Food and Agriculture Organization
of the United Nations

THE NUTRITION AND HEALTH POTENTIAL OF GEOGRAPHICAL INDICATION FOODS

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Abstract

A geographical indication (GI) is a label used to distinguish products with a specific geographical origin and qualities, characteristics or a reputation that are essentially due to that place of origin. Hence, there is a clear link between the product and its original place of production. GIs are used by countries worldwide as a tool to protect products with characteristics that reflect their place of origin. GI-protected products are typically agricultural products, foodstuffs, wine and spirits, handicrafts or industrial products.

Today's world is facing complex nutrition challenges, and nutrition has been put high on the development agenda in recent years. The important role played by traditional foods, diets and food systems in people's nutritional status is recognized in a number of important documents. The impact of the use of GIs on nutrition and diets has been researched much less than that of socio-economics, biodiversity or natural resource availability. The potential of GI foods to contribute to healthy diets and curb non-communicable diseases is worth exploring.

This paper presents five case studies on the nutritional potential of registered GI foods: Carnalentejana (Portuguese beef), furu (Chinese fermented tofu), Parmigiano Reggiano and Grana Padano (Italian fermented cheese), rooibos (South African herbal tea) and indigenous rice varieties from the highlands of Borneo (Malaysia and Indonesia). The study explores the link between the production processes and the nutritional composition of the final products. Indeed, the nutritional characteristics of these foods can be largely attributed to their unique ingredients and production procedures, which are linked to their geographical origins. The analysis of nutritional compositions not only considers ordinary nutrients, but also bioactive compounds, which do not usually appear in nutrition facts tables. A number of foods similar to the case study subjects (not necessarily GIs) are briefly discussed in the respective sections.

After the case studies, three topics are briefly explored: the development of GI specifications to maintain and improve nutritional values, the role of GI foods in healthy diets, and the determination of food composition. Section 4 discusses the limitations of the paper and presents suggestions to leverage GI foods for healthy diets. Many GI-protected traditional foods are fermented foods; hence, the Annex discusses probiotics, prebiotics and gut microbiota.

Contents

TABLES, FIGURES AND BOXES

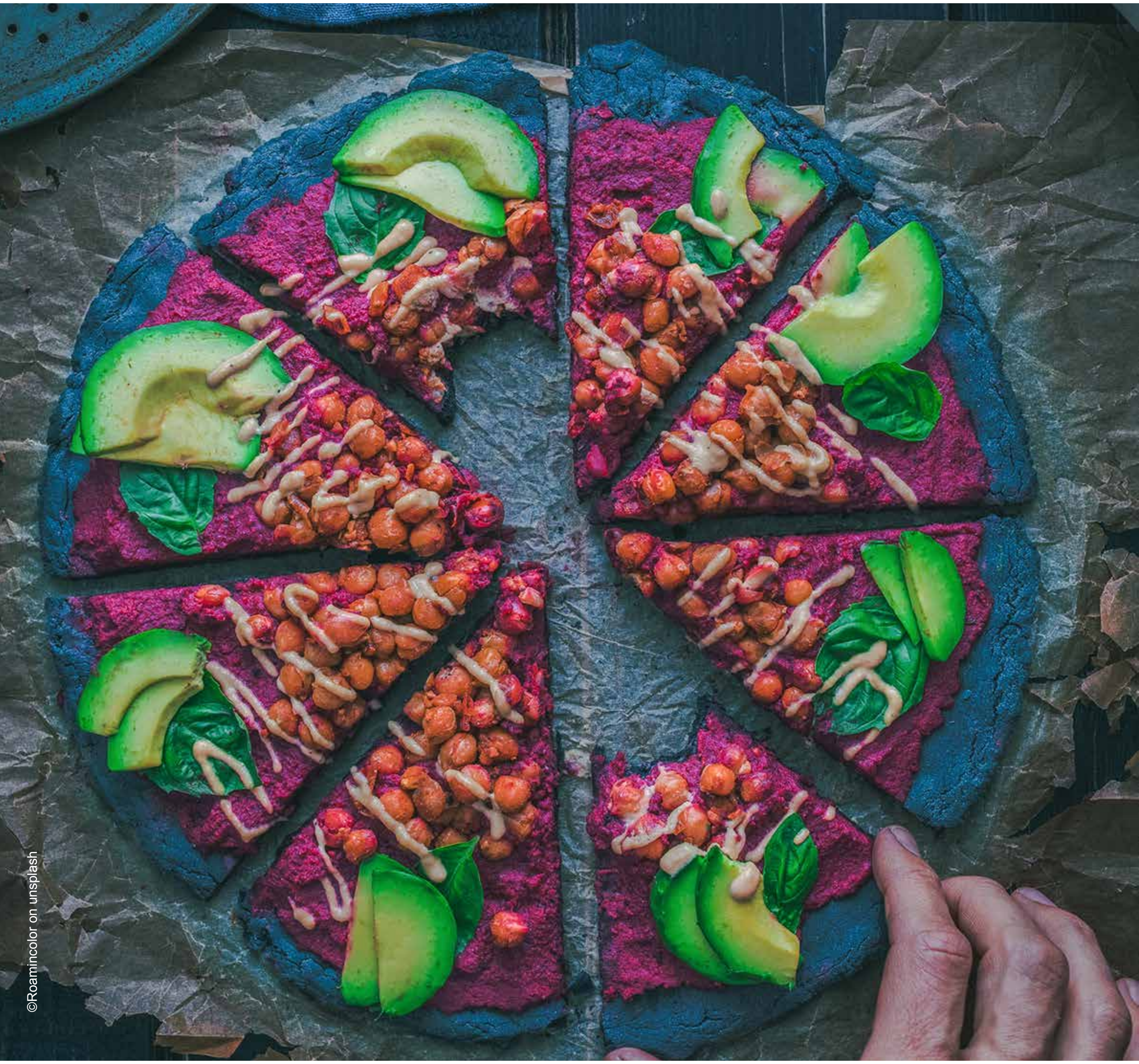
Tables

Figures

Boxes

Abbreviations and acronyms

BFA	Biodiversity for Food and Agriculture
DNA	deoxyribonucleic acid
EU	European Union
EuroFIR	European Food Information Resource
FAO	Food and Agriculture Organization of the United Nations
GI	geographical indication
GMP	good manufacturing practices
HACCP	hazard analysis and critical control points
HLPE	High Level Panel of Experts on Food Security and Nutrition
ICN2	Second International Conference on Nutrition
INRA	Institut National de Recherche Agronomique
NCD	non-communicable disease
oriGIn	Organization for an International Geographical Indications Network
PDO	protected designation of origin
PGI	protected geographical indication
PUFA	polyunsaturated fatty acids
RNA	ribonucleic acid
SFA	saturated fatty acids
TRIPS	(Agreement on) Trade-Related Aspects of Intellectual Property Rights
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America
USDA	United States Department of Agriculture
WHO	World Health Organization
WIPO	World Intellectual Property Organization



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1

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Introduction: geographical indications around the world

1.1. GENERAL BACKGROUND ON GEOGRAPHICAL INDICATIONS

Certain products have a long history of production and are deeply linked to the culture, history and environment of their place of origin. Most of these products are food products, but other types of products, such as for example leather handicrafts, may also have strong links to their origin. All these products possess characteristic qualities that result from the interaction between the local population and the local environment; thus, they have become inseparable from the many elements that uniquely belong to the place of origin or terroir (see Box 1). The unique qualities of these products distinguish them from generic ones (i.e. products that are not strongly linked to or identified by their origins) and hold a special appeal for consumers; thus, the qualities add value to the products.

Box 1. The notion of terroir

Terroir is a French word that originally means soil, territory or region. In the context of geographical indications (GIs), terroir is used to describe the geographical area linked to a product from a sociocultural angle. Its definition encompasses a wide range of meanings and has evolved over time. Some notable definitions are listed below; they all emphasize the interaction between humans and their environment, and this interaction's importance to the local specificity of the product.

Two French national research institutes, the Institut National de Recherche Agronomique (INRA) and the Institut National de l'Origine et de la Qualité (INAO), propose the following definition, which was validated by the participants of a conference organized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2005 ("Rencontres internationales planète terroirs"):

- A terroir is a delimited geographical area, defined on the basis of a human community that over the course of its history builds a set of distinctive cultural features, knowledge and practices based on a system of interactions between the natural environment and human factors. The know-how involved reveals originality, confers typicity and enables recognition of the goods and services originating from this specific geographical area and thus of the people living within it. The terroirs are living and innovative spaces which are about more than tradition only. (Terroirs & Cultures and UNESCO, 2007, p. 26).

Vincent, Flutet and Nairaud (2008) provide the following definition:

- A terroir is a delimited geographical area in which a human community builds, over the course of history, a collective production knowledge based on a system of interactions between a physical and biological environment and a set of human factors, in which the activated sociotechnical pathways reveal an originality, confer a typicity and engender a reputation for a product originating from that geographical area.

A publication by the Food and Agriculture Organization of the United Nations (FAO) defines terroir as follows:

- The term terroir represents the capacity of this territory to confer, over time, specificity and typicity to the product. Natural resources are often linked to human intervention, as the physical environment is also shaped by human choices and adjustments made to adapt production methods to the environment on the basis of a cultural heritage and local know-how ... The terroir and its different components, the traditions and know-how, are the outcome of actions taken by many people from the territory over a long period. This means that the product is tied to a local community and has a heritage dimension (FAO, 2009, p. 12).

Source: references cited in the box and Organization for an International Geographical Indications Network (oriGIn), 2019a.

A number of measures have been developed to protect characteristic origin-linked products, and especially their trade names and trademarks, from unfair competition and counterfeiting. The earliest of such measures dates back to the fifteenth century, when the French Parliament issued a decree regulating Roquefort (a type of blue cheese made with sheep milk from Roquefort, France) (Folkeson, 2006). The modern-day practice of protecting products with GIs (considered collective intellectual proper rights) is built upon a series of international treaties on intellectual property rights, including the Paris Convention for the Protection of Industrial Property (1883), the Madrid Agreement on Indications for the Repression of False or Deceptive Indications of Source on Goods (1891), the Lisbon Agreement for the Protection of Appellations of Origin and their International Registration (1958) and the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) (1995).[1]

The World Intellectual Property Organization (WIPO) defines geographical indications (GIs) as follows:

> A geographical indication is a sign used on products that have a specific geographical origin and possess qualities or a reputation that are due to that origin. In order to function as a GI, a sign must identify a product as originating in a given place. In addition, the qualities, characteristics or reputation of the product should be essentially due to the place of origin. Since the qualities depend on the geographical place of production, there is a clear link between the product and its original place of production (WIPO, n.d.).

GIs are used by countries worldwide as a tool to protect products that have characteristics reflecting their places of origin. GI-protected products are typically agricultural products, foodstuffs, wine and spirits, handicrafts or industrial products. GI protection touches upon aspects relating to legal frameworks, economics and markets, culture, the environment, etc. A large body of literature studies the potential socio-economic and other benefits of GIs (see Box 2).

It should be emphasized that whether and to what extent these potential advantages are achieved depends largely on the social, political and economic (market) context. For some of the effects, current empirical evidence is either scarce or conflicting. Therefore, these linkages should not be taken for granted, but rather treated cautiously and analyzed on a case-by-case basis.

[1] The details of these treaties can be found at www.wipo.int/geo_indications/en/

Box 2. Potential benefits of the use of geographical indications

Socio-economic benefits

Indication of quality to improve consumer welfare and support the interests of producers

Geographical indications (GIs) not only signal to consumers that a product has special characteristics that are linked to its geographical origin; they also indicate reputation, quality or other characteristics. Unlike trademarks, GIs signal the collective reputation of the group that participates in the production of the product. By protecting the collective intellectual property of producers, GIs discourage the usurpation and misappropriation of origin-based names. Products carrying a GI also comply with food safety and quality requirements, and thus offer more guarantees as regards these aspects to consumers.

Improved market access through differentiation and value creation

GIs allow producers to differentiate their origin-linked products in the market, giving them greater power in price negotiations. GIs confer to the products a mixture of origin-based economic, cultural and social values that cannot be found elsewhere. This allows GI products to command a price premium, as consumers are willing to pay more for them.

Rural development dynamics

GIs may affect rural development in two ways: through the remuneration of specific assets that are directly involved in the production process, and by bringing inclusive benefits to all actors within the territory. GIs may also stimulate entrepreneurial attitudes in producers, which may have a long-lasting transforming effect upon rural communities.

The collective dimension of origin-linked products may also strengthen social linkages between local actors by promoting equity amongst producers and bringing together a wide range of actors (e.g. public actors, stakeholders of the tourism industry, schools, etc.). GI processes often create local jobs, especially when the reputation of the GI product boosts local tourism.

Preservation of traditional knowledge

By valorizing products whose production processes draw on traditional knowledge, GIs reward producers that use such processes, and thus encourage the preservation of the associated traditional knowledge.

GIs offer some advantages over other approaches to preserve traditional knowledge. First, GIs protect intellectual property and are thus an effective means to protect traditional knowledge held by local communities. Second, GI protection involves the codification of traditional practices into rules that fall within the public domain; it thus prevents entities or individuals from gaining unique control over the knowledge. Third, the rights to a GI are usually held for an unlimited period of time, as long as the product-origin link is upheld and the indication does not become generic.

Food safety

The use of a GI label may require producers to adhere to food safety standards (e.g. relating to hygiene). In addition, GI labels may contribute to food safety by protecting origin-linked products from counterfeits.

Benefits in terms of gender equality

Some products are predominantly produced by women; promoting them may give social and economic recognition to women's work and provide an opportunity for women's involvement in the creation of added value on farms or in small-scale factories.

International treaties and legal frameworks for GIs currently do not include any provisions related to gender. As such, they fail to acknowledge the often crucial role played by women in the production of GI products. This gender-neutral approach may contribute to the exclusion of women from GI schemes, because they often do not possess the social, cultural or financial capacities required for participation (assistance in this respect is rarely provided). Smallholders (irrespectively of their gender) may face similar obstacles.

Since the 2000s, the role played by women in the preservation of biodiversity, agricultural production and traditional food processing processes has been increasingly recognized in publications by the European Union (EU) and FAO.[2] Both organizations have called for greater attention to the role played by women in legislative and regulative frameworks.

Preservation of biodiversity and natural resources

GIs protect origin-linked products, whose appealing characteristics are based on the use of specific natural resources in the local environment. Thus, producers of GI products have a strong motivation to preserve the environment and the resources it provides. GIs may also promote the preservation of biodiversity through a code of practice or product specifications that include biodiversity considerations.

Origin-linked products are the result of traditional production systems (e.g. extensive livestock farming) which often use techniques and inputs that have a lower environmental impact than those used in modern systems. On the other hand, the use of a GI may boost demand, which may lead producers to increase their output. Thus, it might be necessary to establish a production cap to ensure the sustainable use of local natural resources.

Source: Bramley, 2011; De Rosa, 2014; FAO, 2009; FAO, 2018a; Parasecoli, 2010.

[2] For example: • European Commission, 2019. • Fremont, 2001. • FAO, International Potato Center and Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEAMEO), 2002. • FAO, 2006.

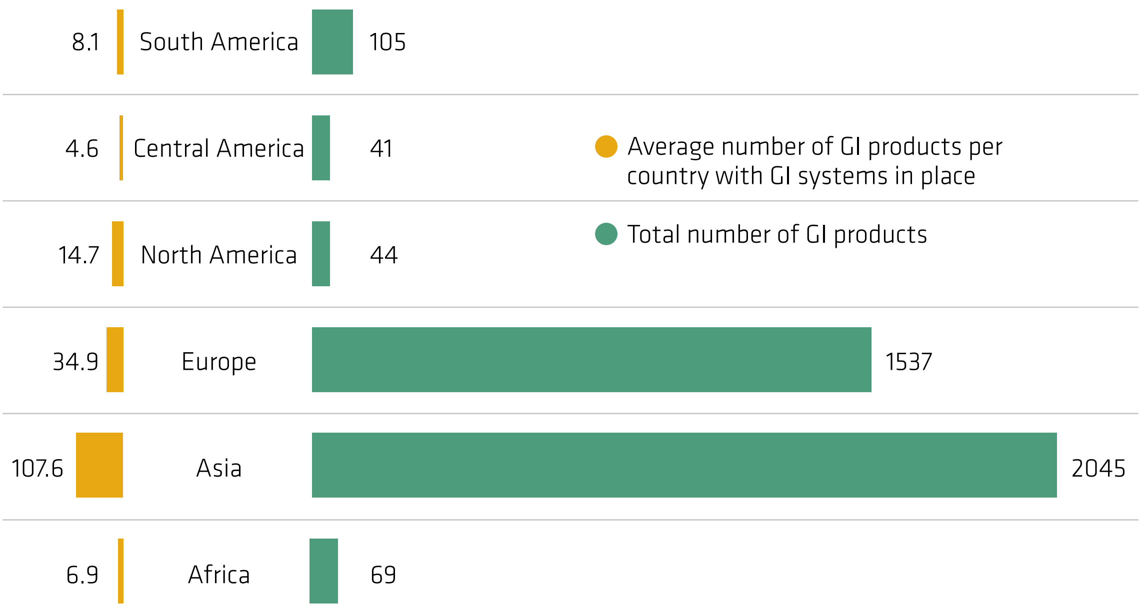
1.2. CHARACTERISTICS OF THE GLOBAL DISTRIBUTION OF GEOGRAPHICAL INDICATION FOODS

Founded in 2003, the Organization for an International Geographical Indications Network (oriGIn) is a global alliance of GI producer associations and related institutions. It maintains an extensive database of GI products that are registered and thus protected in one way or another worldwide.[3] For the scope of this paper, the database was filtered to exclude non-food products and spirits, wines and other alcoholic drinks.[4] The remaining products are labelled "GI foods" in this paper. The number of registered GIs varies widely between continents and between countries on the same continent, as shown in Figure 1 and Figure 2. While the approach to GIs varies from one country to the next, and the numbers might therefore hide differences in processes and standards, they nevertheless indicate how well the concept of GIs is developed and how important GI are in the respective countries.

[3] Available at www.origin-gi.com/i-gi-origin-worldwide-gi-compilation-uk.html (oriGIn, 2019b).

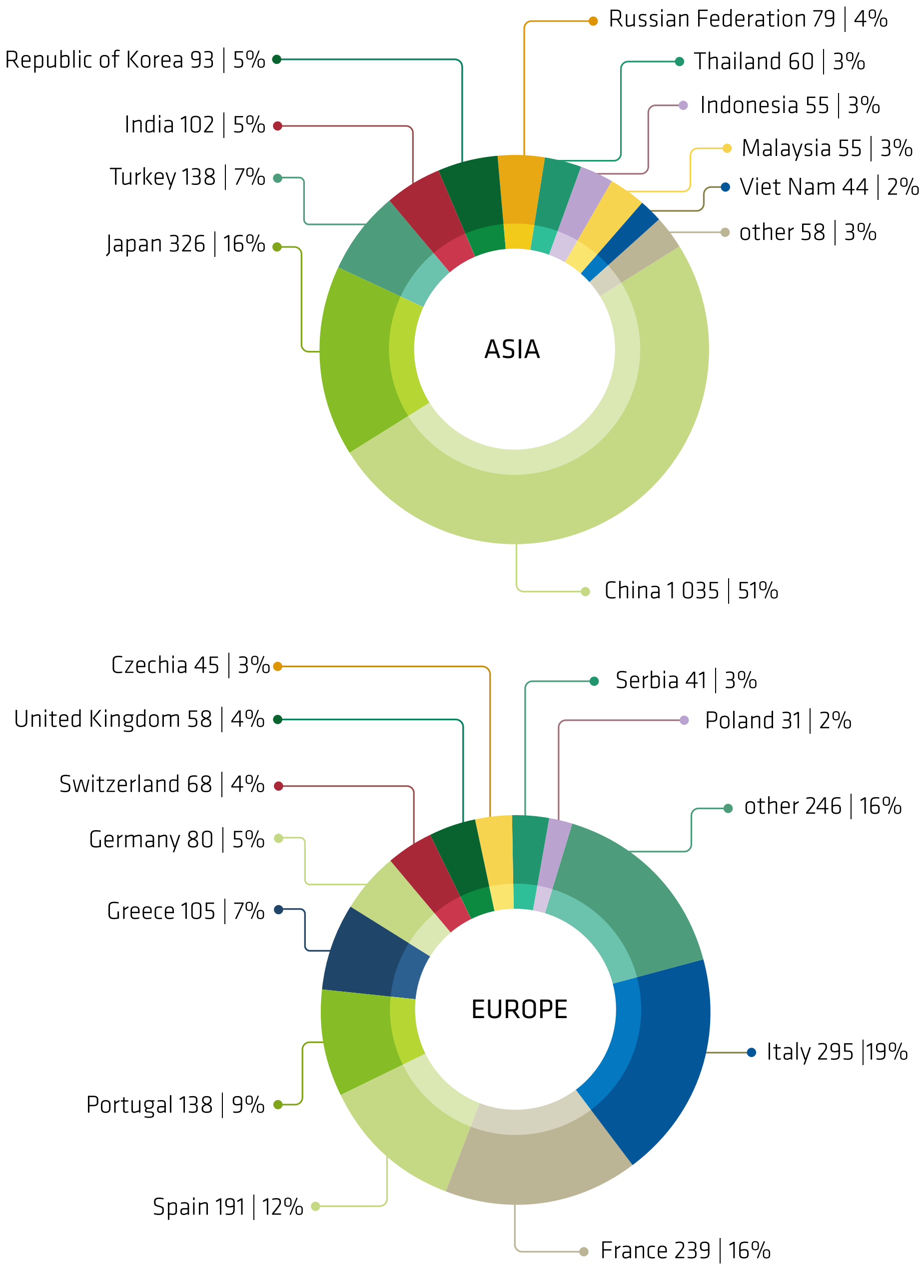
[4] Database last accessed in December 2018.

Figure 1. Total number of geographical indication foods per region, with average number per country (2018)



Notes: for transcontinental countries (e.g. the Russian Federation and Turkey), GI foods are counted in the continent where their origins are located. There is no product in Oceania that fits the selection criteria for GI foods used in this paper.
Source: oriGIn, 2019b.

Figure 2. Number of geographical indication registrations for food products in Asian and European countries (2018)



Notes: for Turkey, all products are counted as Asian; for the Russian Federation, all but three products are counted as Asian.
Source: oriGIn, 2019b.

