preparation steps (rice, *koji* and *amazake* preparations). Three different matrices were tested during the whole process: milled rice, brown rice and germinated rice. The rice germination time was elected following a pilot test in which the concentrations of both GO and GABA were measured over time. The results showed a decrease in GO after the first germination stage (24h), as already reported by Wu et al. (2022), and no statistical differences ($p<0.05$) regarding GABA content from that point onwards.

As reported before, time, temperature, and moisture are the most critical factors influencing starter (*Koji*) making (Okuda et al., 2019). Therefore, the moisture was standardised on the rice preparation phase, and a surface response method was used to find the best time x temperature to increase the starter bioactive compounds while preserving the α-amylase activity to further starch hydrolysis. The results showed that germination significantly changed the rice matrix, mainly due to the partial hydrolysis of starch (Xu et al., 2012); however, the GABA concentration was the highest on germinated rice compared to the other matrices.

The Amazake was optimised to the yoghurt-like texture proposed by the students in the ideation phase; however, the sweetness of the beverage, controlled by the hydrolysis temperature and time, was optimised to the one of commercial amazake as the other compounds present in Amazake influence its sweet flavour (Feng et al., 2014).

After the process completion, the measurements of GO and GABA were performed on the optimised product. While the GABA content presented the highest values, the GO decreased sharply during the starch hydrolysis phase, which may be related to the action of other enzymes that are also formed during *Koji* making, for example, lipases (Allwood et al., 2021; Soccol et al., 2017). Despite these results, compared to the traditional milled rice Amazake, which presented a non-detectable GO concentration, the optimised product presents excellent results.

The evaluation test was performed in a science fair at two levels: a blind test (to assess hedonic preference only) and an informed test to understand the health-related information's impact on the consumers. The results were interesting, as they could be divided in two: half of the users liked the product, and the other disliked it. Various authors (Hong et al., 2011; Laureati et al., 2014; Moskowitz et al., 1975; Prescott et al., 1992; Zellner et al., 1999) reported how cultural differences impact food preferences by performing cross-cultural studies. When applying the FCQ to Japanese and Portuguese consumers, there are differences between both cultures; for Japanese, the health and natural content are more important than sensorial traits; for Portuguese consumers, the sensorial traits are more important (Cunha et al., 2018). Although the food motives regarding rice approached Portuguese from Japanese consumers, the results regarding Amazake showed the differences, meaning rice is considered a staple food for both cultures, while the liking for Amazake is specific to Japanese culture.

Chapter 11. **CONCLUSIONS**

In this work, the Food Product Development process was viewed as a design problem, and the DT method was implemented as a general framework and by the generation and application of design tools in a consumer-centred perspective.

From the DT study, it may be concluded that the concept is evolving, such as the design process itself: it emerged from various perspectives and can be defined as any way of thinking of the artificial as something to improve something in an unknown way. Therefore, it can also be applied to food product development as a design problem. The few reported practical examples (including the one presented here) employed the DT differently, which is desirable, as different problems require different approaches; however, there is a common ground in all of them: the user-centred approach, collaboration and use of prototypes, which are common in the DT approach.

Paper 2 allowed to conclude that the FCQ is a widely used tool to access consumer's food choice motives; it is not static, as proven by the number of modified questionnaires in use. While the modifications made by other authors are mainly based on the literature or experts' opinions, the inclusion of the consumer in the process, through the use of the designed tool, enabled the generation of new items according to the consumers' language and culture. The role of the consumer was visible, particularly on questions regarding food innovation, authenticity and trust in local production. The use of images also allowed a discussion without the interference of the researched.

From the third paper, it was possible to conclude that tools, including images, function as a projective technique and a creative tool, therefore joining the inspiration and ideation phases of DT as the creative insights of the consumers reflect their particular cultures. This approach allowed a better understanding of the motives behind the choice of rice from Portuguese respondents with little impact on the researchers, functioning as an emic approach, helping the rice industry to understand the consumer and better fit their current needs.