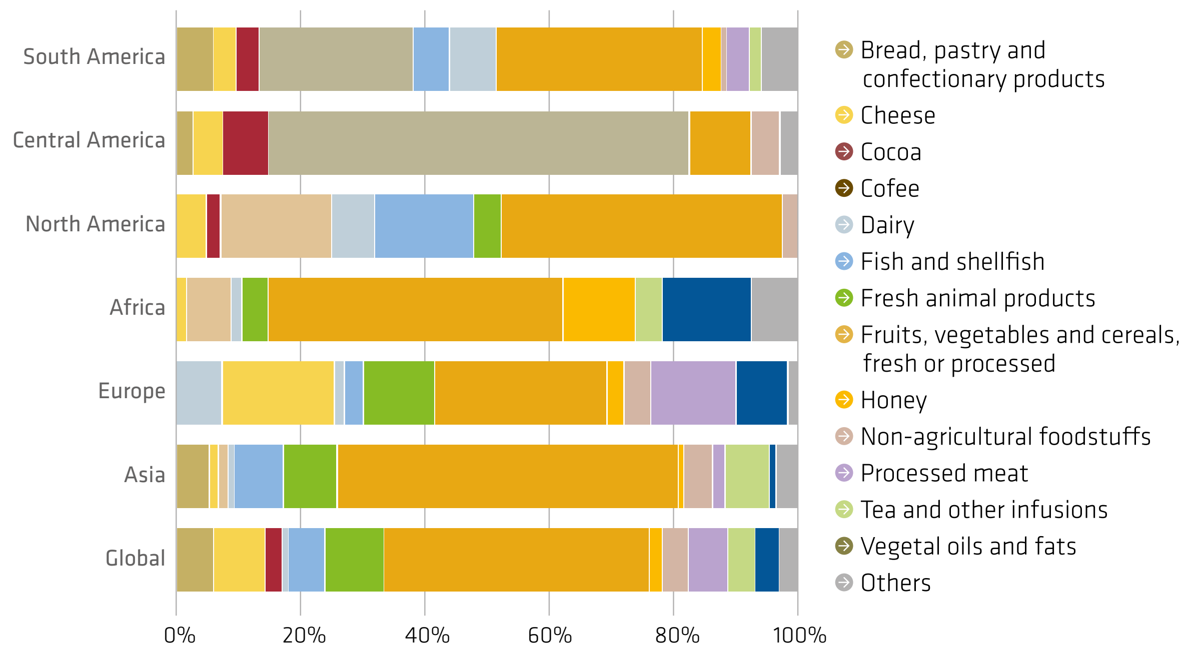
Figure 1 and Figure 2 show that most GI food products in the world are registered in Asia and Europe, which account for 53 and 40 percent of the global total of registered GIs (3 841), respectively. China alone accounts for more than half (51 percent) of total GI food products in Asia, followed by Japan (16 percent) and Turkey (7 percent) (all Turkish products are from the Asian part of the country). In Europe, three countries (Italy, France and Spain) jointly account for about 47 percent of total European GI food products.

The oriGIn database divides GI foods into several categories (types of foods). Figure 3 shows their distribution in different regions. At the global level, fruits, vegetables and cereals account for the largest portion of total GI food products; this is true in all regions except Central America, where most food products registered as GIs are coffee. Some noticeable differences exist between Europe and Asia, the two regions where GIs are most common. Fruits, vegetables and cereals account for the bulk of GI products in Asia; they are less dominant in Europe. Aquatic products (fish and shellfish) and tea also account for a higher share of the total in Asia than in Europe. Meanwhile, cheese, processed meat and vegetable oils account for a larger share of the total in Europe than in Asia.

These characteristics may be partly explained by the nature of GI foods. They have usually been produced in their place of origin for a long time. It can therefore be expected that the distribution of registered GI food categories would, to some extent, reflect the dietary habits and preferences of the local population. This is partly corroborated by the most recent (2010) dietary data published in the Global Dietary Database.[5] The per capita consumption of certain foods and the distribution of GI food categories relevant to these foods in the five countries with the most GI food registrations (China, Japan, Italy, France and Spain) are presented in Figure 4. Some interesting patterns can be observed.

[5] Available at https://www.globaldietarydatabase.org/our-data/data-visualizations/dietary-data-region (Tufts University, 2019).

Figure 3. Geographical indication food categories as a share of total geographical indication registrations, per region (2018)

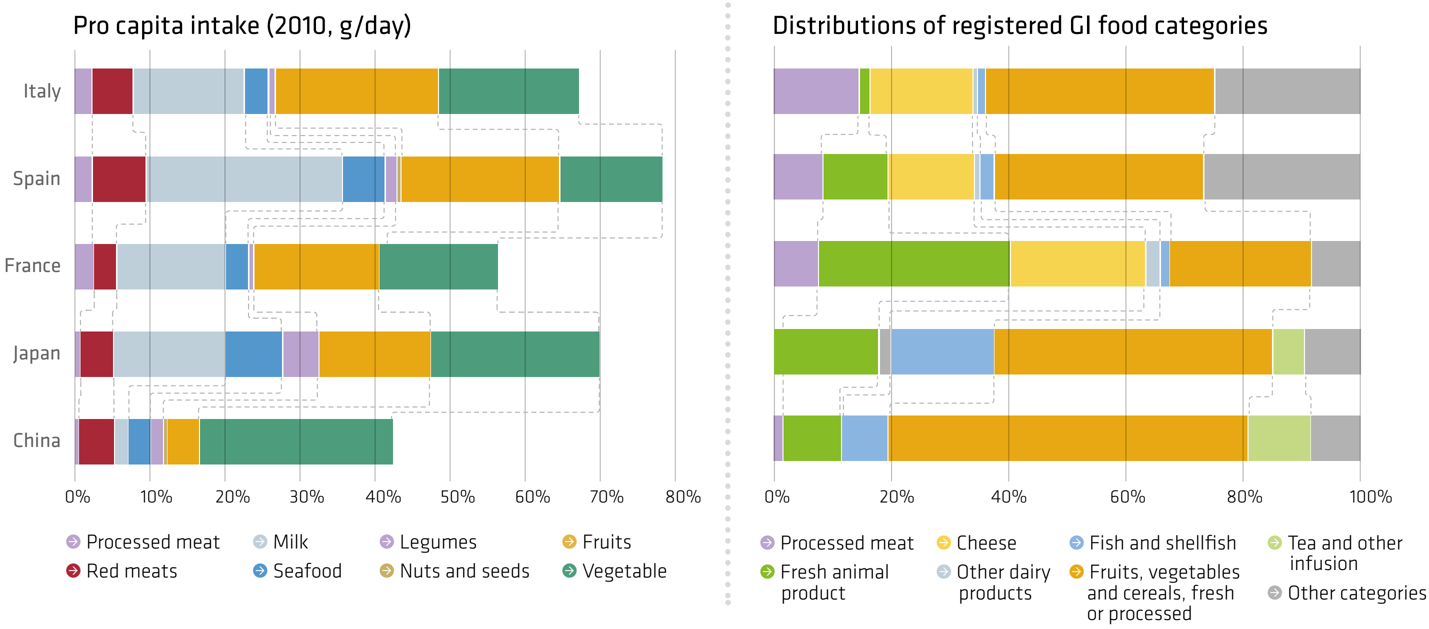


Source: oriGIn, 2019b.

For example, cheese is made from milk, so if milk is not traditionally produced in a place, GI cheeses are unlikely to be developed there. In most parts of China, there is no strong historical tradition of producing and consuming milk and dairy products, so there are no GI milk or cheese products and only one other GI dairy product (a type of milk skin) registered in China. The historical trend is also partly reflected in the low milk consumption in China (17.5 g/day per capita, compared to at least 144 g/day per capita in the other four countries). Although Japan's current milk consumption is similar to that of the three European countries, it does not have a comparably long production history, which may explain why there are no GI cheese products in Japan. Seafood consumption is highest in Japan, an island country (75.4 g/day per capita); accordingly, the percentage that fish and shellfish occupies in the total of GI foods is higher in Japan (18 percent) than in the other four countries. The Chinese and Japanese are big tea drinkers (0.57 kg and 0.97 kg annual per capita consumption in 2016, respectively), while Italians, French and Spaniards drink much less (0.14 kg, 0.20 kg and 0.15 kg annual per capita consumption in 2016, respectively) (Statista, 2020). This is reflected in the number of GI registrations for tea in the five countries: China and Japan both have a fair amount of GI tea products (113 and 17, respectively), while the other three countries have none.

GI registrations do not always reflect consumption patterns, however, for various reasons. First, the registration of a GI requires financial resources for research, promotion, awareness raising, capacity building, etc.

Figure 4. Consumption of certain foods and distribution of relevant registered geographical indication categories in five countries



Source: Tufts University, 2019 (left) and oriGIn, 2019b (right).

Hence, the primary factor driving the selection of food products for GI registration may not be dietary, but financial, especially in developing countries (donor support).

Second, some GI foods are made using special ingredients and processes and are consumed only on special occasions; such foods are not a historic part of local people's everyday diets. Furthermore, some GI foods target high-value markets (e.g. high-income urban consumers or export markets) and are (no longer) destined mainly for local consumption.

1.3. GEOGRAPHICAL INDICATION FOODS AND NUTRITION

Nutrition has been put high on the development agenda by a series of high-level events and initiatives, including the Second International Conference on Nutrition (ICN2) organized by FAO and the World Health Organization (WHO) in 2014, the Sustainable Development Goals adopted by the UN General Assembly in 2015, and the UN Decade of Action on Nutrition 2016–2025.

Today's world faces complex nutrition challenges. Most countries are burdened by multiple forms of malnutrition, including undernutrition, micronutrient deficiencies, overweight or obesity; these challenges may coexist within the same country, household or individual (Committee on World Food Security [CFS], 2016). A population's nutritional status is critically influenced by its diet. Indeed, there is unequivocal evidence that the global pandemic of malnutrition and non-communicable diseases (NCDs) is caused by poor diets (GBD 2017 Diet Collaborators, 2019). NCDs, such as cardiovascular diseases, cancers, chronic respiratory diseases and diabetes, are currently the leading cause of deaths worldwide (FAO, 2018b). Current diets in many parts of the world are high in unhealthy foods such as ultra-processed foods rich in sugar, salt and calories and low in nutritious foods such as nuts, fruits, vegetables and legumes (see Chapter 3.1). This trend is driven partly by rapid urbanization, increasing incomes, and the inadequate accessibility of nutritious foods (Willett *et al.*, 2019). In addition, food production for such diets are pushing the Earth's environmental systems beyond safe boundaries (Willett *et al.*, 2019).

Food systems play an important role in shaping people's diets. Global food systems have changed rapidly and tremendously due to a wide range of factors such as technological advances, market liberalization, urbanization and climate change (FAO and WHO, 2018). Modern food systems undoubtedly improve food security and nutrition in many parts of the world. However, they are also, to various degrees, characterized by a high presence of ultra-processed foods, high rates of food losses and waste, and a lack of affordable and diversified nutritious foods (e.g. fruits and vegetables, legumes, dairy products and fish). Traditional food systems and diets could offer an answer to this challenge and to other related, pressing issues such as environmental degradation and the abuse of agrochemicals and antibiotics.

The role of traditional foods, diets and food systems in people's nutritional status is mentioned in some important documents, such as ICN2's Framework for Action and the Rome Declaration on Nutrition (FAO and WHO, 2014a and 2014b). A 2017 report by the High Level Panel of Experts on Food Security and Nutrition (HLPE) provides a good overview of the challenges faced by current food systems to provide nutritious foods, with a number of chapters specifically discussing traditional food systems and diets (HLPE, 2017).

As the best products of traditional food systems, GI foods have a great potential to contribute to healthy diets and curb NCDs. As shown in Box 2, GIs are great tools to address the underlying determinants of malnutrition such as market access, rural development, income generation, women empowerment, etc. The production of GI products is also in line with the principles of nutrition-sensitive agriculture, such as diversity and sustainability (FAO, 2017). However, the nutritional value of GI foods themselves has not been discussed in detail in the literature on GIs. This paper aims to fill that gap.

The paper is structured as follows. Five case studies on the nutritional potential of registered GI foods are presented: Carnalentejana (Portuguese beef), furu (Chinese fermented tofu), Parmigiano Reggiano and Grana Padano (Italian fermented cheese), rooibos (South African herbal tea), and indigenous rice varieties from the Borneo highlands (Malaysia/Indonesia). These products are selected based on literature availability, nutritional values and geographical balance. They are all good examples of GI products, with a long local production history, a great reputation for quality and strong recognition among consumers. Their production processes are clearly defined and documented by local producers, and the nutritional composition of the final products is known. Various important aspects of these foods have been thoroughly researched: the physical and chemical changes that the raw materials undergo during their production processes, the health impacts of their nutrients, consumers' beliefs, attitudes and behaviours towards the products, and the surrounding policy frameworks. All of the selected foods play critical roles in nutrition. Beef, furu and cheese are high in protein, vitamins and minerals. Rooibos tea is known as a good source of food bioactives. Rice is the dominant staple food in Southeast Asia. The intake of fermented products (furu and cheese) may prevent NCDs because the microorganisms (such as *Actinomucor*, *Mucor* and *Rhizopus* fungi) and lactic acid bacteria (LAB) present in these products generate multiple bioactive compounds.

The cases are structured similarly. After a general introduction, the production process is explained, followed by a discussion of possible food safety risks. The pros and cons of the nutritional values of the food are then explored, with a focus on the link between the food's production process and its nutritional characteristics. Both ordinary nutrients and bioactive compounds that do not usually appear in nutrition facts tables are addressed. A number of foods similar to the case study subjects (but not necessarily GIs) are briefly introduced in the respective sections.

After the case studies, three topics are briefly discussed: the development of GI food specifications to ensure and improve nutritional values, the position of GI foods in healthy diets, and the determination of food composition. A next section discusses the limitations of the paper and presents suggestions for the future leveraging of GI foods for healthy diets. Many GI-protected traditional foods are fermented foods; hence, the Annex discusses probiotics, prebiotics and gut microbiota.

2

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Case studies: the nutritional value of GEOGRAPHICAL INDICATION foods

2.1. CASE 1: CARNALENTEJANA (PORTUGUESE BEEF)

General information

Alentejana is a characteristic cattle breed originating from the central-south and southern regions of Portugal, with a long history of improvement through selective breeding. The meat of Alentejana cattle, called Carnalentejana, was recognized as a Protected Designation of Origin (PDO, see Box 3) in the European Union in 1996 (European Commission, 1996b). Its distinctive production process, combined with the natural environment of the region of production, Alentejo, contributes to the unique nutritional profile of the beef.

Box 3. Protected Designations of Origin (PDO) and Protected Geographical Indications (PGI) in European Union regulations

Protected Designations of Origin (PDO) and Protected Geographical Indications (PGI) are two marks used by the European Union to identify origin-linked agricultural products and foodstuffs.

A designation of origin is a name identifying a product:

a. originating in a specific place, region or, in exceptional cases, a country;
b. whose quality or characteristics are essentially or exclusively due to a particular geographical environment with its inherent natural and human factors; and
c. the production steps of which all take place in the defined geographical area.

A geographical indication is a name which identifies a product:

a. originating in a specific place, region or country;
b. whose given quality, reputation or other characteristic is essentially attributable to its geographical origin; and
c. at least one of the production steps of which take place in the defined geographical area.

A PDO or PGI complies with a specification which includes at least:

a. the name to be protected as a designation of origin or geographical indication;
b. a description of the product, including the raw materials, if appropriate, as well as the principal physical, chemical, microbiological or organoleptic characteristics of the product;
c. the definition of the geographical area delimited;
d. evidence that the product originates in the defined geographical area;
e. a description of the method of obtaining the product and, where appropriate, the authentic and unvarying local methods as well as information concerning packaging;
f. details establishing the following: (i) the link between the quality or characteristics of the product and the geographical environment; or (ii) where appropriate, the link between a given quality, the reputation or other characteristic of the product and the geographical origin;
g. the name and address of the authorities;
h. any specific labelling rule for the product in question.

Source: European Parliament and Council of the European Union, 2012.

Production

Alentejana cattle are raised using a semi-extensive system, as required by the PDO specifications (Alfaia *et al.*, 2006b; Araújo *et al.*, 2014; Quaresma *et al.*, 2012). Only bullocks are used to produce meat; they are allowed to graze and roam freely on natural pastures under holm oak and cork oak. When insufficient, grazing is supplemented with cereals and dry forage (hay and straw). During the last three to five months before slaughter, the animals are fed with formulated concentrate feeds whose chemical composition includes specific amounts of protein, fat and fiber. The animals are around 20–21 months of age when slaughtered. The production process is depicted in Figure 5.

Nutritional characteristics

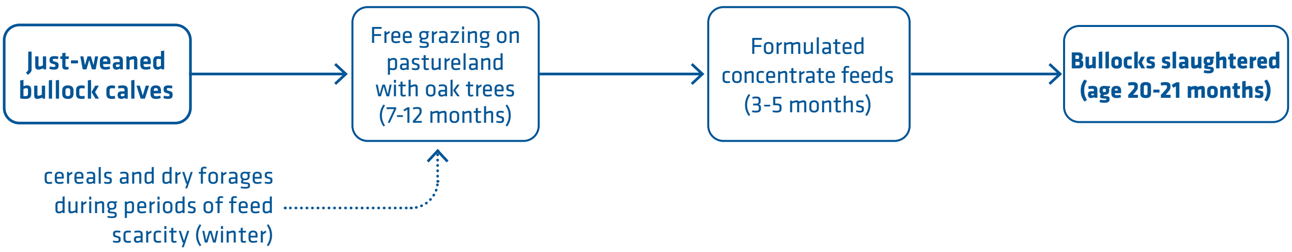
Unlike protein and amino acid contents, the fat and fatty acid (FA) content of beef can be influenced by the selection of the cattle breed and changes in the production process (Scollan *et al.*, 2006). Because of the adverse health effects of fats, current research on the nutritional quality of beef mostly focuses on the FA profile of intramuscular fat. Compared to crossbred cattle fed intensively with concentrate, which is how most beef in the Portuguese market is produced, Carnalentejana PDO meat is more nutritious, as evidenced by the following indicators (Alfaia *et al.*, 2006b):

1) It contains significantly higher levels of several unsaturated FAs such as palmitoleic acid, oleic acid and conjugated linoleic acids (CLAs). CLAs have been shown to protect against several non-communicable diseases (NCDs) such as cancer, obesity, diabetes and atherosclerosis in animal and in vitro studies (Yang *et al.*, 2015).

2) It has a lower *n*-6/*n*-3 polyunsaturated FA (PUFA) ratios than intensively fed beef. High levels of this ratio have been associated with depressive disorders, breast cancer, cardiovascular diseases and other NCDs (Goodstine *et al.*, 2003; Husted and Bouzinova, 2016; Patterson *et al.*, 2012; Wijendran and Hayes, 2004).

The advantageous qualities of Carnalentejana PDO meat seem to result from the combination of breeding practices, characteristics of the local environment and breed specificities.

Figure 5. The process of raising Alentejana cattle



Note: bold print indicates materials and the final product.
Source: Alfaia et al., 2006b; Araújo et al., 2014; Quaresma et al., 2012.

Several recent studies of various kinds of purebred and crossbred cattle raised in Europe, Australia and the Americas have observed multiple advantages of grass-fed beef over grain/concentrate-fed beef (Cujó, Brito and Montossi, 2016; Daley *et al.*, 2010; Fruet *et al.*, 2018; Moloney *et al.*, 2008; Scollan *et al.*, 2014), including:

- Grass-fed beef has higher CLA levels.
- Grass-fed beef contains higher concentrations of *n*-3 PUFA and lower concentrations of *n*-6 FA, consequently resulting in a lower *n*-6/*n*-3 PUFA ratio.
- Though the proportion of saturated FA (SFA) in total FA may be similar in grain/concentrate-fed and grass-fed beef, the latter shows a healthier SFA composition, meaning that it has a higher proportion of cholesterol-neutral stearic acid and less cholesterol-elevating SFAs such as myristic and palmitic acid (Yu *et al.*, 1995).
- The contents of vitamin A and E precursors (carotenoids and α-tocopherol) and other non-nutrient bioactives (flavonoids and glutathione) are higher in grass-fed beef.

It should be noted that Alentejana cattle graze under oak trees, so acorns, which like other tree nuts are rich in unsaturated FA, are probably a substantial part of the cattle's diet. While there is no report that directly analyzes the impact of feeding acorns to cattle on the FA profile of the beef, such studies have been conducted on pigs – especially Iberian pigs (from which several types of GI Iberian ham are made), whose habitat is similar to that of Alentejana cattle (Rey *et al.*, 2006; Tejerina *et al.*, 2011, 2012). These reports demonstrate that for Iberian pigs fattened extensively on pastures covered by holm oak, the FA profiles of the pork are closely impacted by the FA composition of feeds. Pigs that consume more grass and acorns in their fattening period show higher levels of unsaturated FA in their muscle than pigs fattened on concentrate diets. Similar effects have been observed for Croatian and Italian pig breeds (Karolyi *et al.*, 2007; Pugliese *et al.*, 2009). Although the FA synthesis mechanisms of cattle and pigs are different, these findings shed some light on the possible relationship between the FA profile of feed and the resulting beef.

Alfaia *et al.* (2006) compared the FA profiles of Carnalentejana PDO meat from Alentejana cattle slaughtered in October 2002 and June 2003. They found no seasonal variations, although the former batch had access to more abundant grass on pastures than the latter. By contrast, Iberian pigs, which are fed exclusively on grass and acorns, displayed significant seasonal variations in FA profiles (Tejerina *et al.*, 2011, 2012). The steady quality of Carnalentejana PDO meat in terms of FA profile may be attributed to the practice of finishing the cattle on concentrate. Indeed, the cattle that had had more grass to eat had been finished on concentrate for a longer period than those that had had less grass (five months vs. three months). This suggests that the characteristics in beef FA profiles induced by grass feeding could be offset by concentrate feeding, as confirmed in a later report by the same group of authors (Alfaia *et al.*, 2009). In this study, purebred Alentejana cattle were put on different schemes of grass and concentrate feeding (pasture feeding only, pasture feeding followed by two or four months of finishing on concentrate diets, and concentrate feeding only). The comparison of the FA profiles of the four groups distinctly demonstrates the impact of concentrate feeding on the nutritional quality of beef. Indeed, the muscle of cattle fed with more concentrate contains less stearic FA in total SFA, less CLA, less *n*-3 PUFA and less total PUFA, and has a higher *n*-6/*n*-3 PUFA ratio. In fact, the FA profiles are so discriminative that the feeding scheme can be predicted based on the beef's FA profile using canonical discriminant analysis. In another study following a similar experiment design, α-tocopherol and β-carotene contents were discovered to be significantly higher in the muscle of cattle exposed to more pasture feeding (Quaresma *et al.*, 2012).

While grass feeding confers nutritional benefits, the semi-extensive breeding of Alentejana cattle has its own rationale. The slight decrease in nutritional quality caused by finishing the cattle on a concentrate diet should be considered acceptable, as Carnalentejana PDO meat still shows clear nutritional advantages over exclusively concentrate-fed beef. The practice of finishing the cattle on concentrate diets ensures the steady quality of the PDO beef all year round, which is demanded and expected by modern-day consumers. The superiority and stability in nutritional quality are attractive selling points which reinforces the producers' livelihoods. In addition, by adjusting the periods of free-range grazing and concentrate feeding, producers can adapt to annual fluctuations in the availability of grass while at the same time maintaining the beef's nutritional qualities. This potentially makes the semi-extensive production method of Carnalentejana PDO beef an effective climate change-resilient production method.

The low variability in nutritional quality may also be partly due to the characteristics of the Alentejana breed itself. Mertolenga cattle are raised according to breeding practices and in an environment that are very similar to those of Alentejana cattle (their meat, Carne Mertolenga, is also a PDO product). However, the beef of Mertolenga cattle raised in the same way and slaughtered at the same time as the Alentejana cattle in the study by Alfaia et al., showed more conspicuous seasonal changes for several important FA profile indicators, including total *n*-3 PUFA, *n*-6/*n*-3 PUFA ratio and total cholesterol (Alfaia *et al.*, 2006a). In addition, more FA and CLA isomers showed seasonal content changes in Carne Mertolenga beef than in Carnalentejana beef.

Summary

Nutritionally, Carnalentejana beef is distinguished by a healthy FA profile that is stable over the seasons and years. Feeding schemes and breed characteristics are the major determinants of meat quality, and research has shown that this holds true in this case. The pastureland covered by oak trees, the semi-extensive production process combining free-range grazing and concentrate feeding, and the characteristics of the Alentejana breed together bring forth the chemical characteristics of Carnalentejana beef. All these factors are unique to the Alentejo region, and GI protection has proved an effective tool to preserve them. It can be inferred that GI protection may help guarantee the nutritional quality of other GI meats, too.

2.2. CASE 2: FURU (CHINESE FERMENTED TOFU) AND OTHER FERMENTED SOYBEAN PRODUCTS

General information

The soybean (*Glycine max*) originates from China; this country has a very long history of using fermentation techniques to preserve soybean products such as tofu (soybean curd) and give them attractive organoleptic qualities, perhaps of over 2 000 years (Han, Rombouts and Nout, 2001). One of the most popular fermented tofu products is furu (腐乳), also referred to as sufu. Products similar to furu are widely produced in other Asian countries such as Japan, the Republic of Korea, Viet Nam, the Philippines and Thailand, under various names (Han, Rombouts and Nout, 2001). This section focuses on fermented tofu produced in China, and hence uses the name furu.

There are currently seven furu products registered as GIs in China; these products are listed by the National Intellectual Property Administration of China.[6] Mouding oil furu from Yunnan Province and Wutongqiao furu from Sichuan Province are famed for their characteristic production procedures.

Production

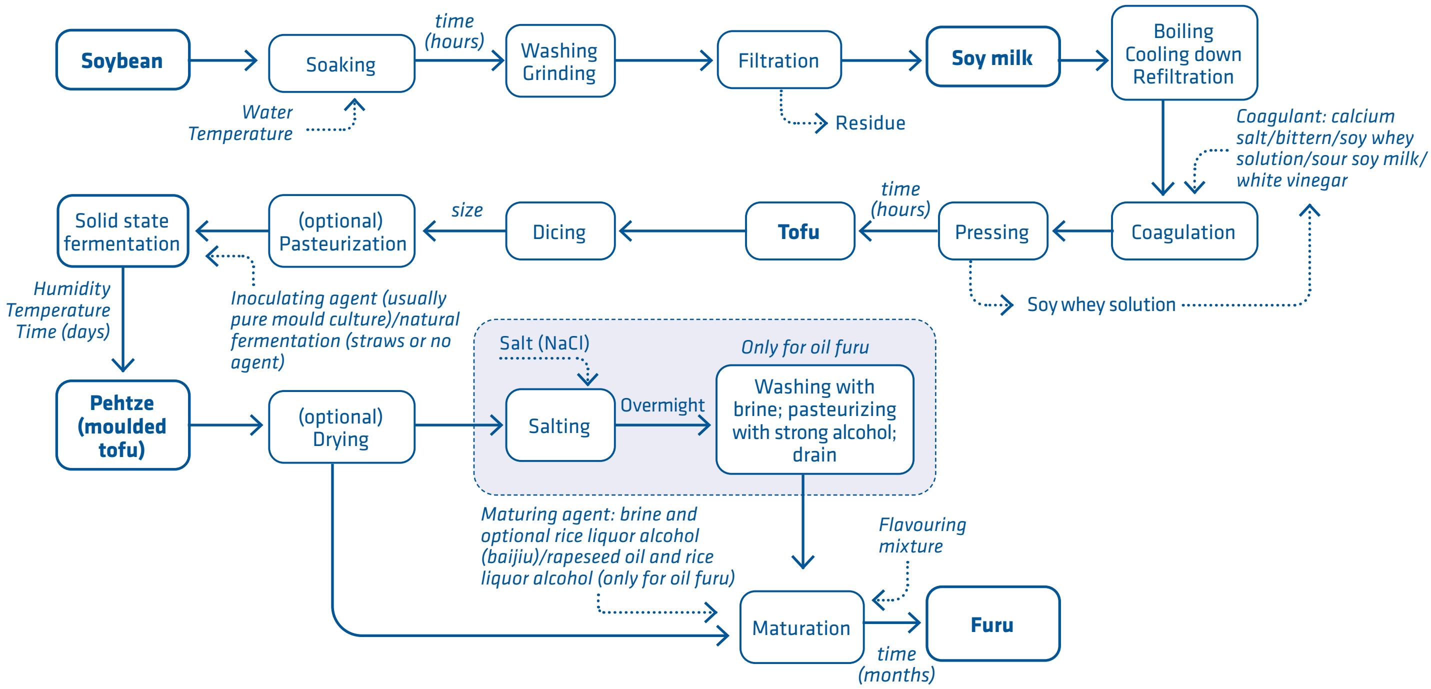
The process of producing furu is roughly similar across China, as summarized in Figure 6. There are three major stages. First, the substrate for fermentation, tofu, is made from soybeans. The tofu then undergoes natural or inoculated fermentation, resulting in pehtze (moulded tofu cubes), which is cleaned and washed. The final stage is to use brine and/or another liquid mixture to pickle and flavour the pehtze; only after this stage can the product be called furu.

The differences between the large-scale/commercialized production process on the one hand and the traditional one (which is required for most GI-protected furu) on the other mainly concern the duration of the production steps, the coagulant used, fermentation conditions (inoculating agent, temperature and humidity), the maturing agent used, and – especially for oil furu – the extra step of salting. In addition, the production materials used for registered GI products (soybeans, water, coagulant, maturing agent, etc.) must be sourced locally. The major differences between the producing processes for mass-market furu, Mouding oil furu and Wutongqiao furu are summarized in Table 1.

The key steps determining the nutritional quality and characteristic flavour of furu are fermentation and maturation; here, mass-market and GI products differ significantly. Mass-market furu products use commercially available agents for inoculation (microorganism cultures) and maturation (salt brine and ordinary rice liquor alcohol). In contrast, the registered GI products use spontaneous fermentation or local-specific microorganism cultures. The maturing agents used for GI furu are produced locally. The fermentation and maturing times of GI products are generally longer than those of mass-market products.

[6] The list can be accessed by searching for “腐乳” (furu) at dlbzsl.hizhuanli.cn:8888/Product/Search

Figure 6. The production process of furu



Note: bold print indicates materials and intermediate and final products; italic print indicates conditions that may be different for large-scale/ commercialized production and GI production.
Source: adapted from Han, Rombouts and Nout, 2001; Nout and Aidoo, 2002; Wei et al., 2018; Meishitai Foodvideo, 2018.

Table 1. Major differences in the producing processes of mass-market furu, Mouding oil furu and Wutongqiao furu

	Mass-market furu	Mouding oil furu	Wutongqiao furu
Production season	All year round.	Only winter and spring.	All year round.
Soybeans	Any soybeans.	Locally produced, non-GMO.	Locally produced, non-GMO.
Water to soak the beans	Clean fresh water.	Local well water.	Local well water.
Soaking temperature and time	25 °C, five to six hours.	Ambient temperature, overnight until beans are fully limp.	Winter: 5–10 °C, 18–22 hours. Spring/autumn: 10–15 °C, 15–20 hours. Summer: 18–25 °C, 13–15 hours. Beans should be fully limp after soaking.
Coagulant	Various; gypsum ($CaSO_4$) most commonly used.	Soy whey solution obtained from pressing	Bittern (sometimes called nigari, solute mostly $MgCl_2$).
Pressing time	Not specified.	10–11 hours.	Not specified.
Diced tofu size	Small (< 2 cm cube).	Large (~ 3 cm cube).	Large (~ 3 cm cube).
Inoculating agent	Various commercial pure mould or bacterium cultures; *Actinomucor*, *Mucor* and *Rhizopus* most commonly used.	Spontaneous fermentation (no inoculation).	Spontaneous fermentation (no inoculation) or *Mucor wutungkiao*.
Fermentation conditions	2–7 days, controlled temperature (12–25 °C) and humidity, adjusted according to the inoculating agent.	5 days, natural temperature (~15 °C) and humidity.	2 days, natural or controlled temperature (20–24 °C) and humidity.
Salting process	No.	Yes.	No.
Maturing agent	Brine (10–12% NaCl) + optional rice liquor alcohol.	Locally produced rapeseed oil + rice liquor alcohol, 1:1 (v/v).	Salt + locally produced rice liquor alcohol.
Maturing time	1–2 months.	3 months.	6–8 months.

Source: Nout and Aidoo, 2002; China, General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ), 2011, 2014.

Food safety and health concerns

One major advantage of furu over tofu is shelf life. Under ordinary room temperature and humidity, fresh tofu can only be stored for one to two days before it becomes sour. Packaging techniques and technologies (sterilization, vacuum packing, Tetra Pak, etc.) can prolong the shelf life of tofu, but usually not beyond two months. These methods are not used for furu products. The long shelf life of furu is mainly due to its maturing procedure, whereby furu is soaked in preserving liquid agents such as brine, alcohol or oil.

Except for the boiling of soy milk, there are no other pasteurization procedures in the production process of furu; there are no sanitary requirements for its production environment other than the general ones for food processing. Common foodborne pathogenic bacteria such as *Staphylococcus aureus*, *Salmonella*, *Escherichia coli*, *Bacillus cereus*, *Clostridium perfringens* and *Listeria monocytogenes* remain either undetected or well below the food safety limits in furu products (Han *et al.*, 2001; Wei *et al.*, 2018). There are two reasons for this absence. First, some pathogens cannot grow under high salt levels (e.g. *E. coli*). Second, being a microbiologically fermented product, furu has unharmful microflora that compete against pathogens and effectively inhibit their growth.

Nevertheless, food safety incidents involving furu contaminated by microorganisms still occur, such as an incident in 2016 in Sichuan whereby one person died and two other persons became gravely ill (Chengdu Economic Daily, 2016). Botulin in home-made furu was identified as the cause of the incident. Due to its anaerobic and spore-forming nature, *Clostridium botulinum* can resist the salty and nearly airtight environment of furu fermentation. *Bacillus cereus*, another highly resistant bacterium (facultatively anaerobic, spore-forming) is also often found as a contaminant of furu products.[7] The presence of these contaminants highlights the utmost necessity of complying with sanitary requirements when producing fermented foods, even if their microflora have antibacterial effects.

Current trends in the development of furu respond to the rising consumer demand for healthier, safer food. The major health concern for furu relates to its high salt level. Wei *et al.* (2018) studied the impact of salt content during fermentation on the quality of furu. It was found that microorganism proteolytic activity (the inoculating agent was *Mucor racemosus*) decreased slower under low-salt conditions than under high-salt conditions, leading to significantly higher levels of free amino acids and free fatty acids. Low-salt oil furu (2 000–4 000 mg sodium/100 g) was found to have a more consistent structure, better spreadability and higher sensory evaluation scores for some aspects. The study imitated the production process of Mouding oil furu, whose sodium content is about 6 000 mg/100 g. These results shed some light on the feasibility of developing a low-sodium version of the GI product.

[7] Some examples of investigations into *Bacillus cereus* contamination in furu in China can be found at:
www.fehd.gov.hk/sc_chi/news/details/20170118_0931.html,
www.cfs.gov.hk/sc_chi/multimedia/multimedia_pub/multimedia_pub_fsf_103_03.html,
www.cnki.com.cn/Article/CJFDTotal-ZNGZ201010006.htm, and http://cdmd.cnki.com.cn/Article/CDMD-10561-1014153886.htm.

Development of inoculating agents: single-strain vs. mixed-strain

Besides complying with sanitary requirements, another approach to ensure the food safety of furu is to intervene at the level of the inoculating agents. A common perception in the fermented food industry is that the inoculating agent should be a biologically pure single-strain culture, with as few interfering microorganisms as possible. Therefore, efforts to optimize the inoculating agents of furu have concentrated on identifying, separating and purifying the most effective fermenting microorganism, and finding the most favourable conditions for it to produce the desired qualities from tofu. Traditional spontaneous fermentation practices have been treated by the industry and academia as microbial repositories of potentially useful fermenters. One example is the discovery and popularization of *Mucor wutungkiao.* It was discovered in 1938 during research into the major active microorganism in the spontaneous fermentation process of Wutongqiao furu, and was named after the area.[8] It has since become one of the most commonly used fermenters in furu research and production in China. The registration as a GI product of Wutongqiao furu in 2012 ensures that the natural environment that contains this particular *Mucor* species is preserved. The fungus used for the commercial production of natto (a traditional Japanese food made from fermented soybeans), *Bacillus subtilis* var. natto (*B. subtilis* subsp. *natto* BEST195), has a similar history (Kubo *et al.*, 2011). The strain was isolated from dried rice straw used to inoculate soybeans and then distributed to major commercial manufacturers. The whole genome of this strain has been sequenced (Nishito *et al.*, 2010).

Holzapfel (2002) compares the pros and cons of single-strain and mixed-strain starter cultures. Using single-strain starter cultures offers control over food quality and safety but has its disadvantages, some of which are akin to those of monoculture cropping. Single-strain starter cultures have a low resilience to the environment, where microorganisms are omnipresent. If not kept well, the culture strain may be outgrown, directly attacked or genetically contaminated by ambient microorganisms, which affects its fermenting performance. Therefore, it is best to maintain the strain using aseptic techniques; however, this may not be feasible in many circumstances. In addition, preserving, transferring and using single-strain starter cultures requires a fair amount of knowledge and skills in microbiology, which may be a major hurdle for households and small-scale producers.

Mixed-strain starter cultures are less susceptible than single-strain cultures to competitors in the environment because of the synergies between the strains. They do not often require strict conditions for storage and application, as evidenced by their widespread and long-standing effective use by households and small-scale producers. In addition, using more strains enables producers to achieve special organoleptic characteristics (aroma, texture, flavour, etc.) that may increase the consumer appeal of final products.

[8] Wutungkiao was the romanized spelling of the name of the area in Sichuan Province where the furu originates at the time of discovery of the fungus, hence the name of the fungus. The current romanized spelling of the name is Wutongqiao, hence the term "Wutongqiao furu".

Box 4. GI as an approach to preserve the biodiversity of food-producing microorganisms

The examples of *Mucor wutungkiao* and *Bacillus subtilis* var. *natto* align well with the principles laid out in a major FAO publication entitled *The state of the world's biodiversity for food and agriculture* (FAO, 2019). The genetic resources of microorganisms used for food processing and agro-industrial processes are included in the scope of biodiversity for food and agriculture (BFA). In their reports to FAO on biodiversity, many countries emphasize the role of fermented foods in diets and the importance of food-processing microorganisms. Priorities emphasized repeatedly in this area include strengthening research into traditional fermentation processes and establishing or improving the supply of starter cultures to small-scale producers (Achi, 2005 and 2005b; Holzapfel, 2002).

However, the publication recognizes that the current situation is not favourable to the implementation of these recommendations. Due to climate change and urbanization and the resulting shift in dietary preferences, traditional food processing practices and indigenous knowledge are on the decline worldwide. The preference of the food industry and academia for developing single-strain inoculations has caused a lack of attention to the potential of mixed cultures and their contribution to attributes of traditional products that are appreciated by and beneficial to consumers. Local producers of fermented products are often ignored or marginalized by legislators, government agencies and financial institutions. Legal frameworks related to intellectual property rights, food safety and claims about the health-promoting properties of particular products need to be strengthened.

GI protection is a solid answer to many of these challenges. Traditional food-producing practices, along with the invaluable microorganism biodiversity and indigenous knowledge they build on, can be preserved and protected through the use of GI systems. Regulations and legal frameworks that address issues related to nutrition, food safety, intellectual property and health claims can be built into or linked with the GI framework. GI registration helps local producers to obtain financial and policy support.

The relative weakness of mixed-strain starter cultures to reproduce may be addressed by controlling production conditions, for example by introducing good manufacturing practices (GMP) and hazard analysis and critical control points (HACCP) practices. Recent advances in high-throughput technologies have made the identification and quantification of strains in a mixed-strain culture easier and faster; such attempts have been made for inoculating agents for furu and other fermented foods (Han *et al.*, 2004; Johansen *et al.*, 2014; Liu, 2017; Liu *et al.*, 2015; Tamang, Watanabe and Holzapfel, 2016). The interaction between strains is another burgeoning research field that has benefitted greatly from technological advances, including high-throughput sequencing and genomics modelling (Frey-Klett *et al.*, 2011; Ivey, Massel and Phister, 2013; Sieuwerts *et al.*, 2008; Smid and Lacroix, 2013; Zhu, Zhang and Li, 2009). Mixed-strain starter cultures could be better stored, used and improved if the strains and their interactions were better understood. The quality and efficiency of fermented food production at all scales (household, small-scale and commercial) could be enhanced with such information.

It should be noted that there is no absolute link between the type of starter culture and the scale of production. There are many established mixed-strain starter cultures that are used in the commercial production of fermented foods, and it is not rare for GI/traditional foods to use single-strain starter cultures (e.g. *Mucor wutungkiao*). Single- and mixed-strain starter cultures have their own advantages and disadvantages, and one is not always better than the other. Choosing which type to use should be done based on the local situation and needs. GI systems preserve traditional practices which generally do not require a high level of technical capacity; they can thus serve as pools for the development of suitable starter cultures for producers at all scales, and particularly for households and small-scale producers.

Other fermented soybean foods

Fermented soybean foods are highly popular in many countries, particularly in some parts of Asia and Africa. Table 2 lists some of these products, together with the major microorganisms used in their fermentation process. The production steps of these products are relatively similar, but their different substrates, microorganisms and environmental conditions endow them with local uniqueness. Apart from the major microorganisms indicated in the table, some others may be present in the final products, especially in those that undergo spontaneous fermentation. For example, several *Bacillus species* including *B. pumilus*, *B. licheniformis*, *B. cereus* and *B. firmusa* and low numbers of lactic acid bacteria and yeasts coexist with the dominant *B. subtilis* (~50 percent of all *Bacillus* species) in the microflora of soybean dawadawa (Dakwa *et al.*, 2005). The effects (both positive and negative) of these microorganisms on the quality, safety and nutritional value of the final products merit further investigation. GI protection has proved an effective way to preserve these products, and thus to allow their study.

Nutrients and other beneficial chemicals

Tofu is well known as a good source of protein, vitamins and minerals (Messina, 2016). As leading health and nutrition experts call for a global shift to plant-based diets to improve the sustainability of food production and counter the NCD pandemic (Willett *et al.*, 2019), the dietary role of tofu is receiving more attention.

Table 2. Fermented soybean products in Asia and Africa

Country	Product name	Form	Major microorganism(s) involved
Thailand	Thua nao	Fermented soybeans	*Bacillus subtilis*
India	Hawaijar	Fermented soybeans	*Bacillus* spp.
Japan	Natto	Fermented soybeans	*Bacillus subtilis* var. *natto*
The Republic of Korea	Cheonggukjang/ chongkukjang	Fermented soybeans	*Bacillus subtilis*
Nepal, India	Kinema	Fermented soybeans	*Bacillus subtilis*
Indonesia	Tempeh	Fermented soybeans	*Rhizopus*
China	Douchi	Fermented soybeans	*Aspergillus oryzae*
Nigeria, Ghana	Daddawa/dawadawa	Fermented soybeans	*Bacillus subtilis*
China	Furu	Fermented tofu	*Actinomucor, Mucor, Rhizopus*
Japan	Miso	Seasoning	*Asperigillus oryzae*
East and South East Asia	Soy sauce	Liquid condiment	*Asperigillus oryzae*

Sources: Anal, 2019; Chen et al., 2012; Dakwa et al., 2005; Omafuvbe, Shonukan and Abiose, 2000; O'Toole, 2016; Parkouda et al., 2009; Sarkar et al., 1994.

Through fermentation and other procedures, the nutritional composition of tofu is altered, and the contents of some nutrients are boosted. Table 3 shows the nutrient contents of tofu and furu.