Paper 4 allowed to conclude that the bran rice extracts showed a cytotoxic effect on tumour cell lines, possibly related to the amount of GO. However, the synergetic effects with other oil bran bioactive compounds should be accounted for. The RB lipid extracts can also effectively inhibit the studied bacteria and fungi, mainly Pseudomonas aeruginosa. Since these pathogenic bacteria and fungi can be easily found on highly manipulated food products, RBO may be explored as a natural additive on processed foods to extend their shelf life. Overall, the results show that rice extracts may be considered potential candidates to be used as antimicrobial agents when incorporated into food matrices, helping to prevent contamination by mycotoxins.

In paper 5, it can be possible to conclude that chefs' idea generation is generally described as an intuitive process, despite the utilization of some known techniques. Even though the students from Culinary Arts were asked to produce innovative ideas in the first approach, the results showed that the inclusion of stimuli led to more creative ideas. Carefully selected word cards and how they are used have benefitted the creative process.

Paper 6 helped conclude that all the measured compounds are affected by germination and fermentation. GO increased with the germination process in raw samples (from 23.09 ± 1.19 to 41.17 ± 0.84 mg/100g), and when fermenting the germinated rice GO (to 44.17 ± 1.8) maintaining the amount after the optimized *Koji* fermentation, after the starch hydrolysis process, the values of GO decreased to 27.65 ± 0.23, however, when compared to the non-detectable values of the traditional milled rice *Amazake*, it is a significant improvement. Regarding GABA, the content increased with fermentation alone from 57.783 ± 3.60 to 249.95 ± 24.31; despite the lower values when fermenting germinated rice, when the predicted optimum conditions apply it increased to 271.53 ± 5.7, maintaining the value after starch hydrolysis, which, comparing to the 163.95 ± 24.7 of the milled rice Amazake is an excellent increment. As expected, α-amylase activity decreased with germination, as starch decreased, showing the *A. Oryzae* metabolism depends mainly on the starch content. Despite the great bioactive values obtained in the *Amazake* optimization, the acceptance values were not high when presented to the consumer. This can be attributed to the product novelty and the fact that Portuguese consumers value sensory appealing more than health benefits when choosing a product.

The importance of this work for consumer sciences follows two lines: one is the emphasis on the importance that consumer sciences have in food product development; the other is the tool creation. Food Choice is an important issue for consumer sciences, and the tool created to modify the FCQ may be helpful to adapt the questionnaire to other realities and develop or modify other consumer sciences techniques. Additionally, it was possible to emphasise the solid traditional background of the consumption of rice by Portuguese consumers.

By studying RB, and in particular, the types and varieties produced in Portugal, this work also contributed to a best knowledge of Portuguese rice in varied ways: it showed RB has very interesting nutritional properties, namely a high content of GO, with potential health benefits for consumers; and how it can be incorporated into innovative food products.

Chapter 12. **FUTURE WORK**

As for future work, other consumers' evaluations and sensory tests should be performed in more controlled conditions to understand the specific characteristics of the consumers or the beverage that

led to the results. As the product is unknown to Portuguese consumers, applying the Food Neophobia Scale would be helpful, as the former beverage evaluation results could have been impacted by a certain degree of neophobia. Including participants who consumed fermented beverages would also contribute to understanding if liking those flavours could influence liking for the Amazake.

An evaluation of the product itself would also be necessary, as the decrease of GO in the starch hydrolysis phase may make its optimization less important, leading to a product reformulation, for example, using milled rice for Amazake making, later incorporating stabilized RB. This hypothesis might also help incorporate other side streams of rice, such as broken milled rice, and RB, being less time-consuming, benefitting the environment and the rice industry stakeholders.

Other interesting and more complex ways of exploring the process would include testing other inoculums (exploring a collection of bacteria and/or fungus) for the Koji fermentation, exploring them in different concentrations to improve the bioactive compounds, and/or exploring other bioactive compounds on the beverage, studying their potential against diabetes and cardiovascular diseases, including in vitro and in vivo tests.

The need for new iteration(s) confirms that the design is not a closed process, and food products can be continuously improved.

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