In the China Food Composition tables, furu is categorized as a condiment, while tofu is categorized under legume products (China, Institute of Nutrition and Food Safety, China Centre for Disease Control and Prevention,

Table 3. The nutritional composition of tofu and furu

Nutrient	Content per 100 g food			
	Tofu, semisoft ("northern style")[1]	Furu, Shibaozhai brand (GI)[1]	Furu, Wangzhihe brand (non-GI)[1]	Furu[2]
PROXIMATES				
Water (g)	78.6	67.4	69.2	70.01
Energy (kJ)	462	479	642	484
Protein (g)	9.2	9.5	12.3	8.92
Total lipid (fat) (g)	8.1	7.7	11.6	8
Carbohydrate (g)	3.0	2.7	0.6	4.38
Dietary fibre	2.8	0.9	0.6	
MINERALS				
Calcium (mg)	105	222	100	46
Iron (mg)	1.5	5.9	5.1	1.98
Magnesium (mg)	63	20	–	52
Phosphorus (mg)	112	202	–	73
Potassium (mg)	106	146	–	75
Sodium (mg)	7.3	5 008.2	2 080.0	2 873
Zinc (mg)	0.74	4.78	–	1.56
VITAMINS				
Vitamin C (mg)	Trace	–	0	0.2
Thiamin (mg)	0.05	0.03	–	0.157
Riboflavin (mg)	0.02	0.08	–	0.101
Niacin (mg)	0.11	Trace	–	0.379
Vitamin B6 (mg)	0.03	–	–	0.091
Folate (µg)	39.8	12.2	–	29
Vitamin B12 (µg)	–	1.98	–	0
Vitamin A (µgRE)	–	18	–	0
Vitamin D (IU)	–	–	–	0
LIPIDS				
Fatty acids, total saturated (g)	3.8	2.6		1.157
Fatty acids, total monounsaturated (g)	2.9	2.7		1.767
Fatty acids, total polyunsaturated (g)	0.6	1.9		4.516
Fatty acids, total trans (g)	–	–		0
Cholesterol (mg)	–	–		0

Notes: –: not tested; blank: no data.
Source: [1] China, Institute of Nutrition and Food Safety, China Centre for Disease Control and Prevention, 2005. [2] United States of America, US Department of Agriculture, Agricultural Research Service, 2019a. Furu here is "tofu, salted and fermented (fuyu)."

2005). The reason is obvious: the long time (several months) of maturation in brine makes furu highly salty. GI furu products usually have a longer maturing time, and their sodium levels are thus noticeably higher than those of non-GI products. This is confirmed by information from the nutrition facts labels printed on the packages of several GI furu products. For example, Mouding furu, Guilin furu and Wutongqiao furu contain 6 000 mg, 3 000 mg and > 4 000 mg sodium per 100 g of product, respectively, according to their nutrition labels. In contrast, the sodium contents of non-GI furu are generally around 2 000 mg/100 g.

Meanwhile, the levels of certain nutrients, and especially minerals, increase during the furu production process. Iron, phosphorus and zinc are apparent examples. The level of calcium is particularly high in Shibaozhai furu, a benefit which non-GI products do not have. The contents of energy, macronutrients and vitamins in tofu and furu are roughly similar. Furu might therefore be considered a good plant-based protein source, like tofu. It should be emphasized that in order to fully reap furu's many nutritional benefits, the product's sodium contents must be considered when determining an appropriate intake. Note that furu can be used as a substitute for salt in cooking.

An interesting observation is that Shibaozhai furu (inoculated using *Mucor mucedo*) contains high levels of vitamin B12 (1.98 µg/100 g, comparable to some animal-based foods) – a nutrient that is not detected in non-GI products. Soybeans and tofu are very low in vitamin B12, so its existence in furu can only be attributed to the fermentation process; research suggests that bacteria, not funghi, may be the key contributing factor. Bao *et al.* (2019) found that the vitamin B12 content in the final furu product increased about fourfold after the introduction of *Lactobacillus reuteri* into the inoculating agent. The study also demonstrated that fungi (mainly Mucor in this case) in the inoculating agent negatively affect vitamin B12 levels. Similar evidence was found for tempeh (or tempe), a fermented soybean-based food originating from Indonesia. Tempeh also contains high levels of vitamin B12 (Nout and Rombouts, 1990), and *Citrobacter freundii* and *Klebsiella pneumoniae* have been identified as the major microorganisms contributing to vitamin B12 formation during its fermentation process (Denter and Bisping, 1994; Keuth and Bisping, 1994, 1993). All this information indicates that the high content of vitamin B12 in Shibaozhai furu could be caused by bacteria in the local production environment or inoculating agent. Further research is needed to gather more evidence on the mechanism of vitamin B12 formation during the fermentation process in furu production.

The fermentation of tofu yields a variety of compounds that do not usually appear in food composition tables. Some of them contribute to nutrition and health, and some are the chemical basis of many favourable organoleptic properties.

It has been suggested that a high intake of soybean foods is associated with many health benefits, such as reduced risks of hormone-dependent cancers (e.g. endometrial, breast and prostate cancers), the alleviation of menopausal symptoms (especially osteoporosis) and the prevention of cardiovascular diseases (Larkin, Price and Astheimer, 2008; McCue and Shetty, 2004). Many studies have been undertaken to build evidence for these links, e.g. dietary intervention studies and clinical trials using dietary soy or soy protein and isoflavone supplementation. However, the results of these studies vary greatly, and the reproducibility between studies is limited (Larkin, Price and Astheimer, 2008).

The mechanisms whereby the nutrients in soybean foods benefit health also remain unclear. Historically, these effects were attributed to the high contents of isoflavones of soy and their assumed antioxidant activities. However, recent studies have suggested that the mechanisms in vivo are more complex, possibly through various signalling pathways triggered by specific proteins (Spencer and Crozier, 2012).

In soybean foods, isoflavones exist in two forms: glycoside and aglycone (Wang and Murphy, 1994). The β-glycosidase of microorganisms during tofu and soybean fermentation can hydrolyse the glycosidic bonds, freeing aglycones from glycosides. This is supported by data showing that aglycone contents are higher in fermented soybean foods than in non-fermented foods, while the levels of glycosides are higher in the latter (Wang and Murphy, 1994). Isoflavone aglycones have been shown to have higher physiological activities than their glycosides in vitro and in mouse models (Naim *et al.*, 1976; Yuan *et al.*, 2003).

Fermentation conditions may influence the chemical composition of furu. High fermentation temperatures and long fermentation times result in high contents of aglycone and low contents of glucoside in furu, as demonstrated by Huang, Lu and Chou (2011). This study used furu fermented by *Asperigillus oryzae*; the highest temperature and longest fermentation time were 45 °C and 16 days. However, the optimal fermentation conditions are different for different fungus strains. In a study on furu fermented by *Actinomucor elegans*, products made at 26 °C contained richer aglycone than those made at 32 °C (Yin *et al.*, 2005).

Human studies into the health effects of isoflavones have achieved inconclusive results. A study using dietary supplements (isoflavone tablets) showed that isoflavone aglycones are absorbed faster and in higher amounts than their glycosides among Japanese women (Izumi *et al.*, 2000). Meanwhile, a study employing a single-bolus dose of isoflavone aglycones and glycosides in 19 healthy premenopausal American women came to the opposite conclusion: the bioavailability (determined by area under the plasma concentration-time graph curve) of the glycoside form is higher than the aglycone form, although the aglycone form reaches its concentration peak faster (Setchell *et al.*, 2001). Another study used soy drinks to administer aglycone and glycoside forms of isoflavones to six European postmenopausal women. The researchers concluded that previous hydrolysis of glycosides to aglycones does not enhance the bioavailability of isoflavones in humans (Richelle *et al.*, 2002). A similar study in which 16 healthy American women between 39 and 53 years of age participated reported that there is no difference in the apparent bioavailability of aglycone and glycoside forms of isoflavones in soybeans 48 hours after the consumption of aglycone and glucoside tablets (Zubik and Meydani, 2003). These conflicting reports demonstrate that a simple conclusion on whether glycoside or aglycone is superior cannot be drawn. Multiple complex factors such as ethnic background, dietary habits and consequential gut microflora and food matrix may play a role in the metabolism and bioavailability of isoflavones in humans (Larkin, Price and Astheimer, 2008; Zubik and Meydani, 2003). Carefully designed, high-quality research is required to understand these factors.

Another group of chemicals in fermented soy products that has been suggested to have positive health effects is short peptides, which are produced by microbial enzymes during fermentation either from hydrolysis of soy proteins or synthesis of free amino acids. These peptides have been found to have antihypertensive (through inhibition of angiotensin converting enzyme, ACE), antimicrobial, antidiabetic and anticancer effects in cell studies and animal models; however, evidence from human studies is lacking (Sanjukta and Rai, 2016). Ma *et al.* (2013) examined the effects of fermentation conditions on the ACE inhibitory activities of furu. In this study, furu was fermented using *Actinomucor elegans* under different NaCl concentrations and time lengths (one to eight weeks). Products ripened under low salt concentrations (5 percent and 8 percent) showed stronger ACE inhibitory activities than those made under high salt concentrations (11 percent and 14 percent). A longer fermentation time (> 5 weeks) increases such activity. In another study, extracts of furu containing mainly peptides smaller than 10 kDa showed strong ACE inhibitory activities; the strength of these effects differed among furu samples produced in Japan and China (Wang *et al.*, 2003).

The unique smell and taste of furu result from a variety of volatile chemicals including esters, alcohols, aldehydes, ketones, acids, alkenes, etc. Chemical profiles (varieties and contents) of furu fermented by different *Mucor* species have been analyzed and compared (Zhuang *et al.*, 2017). Besides apparent differences in chemical contents, clear sensory distinctions between the samples have been perceived by human evaluators. Changes in the chemical composition of furu during the course of fermentation have been explored; it has also been shown how pH affects protease activity (Liu *et al.*, 2018; Moy, Lu and Chou, 2012).

These results indicate that microorganism species and fermentation conditions play instrumental roles in producing the chemicals that have potent health impacts and underlie the attractive organoleptic properties of furu. More in-depth research is needed to optimize production procedures in order to maximize these desired characteristics.

Summary

During fermentation, a variety of chemicals with health and organoleptic benefits are produced in furu, while the nutrients of tofu remain largely stable. Some GI furu products offer advantages over mass-market products in terms of health benefits and organoleptic qualities because of their special production process and environment. In general, GI furu products use local materials (especially inoculating and maturing agents) and are fermented longer. It may be due to these reasons that GI products contain higher levels of minerals and vitamins and carry unique organoleptic properties.

The high salt content of furu, the unavoidable result of its production process and necessary for its flavour, makes it unpopular among health-conscious consumers. The development of low-salt varieties is therefore important.

Furu could also be used as a substitute for salt and spices in cooking.

The inoculating agents, together with fermentation conditions (temperature, time, humidity, etc.), crucially determine the levels of nutrients and other bioactive compounds in furu. Producers and researchers have been working to find good combinations of these factors to produce more nutritious products that are attractive to the senses. Traditional products, which have a proven quality record and are preferred by consumers, can be useful in this respect, as they serve as repositories for successful microorganism species and production practices. GI protection helps preserve the valuable production techniques and environment of traditional products, and thus contributes to nutrition and health.

The effects and functioning mechanisms of bioactive compounds in furu remain largely unclear and need further studying. Robust clinical evidence to support their beneficial impacts on health is particularly needed.

2.3 CASE 3: PARMIGIANO REGGIANO AND GRANA PADANO (ITALIAN CHEESE)

General information

Parmigiano Reggiano (PR) is a type of hard, granular cheese made exclusively in the provinces of Parma, Reggio Emilia, Bologna (only the area to the west of the river Reno), Modena and Mantua (only the area to the south of the river Po), Italy. Parmigiano Reggiano is registered as a PDO; its registration documents (European Commission, 1996c) require the production of milk and its transformation into cheese to take place in this area of about 10 000 km^2. The breed of cow that produces the milk is not prescribed. In the area, indigenous breeds such as White Modenese and Red Cow as well as introduced breeds such as Holstein are used. Both the milk and the cheese from indigenous breeds are sold at a higher price than those from introduced breeds (Sekine, 2019). The history of PR can be traced back to the thirteenth century; the producing techniques and procedure have remained largely unchanged since then. The Consorzio del Formaggio Parmigiano Reggiano (CFPR, Consortium of Parmigiano Reggiano Cheese) was founded in 1928, bringing together several trade unions in the region. It is responsible for the protection of the designation of origin, the promotion of trade and consumption, and the preservation of the typicality and unique features of the product. All producers of PR cheese have joined the consortium.

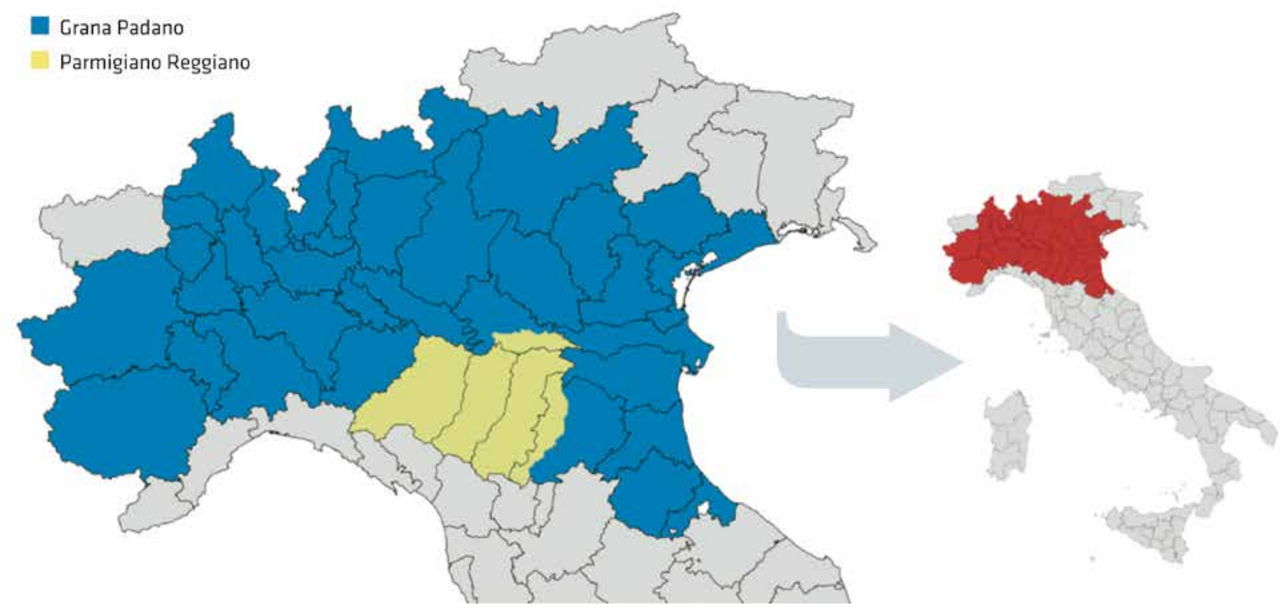
It should be noted that the use of the anglicized form of Parmigiano, parmesan, is regulated differently inside and outside of the European Union. The European Court of Justice ruled in 2008 that parmesan is not a generic term; hence, only authentic, PDO PR cheese can be sold under the name “Parmesan” in the European Union (Tran and Agencies, 2008). In many other parts of the world (e.g. the United States of America), the term parmesan can be used to denote any hard grating cheese that may or may not be produced according to procedures similar to those of PR. For clarity, this paper uses the word parmesan to denote generic Italian-style hard cheese in the context of the United States of America, and the PDO PR cheese is always referred to as Parmigiano Reggiano or PR.

Grana Padano (GP) is very similar to PR. The production procedures of both cheeses are apparently similar, and so is the appearance of the final products. However, there are a number of important differences (elaborated in the paragraphs on production and food safety below), mostly related to requirements concerning the feeding of the cows. As argued in Section 2.1 on Carnalentejana beef, feeding is a key element for the nutritional quality and organoleptic properties of the final product. Like PR, GP enjoys PDO status (European Commission, 1996a). Its designated production area is much bigger than that of PR, spanning northern Italy from the Cuneo and Turin provinces near France, all the way east to Venice by the Adriatic Sea (see Figure 7). The Consorzio per la Tutela del Grana Padano (CTGP, Grana Padano Protection Consortium), established in 1954, is responsible for preserving and promoting the GP heritage.

Production and food safety

No additives are allowed in the production of PR, so the quality of the cheese ultimately depends on the quality of the milk. The CFPR has established regulations regarding the feeding of the dairy cows; these regulations detail which types of feed are permitted and which are forbidden, and stipulate the maximum daily amounts of permitted feeds (CFPR, 2018). The feeding of the dairy cows is based on the use of local forage. At least 50 percent of the cows' daily intake of forage dry matter must be provided by hay. Dairy farms must produce forage that supplies at least 50 percent of the dry matter in the cows' diet.

Figure 7. Production regions of Grana Padano and Parmigiano Reggiano cheese, according to legislation of the European Union



Source: CFPR, n.d.a. and CTGP, n.d.a.

At least 75 percent of dry matter must be supplied by forage originating from the PDO area. Besides fresh grass from meadows, various grains and legumes are permitted, while silage, fermented forage, foraged treated with additives, fruits and vegetables, and animal products are forbidden. The administration of antibiotics to cows and the use of antioxidants in feed are not allowed, either.

GP is made from naturally skimmed milk. Feed regulations for cows producing milk for GP are largely similar to those for PR, but silage of chopped maize and silo hay is allowed (CTGP, *n.d.b*). This may be partly due to the difference in designated territories of PR and GP: while the PR territory mainly consists of mountains with pastures, the GP territory consists mostly of lowlands (e.g. the Po Valley). Silage is prone to contamination by soil bacteria (particularly *Clostridium tyrobutirricum*). To eliminate the risk that these bacteria are transmitted to the cheese, the use of natural lysozyme (extracted from egg white, which effectively inhibits Clostridia growth) is permitted in GP production, with a maximum limit of 25 g/1 000 litre milk. However, in Trentino it is not permitted to feed cows producing milk for GP with silage, so the use of lysozyme is not allowed, either.

Both PR and GP use unpasteurized milk. Producers rely on salination, the competitive growth of unharmful bacteria, and temperature and humidity control during maturation to prevent pathogen contamination. The final products are usually vacuum packaged and shipped through cold chains up to the point of retailing, thus minimizing the risks of cross-contamination. The strict regulations regarding the feeding of the cows also contribute to the safety of the raw materials. In addition, PR and GP producers have adopted a labelling system that can trace the production time and place of each wheel.

The production process of PR bears some similarities with furu in its major stages. As depicted in Figure 8, the process uses a self-inoculation method, whereby the whey obtained from cheese processing the day before is used as the starter culture. Natural rennet, extracted from the inner mucosa of the abomasum (the fourth stomach chamber) of unweaned calves, is the key agent to induce milk coagulation. The procedure is strictly enforced by the CFPR among its members. Together with the practice of inspecting every wheel before branding it with the PR seal, this guarantees the consistent high quality of PR cheese.

Two elements in the production process merit detailed explanation.

- After casein and whey are separated, the whey is collected and fermented to make whey for inoculation (sieroinnesto in Italian). The fermentation equipment and conditions vary between cheesemakers. The fermentation container can be made from glass or steel and be with or without insulation. The fermentation process can be conducted at a controlled (usually at 40–45 °C) or room temperature. The fermentation time may range between 18 and 24 hours.

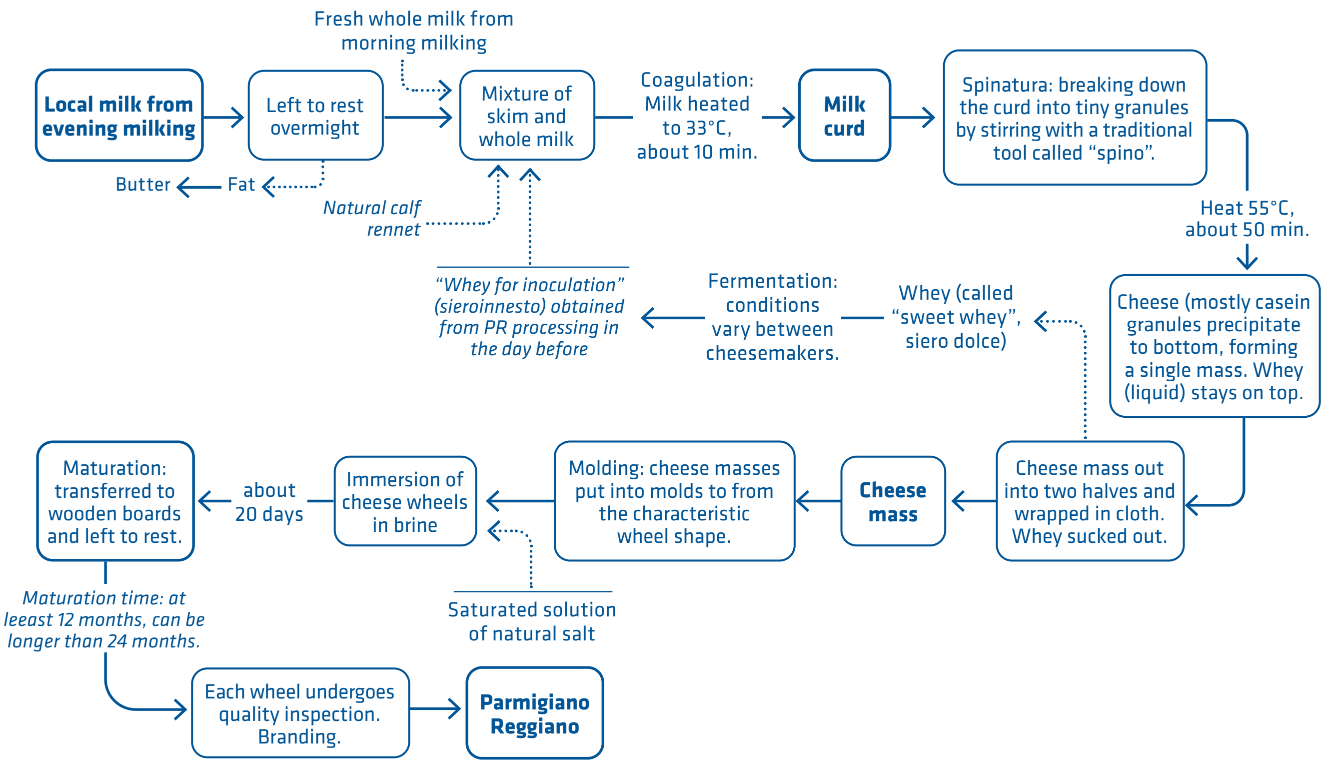
- The minimum maturation time for PR is 12 months. Maturation rooms are air-conditioned (15–20 °C) and humidity-controlled (80–85 percent). Each cheese wheel is turned over about once a week, which nowadays is usually done by robots, rather than manually.

The production process of GP is similar to that of PR, except that the temperature and duration of some of the steps in Figure 8 may be slightly different. Another difference is that the minimum maturation time for GP is nine months.

Meanwhile, regulations in the United States of America for non-GI parmesan and reggiano cheeses (United States of America, US Food and Drug Administration, 2019a, 2019b) are quite different, especially as far as the milk and additives used are concerned:

- Milk should be pasteurized or clarified, or both. This is in line with federal regulations for all cheeses, which require that any cheese must either be made from pasteurized milk or aged at least 60 days.
- Milk can be adjusted by skimming or adding cream, skimmed milk, concentrated skimmed

Figure 8. The production process of Parmigiano Reggiano cheese



Note: bold print indicates materials and intermediate and final products; italic print indicates key agents and conditions.
Source: based on material from CFPG, n.d.b.; CFPR, 2018; Vecchia, 2010.

milk, non-fat dry milk or water in a quantity sufficient to reconstitute any concentrated skimmed milk or non-fat dry milk used.

- Milk can be bleached using benzoyl peroxide or a mixture based on benzoyl peroxide.
- Some additives are allowed: food colouring, enzymes of animal or plant origin and antimycotic agents. In addition, if the final product is grated cheese, spices, flavourings and anticaking agents (most commonly cellulose) are allowed.
- The maturation time is at least 10 months.

As a result of these requirements, the nutrient contents of non–GI generic parmesan and reggiano cheese products in the United States of America vary markedly, as discussed in the paragraphs on nutrients below.

Nutrients

GI PR and GP cheeses are characterized by their long maturation period, which results in a low water content and the almost complete breaking down of lactose. The contents of common nutrients in PR, GP and generic American parmesan cheese are listed in Table 4.

A number of differences in nutrient contents between the three types of cheeses can be observed; these differences may be attributed to differences in the production processes, including the raw materials used. For example, GI PR and GP cheeses usually have a longer maturation period than their generic counterparts, allowing carbohydrates (mainly lactose) to be fully fermented. The differences in fat, mineral and vitamin contents may reflect differences in the milk used (e.g. it is possible that some generic parmesan cheesemakers in the United States of America use fortified milk). It should be noted that the numbers in the table are averages for a sample of products. The milk sources of GI PR and GP cheeses are strictly regulated by the respective consortiums, and the number of cheese producers is relatively limited. Meanwhile, there are no prescriptions as to what type of milk can be used to produce generic parmesan, and producers are given a certain degree of freedom to adjust milk contents and use additives.

Table 4. Nutritional composition of Parmigiano Reggiano, Grana Padano and American generic parmesan cheese

Nutrient	Content per 100 g food		
	Parmigiano Reggiano[1]	Grana Padano[2]	Cheese, parmesan, hard[3]
PROXIMATES			
Water (g)	31.4	32	30
Energy (kJ)	402	398	392
Protein (g)	32.4	33	35.75
Total lipid (fat) (g)	29.7	29	25
Carbohydrate (g)	0	0	3.22
Dietary fibre	0	0	0
MINERALS			
Calcium (mg)	1 155	1 165	1 184
Iron (mg)	0.2	0.14	0.82
Magnesium (mg)	43	63	44
Phosphorus (mg)	691	692	694
Potassium (mg)	100	120	92
Sodium (mg)	650	600	1 175
Zinc (mg)	4	11	2.75
VITAMINS			
Vitamin C (mg)	0		0
Thiamin (mg)	0.03	0.02	0.039
Riboflavin (mg)	0.35	0.36	0.332
Niacin (mg)	0.06	0.003	0.271
Vitamin B6 (mg)	0.06	0.12	0.091
Folate (µg)			7
Vitamin B12 (µg)	1.7	3.0	1.2
Vitamin A (µgRE)	430	224	207
Vitamin E (mg)	0.55	0.206	0.22
Vitamin D (IU)		20	19
Vitamin K (µg)	1.6		1.7
LIPIDS			
Fatty acids, total saturated (g)	19.6	18	14.85
Fatty acids, total monounsaturated (g)	9.3	7.4	7.515
Fatty acids, total polyunsaturated (g)	0.8	1.1	0.569
Cholesterol (mg)	83	98.3	68

Blank: no data.
Source: [1] CFPG, n.d.c. [2] CTGP, s.d.c. [3] United States of America, US Department of Agriculture, Agricultural Research Service, 2019b.

Table 5. Nutritional composition of generic parmesan cheese manufactured by six large retailers in the United States of America

Nutrient	Content per 100 g food						
	Food Lion	Safeway	Meijer	Target	BJ's	Whole Foods	Average ± SD
PROXIMATES							
Water (g)	400	429	393	400	500	400	420.33 ± 37.44
Energy (kJ)	40.00	39.29	35.71	40.00	20.00	40.00	35.83 ± 7.24
Protein (g)	30.00	28.57	25.00	30.00	30.00	30.00	28.93 ± 1.83
Total lipid (fat) (g)	20.00	3.57	0.00	0.00	20.00	20.00	10.60 ± 9.48
Carbohydrate (g)	0.0	0.0	0.0	0.0	0.0	0.0	0
Dietary fibre	0.00	0.00	0.00	0.00	0.00	0.00	0
Total sugars (g)	2.8	0.9	0.6				
MINERALS							
Calcium (mg)	800	1 268	893	800	800	2 000	1 093.50 ± 437.95
Iron (mg)	0.00	0.71	0.00	0.00	7.20	0.00	1.32 ± 2.64
Potassium (mg)		89					
Sodium (mg)	1 600	1 714	786	1 500	1 800	1 200	1 433.33 ± 346.15
VITAMINS							
Vitamin C (mg)	0.0			0.0	0.0	0.0	
Vitamin A (IU)	0			0	2 000	0	
LIPIDS							
Fatty acids, total saturated (g)	20.000	17.860	16.070	20.000	20.000	20.000	18.99 ± 1.52
Fatty acids, total trans (g)	0.000	0.000	0.000	0.000	0.000	0.000	0
Cholesterol (mg)	100	71	89	100	100	100	93.33 ± 10.77

Blank: no data.
Ingredients as shown in the database (United States of America, US Department of Agriculture, Agricultural Research Service, 2019b):
- *Food Lion: pasteurized part-skimmed milk, cheese culture, salt, enzymes, anticaking agents (potato starch, corn starch and calcium sulfate), natamycin (a natural mold inhibitor).*
- *Safeway: cultured pasteurized milk, salt, enzymes, anticaking agents (potato starch, powdered cellulose), natamycin (mold inhibitor).*
- *Meijer: pasteurized milk, cheese cultures, salt, enzymes.*
- *Target: pasteurized cultured cow's milk, salt, enzymes, anticaking agents (powdered cellulose and corn starch), potassium sorbate (added to protect flavour).*
- *BJ's: pasteurized cultured milk, salt, enzymes, anticaking agents (powdered cellulose and corn starch), potassium sorbate (to protect flavour).*
- *Whole Foods: cultured pasteurized part-skimmed milk, salt, powdered cellulose (to prevent caking), microbial enzymes.*

Table 5 shows the nutritional data for products named parmesan cheese manufactured by six large retailers (regional or national) in the United States of America, with their means and standard deviations. It can be observed that there are considerable differences in the contents of some nutrients between manufacturers. For example, the lowest protein content (20 g/100 g) is only half of the highest (40 g/100 g). Carbohydrate content ranges from 0 to 20 g/100 g, and calcium from 800 mg/100 g to 2 000 mg/100 g. There are some apparent differences in the ingredients used by the manufacturers, as shown in the notes to Table 5. The considerable variation in nutritional quality among generic parmesan cheese products may be partly attributed to the lax regulations on production procedures and ingredients (milk and additives).

There is no information on the degree of variation in the quality of PR and GP cheeses, but seasonal differences in some quality parameters of the milk used to produce PR have been documented (Summer *et al.*, 2007). Compared to milk obtained in autumn and winter, spring and summer milk has lower casein and fat contents and a higher somatic cell count. This difference may be due to the fact that the cows mainly feed on pastures in spring and summer, while in autumn and winter more concentrated fodder is given.

Fluctuations between years have also been observed (period studied from 2002 to 2005). However, these variations in nutrients are very small, at the level of 10^{-1} g/100 g to 10^{-2} g/100 g.

The nutritional value and potential biological functions of PR and GP have been recently reviewed by Summer *et al.* (2017). The following paragraphs are largely based on this paper.

PR and GP cheeses are dairy products; hence, the proteins in these cheeses contain high concentrations of all the essential amino acids. The long maturation process hydrolyses a considerable portion of milk proteins into peptones, peptides and free amino acids, which are easier to digest. Some short peptides contained in PR and GP cheese show beneficial bioactivities, such as improving gastrointestinal digestion, countering hypertension through ACE inhibition, boosting the immune system and mediating mineral transport (Summer *et al.*, 2017).

Like all foods containing animal fat, PR and GP cheeses have an abundant amount of CLA. In dairy fat, the dominant CLA isomers are *cis*-9, *trans*-11 CLA (rumenic acid) and *trans*-10, and *cis*-12 CLA. The biological functions of CLA were briefly mentioned in Section 2.1 on Carnalentejana meat. It has been argued that these two particular CLA isomers may have many beneficial bioactivities, including decelerating body fat accumulation, stimulating bone mineralization, regulating allergic responses, and inhibiting carcinogenesis, atherosclerosis, hypertension and diabetes (Summer *et al.*, 2017). It should be noted that the CLA content in cheeses seems to be strongly associated with the cows' feed, as evidenced by the fact that organic GP cheese contains significantly higher CLA levels than conventional GP cheese. This echoes the finding mentioned in Section 2.1 that the CLA level in grass-fed Alentejana cattle muscle is higher than that in concentrate-fed cattle. It is also consistent with the finding in Italy that certified organic milk and other dairy products contain significantly higher levels of CLA and fat-soluble vitamins than conventional ones (Bergamo *et al.*, 2003).

The beneficial bioactivities listed above are mostly evidenced by *in vitro* and animal studies. Human studies are few. One of them is a randomized, double-blind, placebo-controlled trial on the effect of the supplementation of GP cheese in 30 hypertensive patients (Crippa *et al.*, 2016). The results show that including 30 g/d GP cheese in diets results in a significant decrease in systolic and diastolic pressure.

The complete absence of lactose in PG and GP cheeses (contrary to generic parmesan, see carbohydrate in Table 4 and Table 5) makes them a good choice for lactose-intolerant consumers, allowing them to benefit from the rich nutrition of dairy products without the negative effects of lactose. Certain types of oligosaccharides, which may possess prebiotic properties, are present in PG and GP cheeses.

A large body of literature analyzes the legal, political and economic issues related to PR, GP and generic parmesan cheeses, both before and after the 2008 ruling by the European Court of Justice on the use of the name Parmesan. However, there does not seem to be any research that compares the nutritional quality of PR/GP cheese and generic parmesan cheese in a scientific manner. As far as organoleptic properties are concerned, one study compares the composition of headspace substance of New Zealand generic parmesan cheese on the one hand and GI PR and GP cheese on the other, using mass spectrometry (Langford *et al.*, 2012). The study reveals that the concentrations of some volatile compounds in the headspace are so significantly different that the types of cheeses can be discriminated based on these data only. Moreover, different processing plants in individual countries can be clearly differentiated by using multivariate analysis.

Microbiota and probiotic potential

Because of the fermentation process, microbiota in PG and GP cheese consist mostly of LABs. Many of these are believed to have potential probiotic functions. The state of the literature on the health impacts of pre- and probiotics will be explored in the Annex of this paper; the discussion in this section focuses on the research into the composition of the microbiota in the natural whey starter (sieroinnesto) and the final product. Because various kinds of fermentation processes may be used to produce generic parmesan cheese (single-strain, multi-strain e.g. cheese cultures, or natural fermentation), the composition of the microbiota in the final products is too complex for the scope of this paper. Nevertheless, the below paragraphs partially apply to generic parmesan cheese, too.

The microorganisms involved in the making of PG and GP cheese come from two sources: the starter and the raw milk. Environmental microorganisms have little impact, if any, because of the formation of a hard crust that wraps around the cheese mass and the periodic turning over and cleaning of the wheels during maturation. Of major interest among microorganisms are LAB, which are roughly divided into two groups: starter LAB (SLAB) and non-starter LAB (NSLAB). SLAB mainly include LAB in the starter, while NSLAB mainly come from raw milk; it is possible, however, that one contains species more commonly found in the other since both are essentially dairy bacteria.

At the beginning of the production process, the starter and raw milk are mixed together, thus putting SLAB and NSLAB into the same matrix. In subsequent steps, bacteria in the two groups undergo the impacts of heat, salt, acid and time. They thrive and function, altering the chemical composition of the cheese when environmental conditions are favourable, and undergo autolysis when conditions become unviable. How SLAB and NSLAB species fare through this complex and dynamic process has been the subject of intense research. This research has resulted in some recent breakthroughs due to the advance in culture-independent methods based on the direct analysis of deoxyribonucleic acid (DNA) or ribonucleic acid (RNA) (Neviani *et al.*, 2013).

It is now established that while the distinction between the two is not clear-cut, SLAB and NSLAB play a role at different stages of the production process and undergo different processes (Neviani *et al.*, 2013). SLAB grow during the first few hours to months after curd extraction; they largely autolyse after two to six months (Santarelli *et al.*, 2013) because the environmental conditions become increasingly adverse to them (increasing acidity due to lactose fermentation, high osmotic pressure brought about by brine and dairy contents, low temperature in the maturation room, etc.). Their intracellular enzymes and other bioactive compounds, most importantly aminopeptidases, are therefore released into the cheese matrix, continuing to affect the cheese's chemical composition and, consequently, sensory qualities. Meanwhile, the more resilient species of NSLAB gradually prevail after brining, when the competing SLAB start to decline; they play a central role during most of the maturation period.

Culture-dependent methods have determined that *Lactobacillus helveticus* is the main species in SLAB; *L. delbrueckii* ssp. lactis, *L. delbrueckii* ssp. *bulgaricus* and *L. rhamnosus* are also noticeably present (Coppola *et al.*, 2000). More detailed information is lacking. Culture-independent tools allow researchers to observe microbiota in situ, providing information that is more accurate for microbial populations in a real-world setting. These methods have helped to reveal that not all starters of PR are dominated by the aforementioned species (Bottari *et al.*, 2010). Species previously believed to have minor populations, such as *Streptococcus thermophilus*, are comparable in cell count with the lactobacilli in some PR cheese starter samples. In some samples where lactobacilli are dominant, *L. delbrueckii* is present at the same level as *L. helveticus*. There are still some samples where the dominant species cannot be fully identified. Bottari *et al.* (2010) highlights the microbial diversity of natural whey starters. In addition to LAB, *Kluyveromyces marxianus*, a kind of yeast, has been found in whey starter samples (Coloretti *et al.*, 2017). The major species in NSLAB are *L. rhamnosus*, *L. casei/paracasei* and *L. plantarum* (Gatti *et al.*, 2008; Santarelli *et al.*, 2013).

The rich microbial biodiversity of PR and GP cheese has attracted strong interest in the possibility of developing certain strains for probiotic products. NSLAB, due to their resilient nature, are favoured over SLAB. Solieri *et al.* (2014) assessed the potential of some NSLAB strains *in vitro* under antibiotics and biological stress to simulate the human physiological environment. Out of 47 strains (including *L. rhamnosus*, *L. paracasei*, *L. casei*, *L. harbinensis* and *L. fermentum*) tested, one *L. casei* and two *L. rhamnosus* strains had a good overall potential as new probiotic candidates. Similar studies have been conducted for traditional cheese products from Italy, Portugal, Croatia, Serbia, Greece, China and Egypt (Abosereh *et al.*, 2016; Caggia *et al.*, 2015; Casarotti *et al.*, 2017; Dias *et al.*, 2014; Papadopoulou *et al.*, 2018; Pisano *et al.*, 2014; Uroic *et al.*, 2014; Zhang *et al.*, 2016). Whether and how the strains identified by these studies may be transformed into mature probiotic products is interesting to follow up on.

After assessing the presence of potentially beneficial bacteria in PR and GP cheese, the next question is whether these bacteria can indeed be delivered to the human gut through the consumption of cheese, and to what extent they can fulfil their purported functions. A recent report makes a first step towards answering this question (Milani *et al.*, 2019). The study shows that several bacteria found in the bovine gut and in the cattle raising environment can enter the production process of PR cheese and remain in the final cheese. The authors track one particular bacterium (*Bifidobacterium mongoliense* BMONG18), which is found exclusively in the bovine gut, and show that it can be found in the final PR cheese product. Moreover, *B. mongoliense* BMONG18 can transiently colonize the gut of PR consumers.

Summary

Like most dairy products, PR and GP cheese is a good source of protein, fat, minerals (especially calcium), essential amino acids and certain vitamins. Their short peptide and CLA contents have been suggested to have a wide range of health benefits, including preventing and alleviating some NCDs, but clinical evidence remains weak. Their lack of lactose provides lactose-intolerant people with a worry-free option to consume dairy foods.

PR and GP cheese undergo a long period of fermentation and use only natural whey starters. The composition of the LAB microbiotas in the starter and milk and how they change over the production process has been studied in detail. Some strains in NSLAB are considered potential candidates for probiotics, although the quest to confirm their function and elucidate underlying mechanisms has just begun.

PR and GP cheeses may be the most researched fermented cheeses as far as processing procedure, nutritional composition and microbiota are concerned. In addition, their production process is governed by strict regulations. As a result, information on the production and nutritional characteristics of these cheeses is ample and readily available, enabling consumers and researchers to understand and value them. It is largely because of their long history and GI status that the unique production processes of these cheeses are meticulously documented and preserved. Their prestige encourages researchers to apply cutting-edge methods to reveal their deeper fabrics, which in turn contributes to their fame. This kind of virtuous circle may provide a valuable lesson for the development of other GI products.

The characteristics of PR/GP cheese and generic parmesan cheese differ greatly because of differences in the milk used (origin and quality), the use or not of additives and the production procedures. Because a wide range of raw materials can be used to produce generic parmesan cheese, the nutrient contents of generic parmesan products vary considerably between producers, which may confound consumers. The production of PR and GP cheese, on the other hand, is strictly regulated in these aspects. As a result, the quality of PR/GP products is relatively consistent between producers. There are seasonal fluctuations in the quality of the milk, but the degree of fluctuation is tiny.

There is scant scientific literature on how differences in raw materials and production procedures affect the chemical and organoleptic properties of GI PR/GP cheese and generic parmesan cheese. Filling this knowledge gap is critical to maintaining and improving the quality of these products.

2.4 CASE 4: ROOIBOS (SOUTH AFRICAN HERBAL TEA)

General information

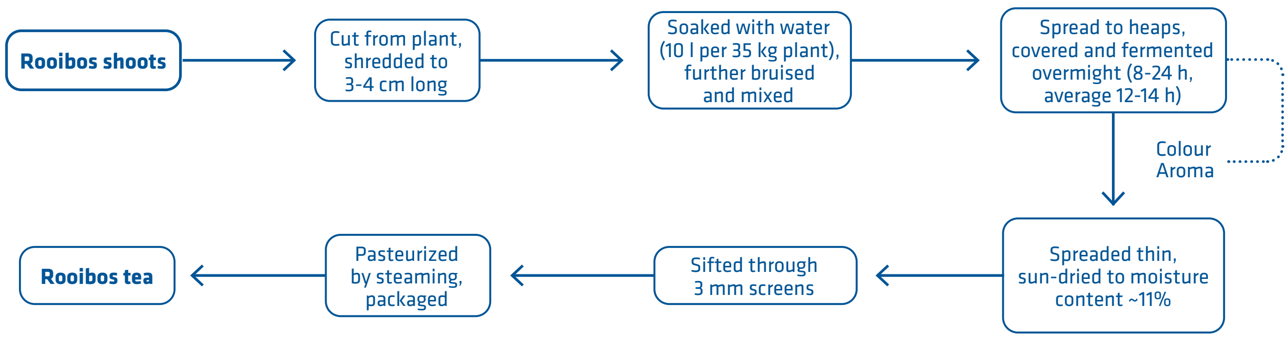
Rooibos (*Aspalathus linearis*, meaning red bush in Afrikaans) is a plant that only grows in a narrow belt stretching along the south-west edge of South Africa, in the Western Cape and Northern Cape provinces. The production area of rooibos is typified by its fynbos vegetation, an evergreen shrubland; it is characterized by its mountainous landscape and Mediterranean climate, with rainfall predominately occurring in winter. Both cultivated plants (called Nortier type after one of the pioneers in the commercial cultivation of rooibos, Pieter Lafras Nortier) and wild plants (called Cederberg type after the mountains where rooibos was originally sourced) are used for the commercial production of rooibos tea (Joubert and de Beer, 2011). The plant that yields common tea varieties (green, black, white, oolong, etc.) is fundamentally different from rooibos. Botanically speaking, rooibos is not a tea. Indeed, the tea plant (*Camellia sinensis*) is a shrub whose leaves are used to produce tea, while rooibos tea is made from the stems and leaves of the rooibos plant. However, since the term "rooibos tea" is widely used, this paper uses the term to indicate the infused drink made from rooibos. Rooibos is a member of the Fabaceae family, possessing some of the common features of legumes such as biological nitrogen fixation. Wild rooibos has been found to have a greater capacity to fix nitrogen in dry and hot weather than cultivated rooibos, indicating a higher level of environmental adaptability (Lötter *et al.*, 2014).

After a long legal battle in the United States of America that resulted in the releasing of the word rooibos from the exclusive control of an American company to the public domain in 2005, the South African rooibos industry realized the critical importance of protecting the name. Thus, the South African Rooibos Council (SARC) was formed. SARC is an independent organization, and rooibos producers join it on a voluntary basis. The organization is responsible for promoting rooibos worldwide and protecting the interests of the rooibos industry and consumers. Rooibos was granted GI protection after the setting up of a trademark-based GI system in South Africa in 2014, allowing products other than alcohols to be registered under collective marks or certification marks (World Intellectual Property Organization [WIPO], 2011). Since then, SARC has been developing and enforcing the quality criteria of rooibos and supporting research into the many aspects of rooibos. The history of rooibos and its unique links with its geographical area of production, that area's soil and climate characteristics, and the cultivation and production practices of rooibos have been documented in detail by SARC (see SARC, 2013).

Production

The common steps of producing rooibos tea are shown in Figure 9. These steps traditionally include a fermentation phase (which is actually an oxidative process, as microorganisms are not involved). Fermentation changes the colour of rooibos shoots from bright green to red-brown and generates the characteristic aroma; the final product is therefore sometimes termed "red rooibos". Although it is a key step that generates some of the most distinguishable features of rooibos tea, fermentation is conducted under natural conditions, with no control over humidity, temperature or the moisture content of the soaked shoots. The

Figure 9. Production process of fermented (red) rooibos tea



Note: bold print indicates materials and the final product.
Source: adapted from Joubert and de Beer (2011) and Morton (1983).

fermentation time is not very strict, either. This results in considerable variations in product quality. Studies have shown that controlled fermentation and drying can improve quality consistency, but the cost and technological requirements of their large-scale application hinder adoption by producers (Joubert and de Beer, 2011).

Unfermented rooibos tea (green rooibos) is also produced. Preventing fermentation is the most challenging part in the production procedure of green rooibos. Drying the crushed shoots rapidly and thoroughly can minimize the risk of oxidation. However, most producers dry their shoots in the sun, and hence cannot achieve this. Dryers and isolation techniques have not been widely adopted by industrial producers due to their high cost.

Nutrients and bioactive chemicals

As a tea drink, rooibos provides neither energy nor important nutrients. It does not contain protein, carbohydrate, fat or fibre and has a very low level of sodium (3.8 mg/100 millilitre of tea) (SARC, n.d.). As for minerals, rooibos tea is found to contain moderate levels of copper (Cu) and manganese (Mn) and low levels of calcium (Ca), iron (Fe), potassium (K), magnesium (Mg) and zinc (Zn) (McKay and Blumberg, 2007). Rooibos is free of caffeine and contains only a very low level of tannin, which may be its most distinguishable feature compared to tea drinks derived from *C. sinensis*.

Rooibos contains a complex composition of flavonoids. Nearly twenty flavonoid compounds and a number of their derivatives have been identified in rooibos, most notably orientin, catechin, isoquercetin, quercetin, vitexin, isovitexin, luteolin and rutin (Joubert and de Beer, 2011; Koeppen, Smit and Roux, 1962; Ligor *et al.*, 2008; McKay and Blumberg, 2007). Green rooibos has a higher content of flavonoids and total polyphenols than red rooibos, because red rooibos undergoes oxidation during which a series of enzymatic and chemical reactions modify and decompose the polyphenols (McKay and Blumberg, 2007).

Three dihydrochalcones, whose structures differ little, are particularly characteristic to rooibos. Aspalathin and aspalalinin are uniquely present in rooibos, while nothofagin exists in only two other plants in addition to rooibos (Joubert and de Beer, 2011). It has been determined that these compounds are also degraded during the oxidation process. Their uniqueness can be used to assess rooibos quality and identify genuine rooibos from counterfeits.

Seasonal and geographical variances in the chemical composition of rooibos, particularly in the phenolic compounds, have been examined. Rooibos teas vary significantly in their content of phenolic compounds depending on the year of production. The year of production cannot be determined based on the contents of individual compounds or subclasses (Joubert *et al.*, 2012 and 2016). However, it can be distinguished by considering entire profiles of phenolic compounds (Joubert *et al.*, 2016). Rooibos teas produced in different areas seem to differ significantly in their contents of dihydrochalcones, with products from the Western Cape exhibiting higher aspalathin and nothofagin concentrations than those from the Northern Cape (Joubert *et al.*, 2016). Variations in the contents of phenolic compounds between wild populations of rooibos can be used to identify several populations (Van Heerden *et al.*, 2003).

Plenty of research efforts have looked into the bioactivities (and especially antioxidative activities) of rooibos and their impact on health. This type of research often compares rooibos with tea derived from *C. sinensis*. Progress in these areas has been periodically reviewed (Ajuwon, Marnewick and Davids, 2015; Erickson, 2003; Joubert and de Beer, 2011; McKay and Blumberg, 2007).

The high contents of compounds like flavonoids in rooibos endow it with substantial antioxidative activity. Aspalathin, quercetin and catechin all exhibit strong antioxidative activities; their potencies are comparable across various assays. During fermentation, aspalathin is converted to orientin and isoorientin, which appear to be weaker free radical scavengers than aspalathin. This may explain the result that fermentation decreases the antioxidative activity of rooibos. Chemical assays have shown that rooibos has about half the antioxidative potency of green and black teas. However, in cellular studies, unfermented rooibos shows antioxidative capacity on a par with green tea; fermented rooibos displays a not so strong, but still very effective, protection against oxidation.

Many cellular, animal and human studies have found that rooibos extract and infusion have a wide range of health impacts (see particularly Table 5 in Joubert and de Beer, 2011, p. 879, for recent studies). They include chemoprevention, hepatoprotection, gastroprotection, osteoblast stimulation, and the inhibition of inflammation, allergies, mutagenicity, diabetes and hypertension, etc. All these reports suggest that rooibos has a role to play in NCD prevention. However, robust human evidence is still scarce, and the physiological mechanisms behind these results are not clear. As discussed in Section 2.2, mounting evidence suggests that similar health impacts of other foods could not be simply attributed to the antioxidant activities of flavonoids.

It has been argued that polyphenols in *C. sinensis* tea interfere with human iron absorption when tea is consumed during meals by forming insoluble chelation complexes with non-heme (i.e. most plant-sourced) iron within the gastrointestinal tract, thus reducing its bioavailability. This could constitute a health risk for populations who face difficulties to access animal-based foods, but not for well-nourished people (Bouglé, 2012). Research on such effects of rooibos is very limited, and has only been conducted in South Africa. In healthy young men, rooibos, unlike *C. sinensis* tea, does not significantly affect non-heme iron absorption (Hesseling, Klopper and van Heerden, 1979). Meanwhile, a study of malnourished rural schoolchildren at risk of iron deficiency showed that neither black tea nor rooibos causes significant changes in iron status parameters (Breet *et al.*, 2005). Another study using adults at risk of developing coronary heart disease found that the consumption of rooibos tea does not affect iron status (Marnewick *et al.*, 2013). It should be noted that the first study was a relatively strict clinical study, where the only iron intake of the subjects measured was iron sulfate and iron citrate solution; the other two studies focused on the biological markers of iron status in humans, without controlling the source of iron intake. These results, although preliminary, indicate that rooibos does not affect dietary (non-heme and heme) iron absorption.

Although large quantities of rooibos are consumed annually (SARC estimates annual global consumption at 14 000 tonnes) (SARC, 2019), no toxic effects have been recorded. Two clinical cases report hepatotoxicity after the consumption of rooibos (Engels *et al.*, 2013; Sinisalo, Enkovaara and Kivistö, 2010). However, these incidents are likely to be caused by cross-contamination or an individual response to the bioactive compounds (for ethical reasons, no re-exposure experiments to confirm the link were conducted).

Summary

Rooibos only grows in a small area in South Africa, making it a highly characteristic and symbolic product. Its production process offers scope for improvement and standardization. However, high implementation costs make producers hesitant to upgrade to better technologies such as controlled drying and vacuum packaging. Rooibos products have an excellent food safety history.

Because there is no non-GI equivalent to rooibos, comparisons of nutritional quality, chemical composition and health effects are made with *C. sinensis*. Rooibos is free of caffeine and low in tannin, which may be the reason why it is preferred by some to the ubiquitously consumed *C. sinensis* leaves. The chemical composition of rooibos has been analyzed in detail, particularly for flavonoids. Two dihydrochalcones, aspalathin and aspalalinin, exist only in rooibos. Both rooibos infusion and extract have been demonstrated to possess plenty of potential health benefits. The health benefits of rooibos (as those of *C. sinensis* tea) are yet to be backed up by sufficient robust human evidence.

Overall, much research is still needed into the nutritional and health value of rooibos, including how it compares with *C. sinensis*. Since the formation of SARC and the protection of rooibos as a GI, rooibos has been attracting more attention. The GI helps South African producers to protect the rooibos name, preserve the way of production and guarantee product quality. Continuous investments in product improvement and research are vital to sustain the growth of the market for rooibos.

2.5. CASE 5: INDIGENOUS RICE VARIETIES FROM THE BORNEO HIGHLANDS (MALAYSIA/INDONESIA)

General information

This section analyzes a number of rice varieties found on Borneo, the island shared by the Malaysian states of Sabah and Sarawak, the Indonesian Kalimantan provinces, and the nation of Brunei. The indigenous people of the highlands of northern Borneo have a long history of growing rice on patches of plateau between hills, and rice growing has become not only their livelihood but also part of their identity. In recent years, a number of indigenous rice varieties have been given GI status. Local and national governments hope that GI protection will improve the livelihoods of indigenous peoples, preserve rice biodiversity, and protect the ecological environment of the Borneo highlands.

Research into various aspects of these varieties (cultivars and names, genetics, nutritional quality, consumer preferences, etc.) has only begun recently. While some valuable information is now available, there remains much to discover and analyze. GI protection is relatively new in Malaysia and Indonesia, and more indigenous rice varieties are likely to obtain GI status. Hence, the long-term impacts of GI recognition remain to be observed. This paper hopes to draw interest to the potential of GI products and encourages stakeholders to foster their future development.

Malaysia enacted the Geographical Indications Act 2000, a GI regulatory framework, in 2000. In 2008, a variety of indigenous Borneo highlands rice was registered as a GI under the name Bario rice (Tay, 2017; "Bario rice gets GI certication", 2009). The GI applicant was the Sarawak Information Technology and Resources Council, an agency of the Sarawak State Government (Omar, Jasmin and Tumin, 2018). Following the registration, the Council set up an intellectual property office at state level to manage and protect the intellectual properties belonging to the Sarawak Government (Teo, 2011a).

GI Bario rice derives its name from the Bario village and its surrounding areas, where this rice variety is mostly planted. Bario is a village close to the Sarawak-Kalimantan border, located on a small plateau about 1 200 m above sea level, and surrounded by hills and mountains (Omar, Jasmin and Tumin, 2018). There are currently no paved roads leading to Bario; the village is only accessible by small propeller airplanes or four-wheel drive vehicles. Solar-generated electricity was installed in 2016.

The registered variety is locally called Adan. The GI covers Adan rice planted in the Bario area, but is not limited to a certain cultivar. Many of the papers and publications mentioning Bario rice or Adan rice do not specifically refer to the GI-registered variety planted in and near Bario, but rather to a group of many cultivars called Bario or Adan found in various locations in Sarawak (including, but not limited to Bario) and sometimes even Sabah. This makes it difficult to tell if the cultivars mentioned in these publications are authentic GI Bario rice.

To make matters even more complex, another GI was registered for Adan rice in 2012, this time in Indonesia. The registered name is Beras Adan Krayan (Krayan Adan Rice) (Eghenter, 2014). The Indonesian GI's designated area is the Krayan region of the province of North Kalimantan, which borders the Bario highlands; the region has an altitude of about 1 000 m and is only accessible by air. The indigenous people of the Krayan highlands and those of the Bario highlands (known as the Kelabit) are considered linguistically and culturally closely related by anthropologists (Antons, 2017; World Wildlife Fund [WWF], 2013). Because of the large distance between the Krayan region and Indonesian urban centres, much of the production of Beras Adan Krayan is actually sold "locally" to Malaysia (mostly in Ba Kelalan, the nearest border town in Malaysia), sometimes under the name of Bario rice (detikNews, 2012). This has led to frictions between the two countries. Some efforts have been made to resolve the argument, most notably by the Alliance of the Indigenous Peoples of the Highlands of Borneo (Forum Masyarakat Adat Dataran Tinggi Borneo, FORMADAT), a transboundary social organization formed by indigenous peoples of the Borneo highlands (including the Kelabit) in 2004. One of the missions of FORMADAT is to preserve the collective intellectual property rights of the indigenous peoples of the Highlands (FORMADAT, n.d.). FORMADAT promotes both Bario rice and Beras Adan Krayan rice as unique products that are closely linked to the environment and to the indigenous people of the Borneo highlands (Mustika, 2019; WWF, 2018).

Lastly, it is worth pointing out that all traditional products are protected under the Malaysian GI law, even those that have not been registered as GIs (yet) (Tay, 2017). The Geographical Indications Act 2000 states that protection shall be given to all geographical indications, regardless of whether or not they are registered. However, certain benefits can only be enjoyed by registered GIs. It is unclear whether similar clauses exist in Indonesian GI law.

Nomenclature and genotype determination

Detailed genetic information about cultivars was not readily available when the GI Bario rice was registered in 2008; this type of information was only published in 2009 and 2014 (Lee *et al.*, 2014; Wong *et al.*, 2009). As pointed out in Section 2.5.1, these publications use the term Bario rice to denote cultivars from locations all around Sarawak. Nevertheless, they provide some valuable genotypic information. Cultivars from the Bario highlands differ in their genetic profiles from those from the Bario lowlands, but overall the Bario and Adan cultivars are closely related (similarity > 70 percent) (Lee *et al.*, 2014). The studies also demonstrate the confusing situation of nomenclature. Some cultivars from different locations, with dissimilar genetic profiles, share the same name; other cultivars with different names have genetic profiles that are so similar that they should be given one and the same name (Wong *et al.*, 2009).

Certain publications claim that Bario rice and Beras Adan Krayan are in fact the same variety (Antons, 2017). However, no strict genotypic evidence supports this claim; researchers may need to collaborate internationally to fill this knowledge gap.

In this section, the term Borneo highland rice is used to indicate the various types of indigenous rice grown by the indigenous people of the highlands of Borneo in Malaysia and Indonesia, regardless of whether they are registered as a GI or not. As the Bario and Adan varieties are genetically alike, and unregistered indigenous varieties enjoy some degree of protection under Malaysian GI law, it makes sense to treat them as a single group. In addition, GI systems are still relatively new in the two countries, and it can be expected that more indigenous rice varieties will become GIs in the future. In fact, two more such varieties from the Sarawak lowlands, Sarawak Beras Biris and Sarawak Beras Bajong, were granted GI status in 2009 (Teo, 2011b).

Production

Farmers in the Borneo highlands use a traditional agricultural system to cultivate indigenous rice. They use traditional irrigation techniques and bamboo as a construction material, and rice cultivation is often integrated with buffalo husbandry (Tay, 2017). Growing rice takes about six months (October to February/March) from seeding to maturation, which is quite long for the tropics.[9] As a result, farmers can only grow one crop of Borneo highland rice a year, instead of two or even three crops as is common in South East Asia. For the rest of the year, the fields are used to graze buffalos. The cattle trample the fields and defecate in them, which functions as field preparation and fertilization (Mustika, 2019). Transplanting, harvesting and drying (by sun) are usually done manually. After drying, the farmers either sell their rice to millers or pay for the milling service and sell to consumers and dealers (Omar, Jasmin and Tumin, 2018).

The rice farmers of the Bario highlands are now facing a choice between maintaining their traditional cultivation practices or embracing modern agricultural techniques and using modern irrigation techniques, chemical fertilizers, pesticides, etc. This challenge has been explored in detail by Omar, Jasmin and Tumin (2018) and Raja (2015). The long-standing fame of Bario rice varieties, which was boosted by GI recognition, has pushed up the demand and price of Bario rice in recent years. Bario rice currently retails at MYR 15–20/kg (USD 3.6–4.8) in Malaysia.[10] This price is similar to that of premium products such as Indian basmati rice or organic rice, but much more expensive than ordinary rice imported from countries like Thailand, Viet Nam or Cambodia (2–8 MYR/kg). Some farmers manage to sell their rice directly to consumers under advance agreements, which builds trust and results in higher revenues for farmers. The prestige of Bario rice is a strong motivation for farmers to increase production, particularly considering that the average household income in Bario is only one third of that of Sarawak as a whole

[9] Crop calendar information was obtained from country briefs of FAO's Global Information and Early Warning System (GIEWS), available at www.fao.org/giews/countrybrief/index.jsp (FAO, 2020).

[10] Price information was obtained from Malaysian online grocery retailers Shopee (https://shopee.com.my) and Jaya Grocer (www.jayagrocer.com) in December 2019..

(1999 data). However, many young people do not find rice farming attractive, and prefer to live in cities. Thus, Bario suffers from an exodus of young people to urban areas and an aging labour force. Plenty of rice fields in Bario are abandoned because of a lack of labour supply. All these factors suggest that the adoption of modern agricultural techniques may be beneficial. However, farmers are concerned about the potential (and as yet unresearched) long-term impacts of such techniques on rice quality and on the local environment.

From 2011 to 2015, the government of the state of Sarawak implemented a project to improve infrastructure, introduce mechanization and revive abandoned fields through a public-private partnership with Ceria Bario, a private company. The Bario Rice Development Project was studied in detail by Raja (2015), who concluded that the project was successful in its major goals. Roads and irrigation infrastructure were improved (e.g. by constructing small dams), machines were introduced in some steps of rice production (field clearing and levelling, transplanting and harvesting) and some abandoned fields were cultivated again thanks to the improved efficiency. Farmers maintained their tradition of not using pesticides or chemical fertilizers.

The link between the Bario rice varieties and the environment of the Borneo highlands is clear and documented by a number of studies. Beras Adan Krayan does not seem to grow well outside of Krayan, while other varieties do not grow well when planted in Krayan (Balang as cited in Mustika, 2019). An attempt to produce two crops of Bario rice a year failed. Some evidence suggests that the long growth period of Bario rice might be due to its genes (Raja, 2015). The Bario Rice Development Project did not try to encourage the production of two rice crops per year but instead maintained the traditional one-crop system, which works better with buffalo husbandry and preserves soil fertility.

Nutritional value

There are three major types of Borneo highland rice, differentiated by their colour after milling: white, red and black. Research on their nutritional value has only begun in recent years. Most studies are conducted by Malaysian researchers on Bario rice.

The nutritional composition of several Bario rice varieties has been analyzed by Nicholas *et al.* (2014). MR 219, a high-yield, fast-growing, disease-resistant rice variety developed by the Malaysian Agricultural Research and Development Institute was used for comparison (Food and Fertilizer Technology Center for Asia and the Pacific Region [FFTC], 2002). The results of the study are summarized in Table 6; for the sake of comparison, the values of raw and cooked ordinary rice are also given.

Table 6 shows that the carbohydrate content of Bario rice varieties is lower than that of MR 219, which is in turn lower than that of ordinary rice. As carbohydrates determine the caloric contents in rice, the energy levels of the different varieties follow the same order. The protein contents of Bario Celum and MR 219 are a bit lower than those of other varieties. Bario rice varieties are higher in dietary fibre than MR 219 and ordinary rice.

In terms of micronutrients, Bario rice varieties are lower in calcium and sodium than MR 219, but higher in potassium, thiamin and niacin. Compared with ordinary rice, Bario rice is exceptionally high in calcium, iron, potassium, sodium and niacin, and low in thiamin. While these differences may to a certain extent be due to varietal features, they may also be the result of soil characteristics and cultivation practices (e.g. the use of chemical fertilizers may boost mineral contents in rice).

However, the bioavailability of micronutrients in rice is known to be poor. Indeed, rice seeds contain abundant levels of phytic acid, the major storage form of phosphorus in plant seeds and a strong chelator to mineral ions.

Table 6. Nutritional composition of Bario rice varieties

Nutrient	Content per 100 g food						
	Bario Adan Halus (white)[1]	Bario Tuan (white)[1]	Bario Merah (red)[1]	Bario Celum (black)[1]	MR 219[1]	Rice polished[2]	Rice cooked[2]
PROXIMATES							
Water (g)	14.73	13.59	14.13	14.12	11.54	12.5	67.4
Energy (kcal)	239	289	297	285	305	349	130
Protein (g)	7.30	6.45	6.95	5.85	5.85	7.1	2.3
Total lipid (fat) (g)	1.05	0.85	0.65	0.50	1.05	0.5	0.1
Carbohydrate (g)	73.96	76.39	75.15	76.76	78.45	79	30
Dietary fibre	1.50	1.40	2.05	1.45	0.90	0.4	0
MINERALS							
Calcium (mg)	0.54	1.08	0.61	1.01	1.31	11	3
Iron (mg)	0.52	0.45	0.48	0.59	0.57	1.4	0.2
Potassium (mg)	19.55	16.55	40.05	24.40	15.85	31	6
Sodium (mg)	0.62	0.47	0.41	0.58	0.67	22	6
VITAMINS							
Thiamin (mg)	0.52	0.63	0.46	0.47	0.34	0.11	0.02
Niacin (mg)	0.20	0.22	0.18	0.28	0.15	3.3	0

Source: [1] Nicholas et al. (2014). [2] Malaysian Food Composition Database, available at http://myfcd.moh.gov.my (Malaysia, Ministry of Health, Nutrition Division, n.d.).

The chelating compounds (called phytate or phytin) are insoluble, stable salts that cannot be absorbed by humans (Perera, Seneweera and Hirotsu, 2018). A study into 30 Bario rice cultivars (including indigenous ones from the highlands and adapted ones cultivated in the lowlands) confirmed that the bioavailability of iron, zinc and calcium in Bario rice is poor (Lee *et al.*, 2015).

Rice is often stored for some time before consumption, so it is worthwhile to study whether the nutritional composition of rice is affected by storage. Bario rice varieties, packed in polyethylene bags and stored at ambient temperature for six months, have been found to undergo no significant changes in macronutrients but significant (severalfold) increases in calcium and iron contents (Nicholas *et al.*, 2013). The potassium levels of Bario Merah decreased by about half over the storage time. Further analysis is needed to confirm the repeatability of these results and identify their possible contributing factors.

Overall, Bario rice is superior to other rice varieties for some nutrients, but inferior for others. However, it is unclear whether these conclusions also hold for cooked rice, as cooking (most commonly steaming) significantly reduces the levels of almost all nutrients in rice. This is illustrated by Table 6, which presents the nutritional composition of cooked rice from the Malaysian Food Composition Database. The impacts of cooking on the nutritional values of Bario rice have not been studied. This is a critical gap to be filled.

Work on the nutritional composition of Bario rice varieties has not been concluded, and data from difference sources sometimes differ greatly. For example, one study reported that the calcium, potassium and sodium contents of Bario rice (unknown cultivar) are 12.42, 146.99 and 4.99 mg/100 g, respectively (Thomas, Bhat and Kuang, 2015). Meanwhile, another study (Lee *et al.*, 2015) reports iron and calcium levels of various Bario rice varieties of 1–3 and 8–20 mg/100 g, respectively. These numbers are several times higher than those reported by Nicholas *et al.* (2014).

Although polished rice is a staple food for a large portion of the world's population, its high consumption has been associated with a significantly increased risk of type II diabetes (Hu *et al.*, 2012). The glycaemic index, a relative score of a food's propensity to increase blood glucose levels after consumption (the reference food, glucose, has a value of 100), is thus an important indicator of the health impacts of rice. Nicholas *et al.* (2014) measured the glycaemic index values of Bario rice varieties and MR 219 and compared them with those of boiled white rice, the most widely consumed form of rice (see Table 7).

Table 7. Glycaemic index of Bario, MR 219 and white rice

Rice variety	Glycaemic index
Bario Adan Halus (white)[1]	72.1 ± 9.5
Bario Tuan (white)[1]	62.2 ± 8.9
Bario Merah (red)[1]	78.3 ± 9.9
Bario Celum (black)[1]	60.9 ± 7.2
MR 219[1]	66.6 ± 6.9
White rice, boiled[2]	73 ± 4

Source: [1] Nicholas et al. (2014). [2] Atkinson, Foster-Powell and Brand-Miller (2008).

Bario Tuan and Bario Celum have a clearly lower glycaemic index than white rice, which suggests that they may be good substitutes for ordinary rice as part of healthy diets. It should be noted that there are hundreds of white rice varieties and that the value in the table is an estimated average. Fitzgerald *et al.* (2011) predict the glycaemic index of 235 rice varieties using an *in vitro* approach; the values are found to range from 48 to 92. In addition, mutations of the rice's waxy gene are found to be associated with the variations in the glycaemic index. Whether this applies to Bario rice would make an interesting study topic.

Another aspect of the nutritional quality of Bario rice that has drawn researchers' attention is its phytochemical content, especially for pigmented varieties. Lee *et al.* (2015) quantify the total phenolic content of three pigmented Bario rice varieties and 27 non-pigmented ones, and find that the former (red and dark purple) have a higher total phenolic content (382.7–852.0 µg gallic acid equivalent/g) than the latter (52.7–272.0 µg gallic acid equivalent/g). An *in vitro* study confirms that pigmented Malaysian highland rice varieties (named Hitam, Bario and Udang in the report) possess higher antioxidant activities than lowland white and pigmented rice varieties (Kamdi, 2018). The author takes a further step by examining the antioxidant activities of cooked rice, and finds that an average 75 percent of the total antioxidant and enzymatic activities of rice are decomposed or inactivated by cooking. The study briefly explores the thermostability of a few antioxidant proteins by computer simulation.

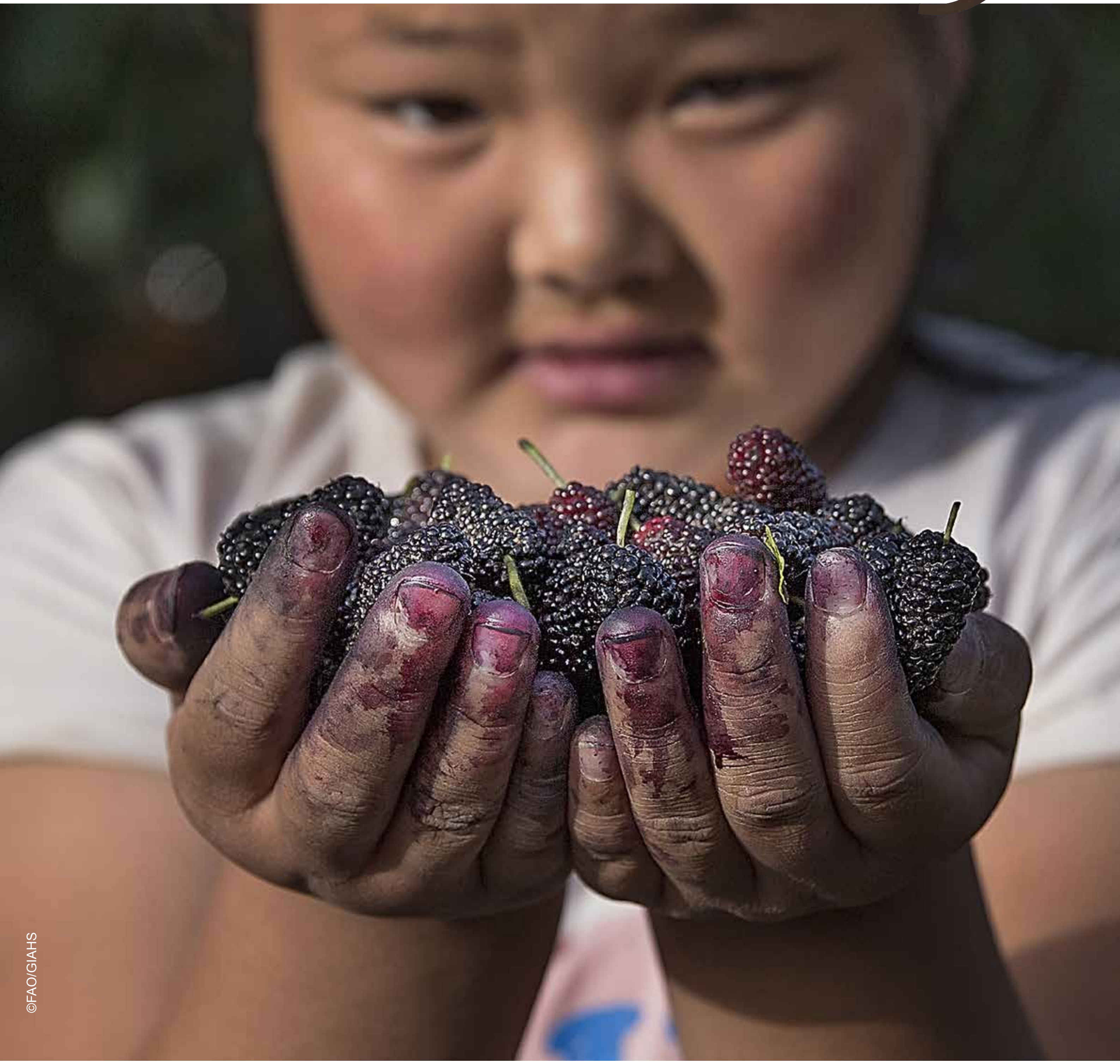
Other interesting studies into the nutritional qualities of Bario rice varieties include a study on their chemical and physical properties for food processing (Thomas *et al.*, 2014a), and another study comparing the physical and sensory qualities of rice noodles made from Bario and Basmati rice (Thomas *et al.*, 2014b). Bario rice varieties are suitable for further processing, and consumers strongly prefer rice noodles made from Bario rice over those made from basmati rice.

Summary

The indigenous rice varieties and relevant agricultural practices of the Borneo highlands have been forged by the area's indigenous population in its characteristic natural environment over several centuries. The recent recognition of rice's crucial importance for the livelihood of the local people and the biodiversity of the local environment was inspired by the designation of GI status for Bario and Beras Adan Krayan rice. Research into the genetic and nutritional straits of these rice varieties is increasing. Preliminary results show that some indigenous rice varieties from the Borneo highlands have a great potential to contribute to healthy diets due to their low glycaemic index, high antioxidative activity, good properties for processing and the characteristic sensory qualities of their processed products. Meanwhile, various development efforts, most notably the Bario Rice Development Project, aim to significantly improve rice farmers' livelihoods while preserving the essentials of traditional agricultural practices to ensure environmental sustainability.

Among the many knowledge gaps mentioned in this section, nomenclature is the most critical one. The term Bario rice is loosely used to denote rice varieties from Bario (i.e. not necessarily planted in the highlands), even though it is a formal GI name. There are also inconsistencies in reports on the GI rice: some limit Bario rice to white rice, while others include white, red and black varieties. The situation for the term Adan is similar. This makes it impossible for consumers to tell if a product is from the indigenous varieties grown in the Borneo highlands. This incongruity may also have contributed to the large variation in data on the nutrient contents of Bario rice varieties. Built on the initial achievements in genotyping, efforts should be made to identify the characteristic rice cultivars of the Borneo highlands with precision, and build a proper nomenclature system. This information could constitute a basis of further developments (e.g. addition of the varieties to national food composition databases, inclusion of the correct nutritional information on labels, better GI designation schemes and marketing strategies, etc.).

3



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Special topics

3.1. DEVELOPMENT OF SPECIFICATIONS FOR GEOGRAPHICAL INDICATION FOODS TO IMPROVE NUTRITIONAL QUALITY

For GI foods to exhibit their specific nutritional characteristics, a series of procedures covering key stages of the production process must be well defined and followed. These stages concern in particular the production of materials (e.g. the use of specific local ingredients such as those used in fermentation) and processing. The analysis of furu and Parmigiano Reggiano in this paper, for example, has demonstrated that materials and processing conditions (mainly temperature, humidity and time) directly determine the contents of nutrients and bioactive chemicals. The specifications of GI foods prescribe procedures that reflect long-standing experience; they do so in in a quantitative manner, so that compliance reliably yields products of the same high quality. For many non-GI traditional foods, however, such procedures have not been clearly established or solidified in the form of repeatable operation protocols; this jeopardizes product safety and quality and consequently consumer confidence, not only in the traditional foods themselves but in the producers of traditional foods (often small-scale producers or households) in general.

It is well accepted that improper processing can result in unsafe food products; its impact upon nutritional values, however, is not often mentioned. Many GI and traditional foods undergo processing, usually within the boundaries of NOVA groups 1, 2 and 3 (see Box 5). As shown in the analysis of furu and Parmigiano Reggiano, processing techniques such as fermentation can be complex, and their execution requires a certain knowledge. This may be problematic in areas where capacities and facilities are limited and regulations are lax. Producers without adequate knowledge or equipment may be inclined to overuse ingredients such as sugar, oil and preservatives. Thus, foods that originally belonged to group 1 are modified to belong to group 3 or 4, i.e. foods that form the basis of healthy diets are transformed into foods whose consumption is positively associated with increased risks of NCDs.

Well-established and well-implemented GI product specifications may help ensure the safety and consistency in nutritional quality of traditional foods. In this respect, the formulation and registration of production and processing procedures, and compliance therewith, are critical. It is recommended to raise producers' awareness of the relationship between production methods and a product's nutritional quality; this awareness may help them define GI specifications in a way that enhances or maintains the nutritional quality, and hence contribution to healthy diets, of the GI product. In some specific contexts, new products (e.g. furu with a low salt content) may be developed to incorporate more considerations related to health and nutrition. This topic is further explored in Section 3.2.

Box 5. The NOVA classification system of foods and their dietary implications

The NOVA classification system groups all foods according to the nature, extent and purposes of the industrial processes they undergo. These involve physical, biological and chemical techniques used after foods are separated from nature, and before they are consumed or used to prepare dishes.

Group 1: unprocessed and minimally processed foods

Unprocessed (or natural) foods are the edible parts of plants (such as fruits, leaves, stems, seeds or roots) or animals (such as muscle, offal, eggs or milk) and fungi, algae and water, after their separation from nature.

Minimally processed foods are natural foods that are altered by methods such as the removal of inedible or unwanted parts, or by processes such as drying, crushing, grinding, powdering, fractioning, filtering, roasting, boiling, non-alcoholic fermentation, pasteurization, chilling, freezing, placing in containers and vacuum packaging. These methods and processes are designed to preserve natural foods, make them suitable for storage, or make them safe or edible or more pleasant to consume. The distinction between unprocessed and minimally processed foods is not especially significant.

In appropriate combinations, and with an appropriate level of variety, all foods in this group form the basis of healthy diets.

Group 2: processed culinary ingredients

Processed culinary ingredients include oils, butter, lard, sugar and salt. These are substances derived from group 1 foods or from nature by processes such as pressing, refining, grinding, milling and drying. They are rarely, if ever, consumed by themselves. They are used in combination with foods to make dishes more palatable, diverse, nourishing and enjoyable.

Many culinary ingredients are cheap, and can be overused. When used carefully and in small amounts, they result in tasteful dishes that are nutritionally balanced, with energy densities much lower than those of most ready-to-consume food products.

Group 3: processed foods

Processed foods, such as bottled vegetables, canned fish, fruits in syrup, cheeses and freshly made breads, are essentially made by adding salt, oil, sugar or other substances from group 2 to group 1 foods. The processes used include various preservation or cooking methods, and, in the case of breads and cheese, non-alcoholic fermentation.

Most processed foods have only two or three ingredients, and are recognizable as modified versions of group 1 foods. They are edible by themselves or, more usually, in combination with other foods. The purpose of processing is to increase the shelf life of group 1 foods, or to modify or enhance their sensory qualities.

Like processed culinary ingredients, processed foods can be overused. When used sparingly, and in the case of processed meats also only occasionally, they result in tasty dishes that are nutritionally balanced, with energy densities lower than those of most ready-to-consume food products.

Group 4: ultra-processed foods

Ultra-processed foods, such as soft drinks, sweet or savoury packaged snacks, reconstituted meat products and pre-prepared frozen dishes, are not modified foods but formulations made mostly or entirely from substances derived from foods and additives, with little if any intact group 1 food used.

Processes to manufacture ultra-processed foods involve several steps and different industries. Ingredients of ultra-processed foods are usually also used in processed foods, such as sugars, oils, fats or salt. However, ultra-processed products also include other sources of energy and nutrients that are not normally used in culinary preparations.

Evidence from the analysis of nationally representative data sets collected in 11 countries from 2001 to 2015 shows that the displacement of non-ultra-processed by ultra-processed foods is consistently associated with an overall deterioration of the nutritional quality of diets. Indeed, evidence gathered by studies with different designs and undertaken in a great number of countries consistently shows that the displacement of non-ultra-processed by ultra-processed foods increases the risk of obesity and several other diet-related NCDs, as well as premature mortality.

Source: adapted from Monteiro et al., 2018 and 2019.

3.2. THE POTENTIAL CONTRIBUTION OF GEOGRAPHICAL INDICATION FOODS TO HEALTHY DIETS

GI foods reflect and preserve ways of cultivating plants, raising animals and processing foods that define traditional, local diets. While industrialized food production has significantly boosted the quantity of the food supply over the past decades, it also brings serious and stubborn health problems such as the global pandemic of obesity and NCDs. These problems are partly due to the popularization of ultra-processed foods and the consequent shift in diets (Monteiro *et al.*, 2019; Srour *et al.*, 2019). Indeed, unhealthy diets are believed to be accountable for almost 20 percent of global deaths in 2017 (GBD 2017 Diet Collaborators, 2019). Increasing the adherence to traditional diets, or at least promoting the consumption of unprocessed and minimally processed foods that are amply present in traditional diets, has been proposed as an answer to the global health challenge (International Center for Advanced Mediterranean Agronomic Studies [CIHEAM] and FAO, 2015; Sofi *et al.*, 2008; Willett *et al.*, 2019). GI foods (or traditional foods in a wider sense) present, through their own qualities and through their influence on consumer behaviour, a great potential to revert the shift towards unhealthy diets.

Inclusion of GI foods in diets

The substitution in daily diets of certain foods by more nutritious alternatives would improve consumers' health. This could be achieved by promoting the consumption of traditional (GI) foods. Indeed, the analysis of the GI foods in this paper has demonstrated that certain GI foods possess better nutritional qualities than their non-GI counterparts.

In a double-blind, randomized study involving 50 healthy volunteers, Weill *et al.* (2002) provided exact meals to a control and an experimental group for a relatively long time (two 35-day periods with an 18-day washout interval), the only difference between the type of meals concerning the animal-sourced foods in the meals. All animals used were of the same breed and sex and raised under similar conditions. However, the animals used for the foods in the control group were fed with conventional feed, while those used for the experiment group were given feed supplemented with linseed. The products (milk, eggs, pork and chicken) sourced from the animals that were given linseed had higher contents of CLA and *n*-3 FA (note that these characteristics in FA composition are similar to those for Carnalentejana beef). At the end of the period of experimentation, the researchers measured the blood lipid profiles of the participants and found that the experimental group exhibited higher levels of *n*-3 FA and CLA and lower *n*-6/*n*-3 ratios, indicating a healthier average lipid status than that of the control group. Although similar studies are not available for other foods, the report shows that the food substitution approach may achieve good results.

It should be noted that substitution need not be limited to the same type of food. For example, furu may be used as a substitute for salt in cooking; this introduces the many beneficial nutrients of furu into a diet, while taking advantage of its downside i.e. its high salt content.

In addition, this approach has the advantage of not requiring consumers to change their eating habits at all. Admittedly, changing dietary habits is a more thorough approach with longer-lasting benefits; however, realizing behavioural change is always a daunting task due to the great cultural and socio-economic obstacles.

Influence on consumer behaviour

The topic of consumer food preferences is complex and subject to much research. While a thorough discussion of the topic is beyond the scope of this paper, a few points are worth pointing out.

First, studies on the impacting factors of consumer behaviour often lead to inconsistent conclusions due to the large differences in populations, types of food and regions, not to mention technical details such as sample size, representativeness and methodologies. In the case of organic foods, altruistic aspects (related, for example, to the environment or animal welfare), individual aspects (e.g. concerns about health, nutrition and food safety, food tastes and product freshness) and other factors (e.g. search costs, dietary patterns and awareness of labelling) have all been reported as important considerations for food purchasing and consumption (Padilla Bravo *et al.*, 2013). It is unlikely that consumer preferences for GI and traditional foods, which have a large overlap with organic foods, are driven by only a handful of factors.

Second, labels referring to a food's GI/organic/traditional/local nature are often treated as a property separate from nutrition (in the "narrower" sense of nutrient contents), i.e. in consumers' perception, GI/organic/traditional/local foods do not necessarily have a higher nutritional value (Feldmann and Hamm, 2015; Gracia and de-Magistris, 2016; Grunert and Aachmann, 2016).

Third, evidence suggests that emphasizing health and nutrition alone may not suffice to change consumer behaviour. Arguments based on health and nutrition may be too complicated or abstract for the general population; they may also not be the dominant influencing factor (Guthrie, Mancino and Lin, 2015). An interesting area of research is whether and how the organoleptic qualities of a GI food and its link to the origin (to the local community, its culture and traditional practices) may contribute to the implementation of dietary guidelines, i.e. whether GI products may promote healthy diets based on their sensory properties and socio-psychological mechanisms (Fischler and Masson, 2008).

Fourth, research into consumers' willingness to pay for GI foods often does not consider nutritional value as an impacting factor. Nutritional value is taken into account in certain studies on the willingness to pay for organic and traditional foods; however, detailed aspects such as the content of micronutrients and other beneficial chemicals have not been explored.

Summary

Nutritious GI and traditional foods have a potential to become an important part of healthy diets; however, both researchers and consumers lack awareness of this possibility. More efforts need to be made to refine and confirm this theory of change. To what degree GI and traditional foods should become a part of everyday diets depends on the composition of the diets, the nutritional status of the population, the availability, affordability and supply stability of such foods, and cultural and socio-economic factors. A thorough assessment covering all these areas is ideal, but may in many cases not be feasible. Priority should therefore be given to the assessment of the detailed composition of diets of different populations and to piloting measures that may increase the consumption of nutritious foods. On the supply side, more GI foods that meet consumers' nutritional needs should be developed, and nutritional considerations should be integrated in the development and marketing of GI foods.

3.3. FOOD COMPOSITION DETERMINATION

Knowing what chemicals foods contain is the very basis of the understanding of their intrinsic nutritional value. All case studies in this paper present the detailed nutritional composition of the foods as the starting point for analysis. Unfortunately, comprehensive information regarding the nutritional value of many traditional/GI foods is not available. This may be due to the fact that such foods are often neglected when food composition databases (FCDBs) are built or updated. Hence, it is impossible to explore their potential to improve nutrition.

The awareness of traditional foods has been growing in recent years. As a result, a number of efforts have been undertaken to determine the nutritional composition of traditional foods, for example by European Food Information Resource (EuroFIR) (Finglas, Berry and Astley, 2014). Under the Traditional Foods Work Package of EuroFIR, a definition of "traditional" was developed, traditional foods from participating countries were selected and sampled, nutrients to be analyzed and analytical methods were agreed upon, and experimental data were obtained and prepared for inclusion in FCDBs (Costa *et al.*, 2010). In sum, the project established an approach to obtain new and reliable nutritional data on traditional foods through multinational collaboration.

In addition to foods such as cured hams and cheeses, many of the traditional foods analyzed under the EuroFIR project are dishes made from various ingredients, such as soup, ravioli/dumplings, pizza, kebab, vegetable and meat dishes, biscuits, etc. This reflects an emerging consensus amongst researchers that conventional FCDBs, or nutrition research in general, are too restrictive i.e. they fail to consider the many factors that influence the bioavailability and in vivo bioactivity of nutrients, notably food processing and interactions between food ingredients (Jacobs and Tapsell, 2007; Jacobs and Temple, 2012; Moughan, 2020).

A review of the factors affecting the digestion of macronutrients found that the bioavailability of macronutrients in foods can be greatly influenced by the structural forms in which macronutrients exist in foods, the processing procedures foods are subject to, and dietary components that interact with digestive processes (Capuano *et al.*, 2018). Based on data from digestibility studies, the review also found that the actual energy intake of a diet high in dietary fibre and whole grains or seeds turns out to be significantly lower than the intake calculated on the basis of the nutrition facts on labels, which are taken from FCDBs.

There are still many technological barriers to overcome before energy and nutrient intake can be measured accurately; to this end, a fundamental revamp of the principles behind FCDBs may be needed. Assessing the nutritional contents of actual dishes is a good start. Following the EuroFIR initiative, more data on traditional dishes have been generated (Costa *et al.*, 2013; Durazzo *et al.*, 2019, 2017).

As the case studies show, some bioactive food components that are not usually included in FCDBs are highly beneficial to health. Generally, only academics or health-conscious individuals pay attention to them (partially because it is not mandatory to mention their contents on nutritional labels). There are no official methodologies to measure their contents and hence no authoritative data, which contributes to the confusion over health claims based on these bioactive chemicals. Official indicators and measuring methodologies should be established, starting with those for which tried and tested methods are available, such as total polyphenol and total flavonoid (Durazzo *et al.*, 2017). However, it is debatable whether bioactive food components should be included in FCDB, as the relationship between their consumption and health is still not fully understood. This holds particularly true for antioxidants, one of the most extensively researched group of bioactive food components, as shown in Box 6.

Box 6. Current opinions on the health effects of antioxidants

The effects of antioxidants on human health appear to be associated with the form and dose of antioxidant intake.

On the one hand, it has been firmly established that fruits and vegetables, which are high in antioxidants, are a vital part of healthy diets. All global and national dietary guidelines strongly recommend increasing their intake, based on substantive evidence that doing so reduces the risks of several non-communicable diseases (NCDs).

On the other hand, most large-scale, long-term, double-blind clinical trials of antioxidant supplements have not found that high doses of antioxidant supplements (i.e. higher than the dose provided by a balanced diet that includes fruits and vegetables) could prevent NCDs and some other diseases. In fact, high-dose supplements of antioxidants may be linked to increased health risks in some cases.

Whether the effects of fruits and vegetables in terms of the prevention of NCDs can be attributed to their antioxidant contents is not clear because other components are present in these foods, other foods are included in diets, and other factors (e.g. socio-economic status and lifestyle) cannot be fully ruled out. In addition, the chemical form of naturally occurring antioxidants is sometimes different from that in supplements. How this affects the antioxidants' effects remains largely unknown.

Source: adapted from National Center for Complementary and Integrative Health [NCCIH], 2013; Swedish Agency for Health Technology Assessment and Assessment of Social Services [SBU], 1997; WHO, 2014.

Microorganisms in fermented foods have potent and wide-reaching health impacts, as demonstrated in Section 2.2 and Section 2.3 on furu and PR. Although microorganisms are beyond the scope of FCDBs, it may be necessary to establish typical microbial profiles of common fermented foods. This information can serve as a quality assurance and anti-counterfeiting measure.

Another important part of food content that is not currently incorporated in FCDBs is the level of additives. The positive association between the consumption of ultra-processed foods (as defined in the NOVA classification in Box 5) and the risks of NCDs indicates that some additives, and particularly those that can only be found in ultra-processed foods, may have grave adverse health impacts. As briefly discussed in Chapter 3.1, GI and traditional foods are often unprocessed or minimally processed (although many such foods should indeed be classified as processed), and may thus be preferable to ultra-processed foods in terms of health. Incorporating the levels of additives in FCDBs could help improve the inclusion of healthy foods in diets.

Finally, it is worth noting that GI registrations improve the knowledge on the nutritional value of traditional products by laying down specifications as to the composition and nutrients of GI foods. The consumption of these foods contributes to the diversification of diets with specific nutrients that are linked to characteristic indigenous varieties, soil composition, climatic conditions and traditional practices.

4

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Conclusions

4.1. LIMITATIONS

The limitations of the current literature on the nutrient contents of GI foods have been mentioned in previous sections. The below paragraphs provide a summary.

Fruits and vegetables are highly nutritious; however, they are consumed in greatly insufficient quantities worldwide (Willett *et al.*, 2019). This paper does not include an example of a GI fruit or vegetable (although there are many), as there are no studies that compare the nutritional value of GI and non-GI fruits or vegetables. Efforts related to the food composition of these foods should concentrate on the accumulation of (variety-specific) information, which may provide a basis for market differentiation. Nearly all fruits and vegetables (as long as they are safe) are nutritious enough to warrant recommendations to increase their intake.

It may be very challenging, or sometimes even technically impossible, to pinpoint a few compounds or foods as the definite culprit, or medicine, for NCDs. This has been evidenced by the contradictions between the (inconclusive) reports discussed in this paper. Some major points are worth summarizing here:

- The number of rigorous human studies is very limited, and those that conform to the strictest standards (double-blind, randomized, placebo-controlled, large-scale and long-term) are particularly scarce. Such studies are difficult to conduct and very costly in terms of both money and time; however, they are the only way to prove the existence or absence of a link between a compound/food and a disease.
- One important reason why in vitro and animal studies are not sufficiently conclusive is that they cannot reflect the process of human metabolism; hence, they cannot take into account bioavailability, a critical factor for compounds and foods to achieve health impacts in humans.
- Food is a complex matrix; this complexity may increase exponentially with processing and cooking. How the physical and chemical properties of the food itself are modified as a result of processing and cooking, and how ingredients change and interact accordingly, still requires a great amount of research.
- Foods are consumed as part of a diet. This brings in the question of the interaction at diet level between different foods – another important challenge for future research.
- The onset of most NCDs is multifactorial by nature. Besides diets and individual characteristics, plenty of factors such as lifestyle, healthcare, hygiene, socio-economic status, environment and others may all play a role. This makes it particularly challenging to formulate policies and allocate resources to reduce NCDs.
- An element that has not been discussed in this paper but is worth singling out, is that while nearly all research to date has focused on population and dietary patterns in the

West, the incidence of NCDs is also high – and has been accelerating in recent years – in other parts of the world.

However, one causal relationship has been convincingly established: a balanced, healthy diet significantly reduces the risks of many NCDs (GBD 2017 Diet Collaborators, 2019). It is therefore worthwhile to explore the possible roles that GI/traditional foods may play in the promotion of healthy diets.

A vast amount of research exists on the sensory properties of GI foods, and on consumer attitudes towards them. This important topic is beyond the scope of this paper. However, it strongly influences consumers' preference for foods and thus intake, and therefore plays an essential role in shaping diets. The topic of consumer attitudes towards sensory properties merits a detailed review, as it constitutes a significant piece of the whole picture of the role of GI foods in healthy diets. It is also important to investigate the role of culture and related socio-psychological factors in consumer emotions and behaviours about GI foods.

4.2. WAYS FORWARD FOR RESEARCH AND DEVELOPMENT IN GEOGRAPHICAL INDICATION FOODS

By showcasing the nutritional characteristics of a number of GI foods, this paper makes a first attempt to advocate a greater role for GI/traditional foods in healthy diets. GI recognition helps maintain traditional product qualities; it may also boost the importance of traditional foods in nutrition, for both current and future GI products.

Current specifications for GI products do not systematically include nutrition-related criteria. Even where studies into the nutritional aspects of such foods were conducted in preparation of a GI registration, such data are rarely published. However, the nutritional value of some GI foods has been researched continuously, as the case studies have shown. This research is prompted by strong interest from businesses, consumers and academia, possibly sparked by the initial recognition of the GI. Producers and distributors of a GI food may consider nutrition as a potential marketing tool that adds value to a food. Consumers may perceive a GI food as more nutritious, and ask for research to confirm it. Academic institutions in or near the designated geographical area of the GI food (referred to as local institutions below) may be motivated to generate knowledge on the nutritional value of the food due to social and cultural ties. These mechanisms may be leveraged to widen the range of GI foods for which nutritional research is conducted, starting with the best-known or most profitable ones.

The determination of food composition is highly costly in terms of both money and time; in certain cases, the equipment and personnel required are not available (at least not near the area where the foods are produced). It may therefore not be realistic to require GI specifications worldwide to include quantitative nutrient information. However, wherever such data were produced to apply for GI recognition, their publication should be encouraged. Additionally, efforts should be made to motivate stakeholders including producers, consumers and academia to incorporate nutrition into GI specifications. To this end, the following measures may be taken:

- Awareness raising of producers on the nutritional quality of their products, on how it is linked to local conditions and practices, and on how it may be enhanced in a way that also preserves origin-linked quality. Wherever appropriate, support should be provided to help maintain and improve the nutritional value during production and processing.
- Awareness raising in the wider society on the importance of healthy diets and lifestyles.
- Capacity building for research into nutrition. Depending on the context, the focus could be on the determination of food composition (including bioactive compounds and microbial profiles of fermented foods), *in vivo* biological activities of food components, or robust clinical trials. The literature review done in preparation of this paper shows that local institutions are the dominant force in GI food research, i.e. research on GI foods is mostly conducted by institutions in the geographical areas linked to those foods. Capacity building efforts should target such institutions.

Foods are always consumed as part of a diet. GI/traditional foods may contribute to healthy diets by substituting similar foods or becoming an integral part of diets, thus contributing to a reverse dietary shift. GI food are diversified and have unique qualities, so the more GIs are developed and recognized, the more they can contribute to healthy diets. The composition of diets is key information for planning programmes that encourage the intake of nutritious foods. In addition, many concepts and thoughts embodied by GIs, such as the way of interacting with nature, the focus on preserving the environment, the cherishing attitude towards foods, and the approach of prioritizing quality over speed, may be applicable to other aspects of sustainable development, beyond diets.

On a more general level, to provide concrete evidence for NCD prevention and health improvement, nutrition research needs to undergo a paradigm shift from reductionism (focusing on specific compounds) to concentrating on the interaction between ingredients in single foods (food synergy) and combinations of foods in diets (Jacobs and Tapsell, 2007). Future nutrition policies should be built upon similar system thinking to induce system-level change. This includes a shift from viewing health solely as a medical issue to systematically addressing the personal, community, sociocultural, national and global determinants of food environments (Mozaffarian, Rosenberg and Uauy, 2018).


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A

ANNEX
Probiotics, prebiotics, fermented foods and gut microbiota

The food industry and academia have held a strong interest in probiotics and prebiotics for a long time. A plethora of studies in this field have been conducted, and many products have been developed. There has been a surge in gut microbiota research in recent years, partly thanks to the advance in culture-independent methods (most notably high-throughput 16S rRNA and shotgun sequencing), computing power and analytic techniques in bioinformatics (see Table 1 in West *et al.*, 2015, p. 5). Some manufacturers of functional foods have begun to explore the possibility of linking their health claims to gut microbiota. Pro- and prebiotics, due to their nature, might influence gut microbiota through various direct and indirect mechanisms (Hemarajata and Versalovic, 2013). Many traditional and GI foods are fermented products that might contain probiotics (especially for dairy products); the interaction with gut microbiota offers scope for research and development of these foods. This section briefly introduces the current status of several issues on this topic.

1. DEFINITION AND COMMON TYPES

A joint FAO/WHO working group defines probiotics as:

> Live microorganisms which when administered in adequate amounts confer a health benefit on the host (FAO and WHO, 2002).

One widely accepted definition of prebiotics is "a nondigestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon and thereby improving host health" (Gibson and Roberfroid, 1995). Participants at a FAO technical meeting proposed to expand this definition by including any interacting mechanism with microbiota:

> A prebiotic is a non-viable food component that confers a health benefit on the host associated with modulation of the microbiota (Pineiro *et al.*, 2008).

A panel of experts on pro- and prebiotics reached consensus on the following definition of prebiotics, which retains similarity with the first definition on selectivity and the use of the term substrate:

> A prebiotic is a substrate that is selectively utilized by host microorganisms conferring a health benefit (Gibson *et al.*, 2017).

Also relevant is the concept of synbiotics, which are products that contain both probiotics and prebiotics. Synbiotics are usually designed to achieve a synergistic effect from its prebiotics and probiotics components.

The definition of microbiota in the Oxford English Dictionary is "microfauna and microflora considered together; specifically that of a given habitat, region or epoch." In the context of humans, microbiota are "the microbial taxa associated with humans" (Ursell *et al.*, 2012). Of major interest in human nutrition are those in the digestive system, "the collection of bacteria, archaea and eukarya colonizing the gastrointestinal tract", termed the "gut microbiota" (Thursby and Juge, 2017). The collection of the genomic content of gut microbiota is thus named gut microbiome, but these two terms are often used interchangeably (Ursell *et al.*, 2012). This paper maintains the difference between them.

The most extensively researched group of probiotics is lactic acid bacteria (LAB), including *Lactobacillus, Bifidobacterium, Streptococcus, Enterococcus, Bacillus*, etc. Lactic acid is the common major metabolic product of the carbohydrate fermentation process they participate in. In food processing, LAB are the major agent in traditional and commercial dairy fermentation. They are also found in other products such as kimchi (as reflected in the term *Lactobacillus kimchii*), sauerkraut and other fermented vegetables, sourdough bread, and various traditional fermented foods and beverages (Mokoena, Mutanda and Olaniran, 2016; Rizo *et al.*, 2018). Almost all commercial probiotic supplements are based on LAB (mostly *Lactobacillus* and *Bifidobacterium*). The literature on the probiotic potential of other widely used food-producing microorganisms is limited.

In foods, prebiotics are soluble fibre, including inulin, oligosaccharides, pyrodextrins, lactulose, etc. The majority of studies has so far focused on inulin, fructo-oligosaccharides and galacto-oligosaccharides (Gibson *et al.*, 2017; Pineiro *et al.*, 2008).

2. DIET AND GUT MICROBIOTA

It has been observed that significant changes occur in infants' gut microbiota composition along with dietary shifts (Ursell *et al.*, 2012; Zmora, Suez and Elinav, 2019). Plenty of evidence has confirmed that this applies to adults too, as shown below.

Differences in diets can result in differences in gut microbiota compositions, especially between persons. Several mid- to long-term human feeding experiments involving obese and healthy individuals and diets with different levels of calories, fat, carbohydrates and fibres (including resistant starch and non-starch polysaccharides) demonstrate that diet types reliably correlate with the composition of gut microbiota (Duncan *et al.*, 2007; Jeffery and O'Toole, 2013; Ley *et al.*, 2006; Simpson and Campbell, 2015; Walker *et al.*, 2011; Wu *et al.*, 2011). Generally, strong increases are observed in microorganisms involved in metabolizing the high-level ingredients of diets. Diets high in fat and sugar (which are typically also low in fruits and vegetables) decrease potentially beneficial Firmicutes and increase Proteobacteria, which include several known pathogens, while diets high in plant-based foods (ie. rich in fibre from fruits, vegetables and legumes) are associated with high *Prevotella:Bacteroides* ratios. The diversity of gut microbiota is also greater in long-term consumers of plant-based diets.

Short-term dietary shifts can also affect gut microbiota. The a*d libitum* intake of entirely animal-based diets (meats, eggs and cheeses) or plant-based diets (grains, legumes, fruits and vegetables) rapidly (five days) alters gut microbiota (David *et al.*, 2014). In the animal-based diet group, the amount and activity of microorganisms tolerant of bile acid (indispensable for the metabolism of animal fat) significantly increase, while those of bacteria essential for digesting plant polysaccharides decrease. Similar differences exist between herbivorous and carnivorous mammals. In addition, data suggest that foodborne microbes can survive the transit through the digestive system and may be metabolically active in the gut.

A number of studies on the gut microbiota of the Hadza, a community of hunter-gatherers in Tanzania, offer a unique insight into the traces that the perhaps most fundamental causes of dietary shifts in history – the advent of agriculture and animal domestication, and industrialization – may have left in humans' biological composition (Fragiadakis *et al.*, 2018; Rampelli *et al.*, 2015; Schnorr *et al.*, 2014; Smits *et al.*, 2017). The comparison of the gut microbiome of the Hadza with that of other populations from both developing and industrialized countries around the world reveals a close correlation between gut microorganism profile and lifestyle (hunting-gathering, rural agricultural, industrial/Western), which is probably attributable to diets. The levels of microorganisms related to the digestion of fibre are much higher in the guts of the Hadza. Particularly, Hadza people possess significantly more microbes that help digest complex polysaccharides from refractory plant foods than rural agricultural populations in certain developing countries. One striking discovery is that *Bifidobacterium*, which infants obtain though breastfeeding and is usually one of the dominant genera in gut microbiota, is completely absent in the guts of the Hadza. A possible explanation is that the Hadza diet doesn't contain any foods from agriculture and domesticated animals, which make up almost all diets elsewhere in the world. Intra-Hadza differences in gut microbiota composition are observed between sexes and seasons. This substantiates the modulatory effects of diets, because such differences are in accordance with the distinctions in Hadza diets between sexes (due to the division of labour, women consume more plant foods, while men consume more game meat and honey) and seasons (meat consumption is higher during the dry season than during the wet season).

The absence of *Bifidobacterium* challenges the habitual thinking that some gut microorganisms are indispensable for human health. Indeed, many probiotics and functional food products rely on *Bifidobacterium* strains for their health benefits. This finding, however, suggests that the lack of *Bifidobacterium* in the gut does not affect health negatively if the intake of foods related to this genus is low; hence, the basis for these health claims becomes questionable. Indeed, the health benefits brought by probiotics, even for strains that have been used for a long time, may be diet-dependent.

3. GUT MICROBIOTA AND HEALTH

There is by far enough evidence to safely assert that shifts in diet can cause changes in gut microbiota composition, relatively fast. The next piece of the puzzle is how such changes translate into health conditions, as this may offer some insight into the presumed link between the worldwide popularization of Western diets (characterized by high levels of calories and processed foods) and the surge of NCDs.

Current research attempting to elucidate the molecular mechanisms of how dietary nutrients and patterns affect human physiology via gut microbiota are reviewed in detail by Gentile and Weir (2018) and Zmora, Suez and Elinav (2019). Plenty of animal and human studies have recorded the responses of gut microbiota to nutrient changes in diets, as well as their subsequent physiological impacts.

The literature identifies a number of molecular signalling pathways by which gut microbiota may relate to metabolic syndromes. A high-fat diet increases the amount of bacteria that contain lipopolysaccharide (e.g. in Gram-negative bacteria's outer membrane) in gut microbiota. Elevated lipopolysaccharide levels in the human body induce inflammatory responses, insulin resistance and obesity. If this state persists for a certain period of time (e.g. in the case of a long-term high-fat diet), the onset of NCDs could be inevitable. Similar explanations can be formulated for the negative effects of red meat (L-carnitine in red meat converted to trimethylamine oxide by gut microbiota) and the benefits of fibre (fermented in guts to produce short-chain fatty acids). However, there are still many gaps in the literature. In addition, more studies that consider entire diets, rather than focusing on single nutrients, are needed.

In patients already suffering from NCDs, changes in gut microbiota are observed. This has been reported for cardiovascular diseases, diabetes, hypertension, asthma, some types of cancer, inflammatory bowel disease, neurodegenerative diseases, etc. (Althani *et al.*, 2016; Dietert and Dietert, 2015; Noce *et al.*, 2019; West *et al.*, 2015). It should be noted that the links reviewed in these papers are correlations or associations only, and are not substantive enough to claim that gut microbiota dysfunction causes NCDs.

4. TREATMENT AND SUPPLEMENT TARGETING GUT MICROBIOTA

Evidence suggests that interventions to restore the balance of gut microbiota may be a treatment method for NCDs and other conditions. Not surprisingly, such efforts have been undertaken frequently in recent years. There are two common intervention methods: administering pro-, pre-, and synbiotics, and fecal microbiota transplantation. Only the first type is discussed in this paper.

Dietert and Dietert (2015) list numerous studies that show that administering pro, pre- and synbiotics is effective against several NCDs. The authors propose an approach of microbiome management that involves monitoring and adjusting personal microbiota throughout different stages of life, from infancy to adulthood. Noce *et al.* (2019) and West *et al.* (2015) provide additional information, expanding the range of administered reagents and diseases targeted. The outcomes are generally positive, although there are studies reporting little or no improvement. Markowiak and Śliżewska (2017) focus more on human clinical trials. It should be noted that all these reviews treat the subject from a medical angle, i.e. pro-, pre- and synbiotics are considered as drugs to treat patients with NCDs and to protect other vulnerable groups (infants, elderly).

Unfortunately, the literature exploring the topic for disease-free population groups is limited. The only systematic review available is that by Kristensen *et al.* (2016), who evaluate the possible effects of probiotic supplementation on the composition of fecal microbiota in healthy adults. The authors screened the existing literature based on rigid principles (healthy subjects, randomized controlled experiments, no combination of probiotics with other substances), and considered seven studies fitting for their scope. These studies did not present convincing evidence for consistent effects of probiotics on fecal microbiome, implying that probiotic supplementation might have no effect on gut microbiome in healthy adults. Another review (Khalesi *et al.*, 2019) suggests that healthy adults (and in particular, older adults) may achieve some health benefits from the consistent use of probiotics, but it is likely that such benefits only exist in specific cases or conditions. The majority of reports show that probiotics intake can only induce transient changes (lasting one to three weeks after the supplementation stops) in the gut microbiota of healthy people, although passing through the gut might be enough to achieve some health benefits. The review also finds that probiotics supplementation can increase some health markers such as immune system responses, stool consistency, bowel movement and vaginal lactobacilli concentration; however, the evidence is insufficient to prove that probiotics can help improve blood lipid profiles.

Many fermented foods contain microorganism strains that are similar to commercial probiotics, and plenty of human studies have argued that they are beneficial to health. As reviewed by Marco *et al.* (2017), the supplementation of various types of fermented dairy, vegetable and soy products has positive impacts on obesity, cardiovascular diseases, type 2 diabetes, inflammatory bowel diseases and other immune-related diseases, and brain activity. However, the physiological mechanisms of these effects, and whether and how gut microbiota is involved, remain unclear. An interesting study using healthy adult female monozygotic twins found that the mid-term consumption (four months) of fermented milk products containing commercial probiotic strains causes no significant changes in the subjects' fecal bacterial species composition (McNulty *et al.*, 2011).

5. SUMMARY AND FUTURE DIRECTIONS

There is now adequate evidence to demonstrate that diets play a critical role in shaping gut microbiota, and that dietary change leads to shifts in microbiota composition. Based on the known functions of bacteria in gut microbiota, it can be inferred that such shifts may increase or decrease the levels of some metabolites from food nutrients, which would trigger subsequent physiological pathways believed to contribute to the onset of a few NCDs. However, due to the complexity of the human physiological system, the link between microbiota, nutrient metabolites and NCDs is not as firmly established as that between diet and microbiota – although correlations are manifest in some cases.

Many efforts have been made to fine-tune gut microbiota to protect against NCDs and other diseases through the supplementation of pro-, pre- and synbiotics. The results range from positive to no effect, highlighting the complexity between different diseases, treatments and populations; where positive effects are observed, it remains to be ascertained whether such effects are mediated by gut microbiota. In addition, current evidence shows that the impacts of the supplementation of probiotics on gut microbiota are temporary. The current literature has demonstrated the notable differences in gut microbiota composition between populations. However, clinical studies are scarce outside the Western world, and even within the West, there are very few population comparisons. Initiatives such as the NIH Human Microbiome Project (www.hmpdacc.org), American Gut (www.americangut.org) and Earth Microbiome (www.earthmicrobiome.org) intend to collect a colossal amount of data on the human microbiome around the globe, to elucidate the composition of gut microbiota and their functions at the level of populations. Combined with detailed dietary intake data, these data will help understand the relationship between diet and gut microbiota.

Another prospect is the wide availability and application of individual gut microbiome data, perhaps similar to the recent trend of individual genome sequencing. Technological advancement has made individual genome sequencing services fast, reliable and affordable, and companies providing such services to the public fuel its popularity. In the medical field, clinical-level individual genome sequencing and subsequent targeted therapy for some types of cancer have achieved considerable success. Although there is still a long way to go, individual gut microbiome data could serve as a foundation for personalized nutrition, which may be a solid answer to NCDs. Due to the multifactorial nature of most NCDs, it is difficult to assert whether such an approach based on gut microbiota would be successful – the prospect is, however, undoubtedly promising.

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