Fine tuning European geographic quality labels, an opportunity for horticulture diversification: a tentative proposal for the Spanish case

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Declarations of interest: none

Abstract
European horticulture, especially in the southern states, must exploit new qualities to increase the added value of its vegetables. This article aims to analyze the situation of the European geographical quality labels Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) to ascertain whether they are useful for this purpose. To this end, we studied the registers of the current horticultural products awarded PDO or PGI status, and we surveyed the authorities responsible for managing the labels for these products. We found that protected labels have grown steadily since their inception about thirty years ago, becoming a powerful mechanism for landrace conservation and a source of added benefits. The strongest points in the management of these labels include anchoring the products in the local history and culture roots and defining the prominent characteristics of their external appearance, and the weakest points are the lack of information about chemical traits and especially about sensory traits (texture, odor, taste). To strengthen PDO and PGI labels, we propose increasing the requirements for sensory descriptions, homogenizing protocols for analyzing sensory traits, incorporating methods combining trained sensory panels and instrumental methods such as spectroscopy, and involving public administrations in both obtaining and managing the labels. As an example of the potential impact of European geographical labels on territorial rebalancing and the organization of European horticulture, we propose a panoply of products in Spain that are good candidates for protected status.

Keywords
Sensory analysis, food control, Near Infrared Spectroscopy, NIR, agrobiodiversity, Protected Designation of Origin, Protected Geographical Indication, landraces

1. Introduction

1.1. Quality as added value in agri-food products
Quality lies in the eyes of the beholder. Researchers, farmers, and processors tend to view quality in terms of the fruit or vegetable's inherent attributes such as sugar content, color, or firmness; by contrast, consumers, marketers, and economists tend to view quality in terms of consumers' demands and needs (Shewfelt, 1999). The European Commission considers food

quality to be a complex, multidimensional concept including nine items related to nutritive, sensory, or ethical aspects (European Commission, 2019a). The term "quality", beyond its relationship with the characteristics of a product, conveys a positive connotation of high value, class, or degree of excellence (Barrett, Beaulieu, & Shewfelt, 2010). Thus, Kramer (1965) defined food quality as the combination of characteristics that differentiate the individual elements of a product that determine the level of acceptability or desirability of those elements for the people that use the product.

Agri-food production should aim to satisfy consumers, meeting their needs, fulfilling their expectations, and satisfying their desires. It is important to remember that consumers' preferences vary widely among countries and regions, as well as within regions, depending on factors such as age, gender, socioeconomic level, and educational level; moreover, these preferences change over time (Dagevos, 2005; Roininen et al., 2001; Verain, Sijtsema, & Antonides, 2016). One well-studied case is the difference in the sensory preferences of consumers of olive oil in different countries: whereas Spanish consumers prefer strong-flavored green oils with fruity and spicy notes, consumers in North America generally prefer milder-tasting oils with fruity and flowery notes. Nevertheless, preferences vary even within countries; for example, although most Italians prefer strong-flavored oils, this preference is more marked in the south than in the central and northern regions of the country (Cicerale, Liem, & Keast, 2016). Other examples of geographical differences include preferences for different types of grains of rice among countries (Suwannaporn & Linnemann, 2008) and preferences for sweet or tart apples in different regions of Europe (Bonany et al., 2014).

Nowadays, food is plentiful in developed countries, although it may be unequally available to all members of society. Logically, once alimentary needs are satisfied, consumers can prioritize characteristics of food beyond its price, making it necessary for producers and agents in the food chain to try to satisfy their priorities (Sijtsema, Linnemann, Gaasbeek, Dagevos, & Jongen, 2002). In addition to the increased focus on internal quality, consumers are increasingly showing interest in the impact of growing practices on the environment (organic versus conventional agriculture) or in the origin of the food they buy (local or regional products, zero km food) (Magnusson, Arvola, Hursti, Åberg, & Sjödén, 2003; Moser, Raffaelli, & Thilmany-McFadden, 2011). It is worth noting, however, that consumers base many decisions on beliefs (i.e., their own perception of quality) that can differ from "true" or measurable quality (Grunert, 2005; Palma, Collart, & Chammoun, 2015). For this reason, consumers' decisions are subject to fads that can make it difficult to consolidate stable production models.

A good example of how consumers' perceptions can diverge from objective quality measures is organic fruits and vegetables, for which both the demand and supply have grown significantly in recent decades (Lee & Hwang, 2016). This growth is largely due to many consumers' perception that organic products are more flavorful, healthier, and better for the environment than non-organic products (Dinis, Simoes, & Moreira, 2011; Hwang & Chung, 2019; Rana & Paul, 2017). The fact is, however, that to date the evidence from scientific studies on the relative health benefits of organic products is inconclusive (Barański, Rempelos, Iversen, & Leifert, 2017; Smith-Spangler et al., 2012; Vigar et al., 2019). Nevertheless, many studies have shown that consumers are willing to pay more for organic products (Brugarolas, Martínez-Carrasco, Martínez-Poveda, & Rico Pérez, 2005; Loureiro & Hine, 2002; Maguire, Owens, & Simon, 2004; Skreli et al., 2017; Zander & Hamm, 2010), and it seems reasonable to assume that they might also be willing to pay more for other perceived quality characteristics such as geographical origin or tradition; some studies suggest this is the case (Balogh, Békési, Gorton, Popp, & Lengyel, 2016; Carpio & Isengildina-Massa, 2009; Grebitus, Lusk, & Nayga, 2013; Miller et al., 2017). Thus, it seems that consumers in wealthier countries are making choices based on perceived quality features rather than on price (Grunert, 2002; Profeta, Balling, & Roosen, 2012), suggesting that the time is right to offer agri-food products with different quality features.

1.2. The sensory phenotype

Sensory quality (i.e. quality perceived through the senses) can be difficult to define because it depends not only on the intrinsic properties of the food, but also on the consumer's interaction with those properties (Casañas & Costell, 2006). Human beings' experience of food involves not only sight, taste, and odor, but also touch and hearing. To assess food quality, consumers integrate sensory inputs related to visual appearance, odor, flavor, texture, feel in the hand and in the mouth, noise on chewing, etc. (Abbott, 1999). Eating generates nerve impulses that carry information to the brain, resulting in different types of responses to the stimuli: an objective identification of the perception (e.g., this is sweet), a subjective reaction (e.g., I like it/I don't like it), and/or an emotional response (e.g., this reminds me of summer vacation).

Sensory quality can be objectively evaluated by sensory analysis, defined as "the science involved with the assessment of the organoleptic attributes of a product by the senses" (ISO, 2008a). Techniques have been established and consolidated for the sensory assessment of organoleptic attributes of some processed products (e.g. wine, olive oil, or cheese), and standardized approaches have been used to evaluate these products for years (Amerine & Roessler, 1976; Etaio et al., 2010; IOC, 2018; ISO, 2008b; Talavera-Bianchi, Chambers, Carey, & Chambers, 2010). Recent years have also seen significant advances in the sensory analysis of fruits such as apples (Corollaro et al., 2013), pomelo (Rosales & Suwonsichon, 2015), and peaches (Belisle, Adhikari, Chavez, & Phan, 2017), as well as of horticultural products such as potatoes (Montouto-Graña, Fernández-Fernández, Vázquez-Odériz, & Romero-Rodríguez, 2002; Thybo & Martens, 1998), tomatoes (Hongsoongnern & Chambers, 2008), lettuce (Lespinasse, Navez, Jost, Thicoïpé, & Pain, 2001), and dry beans (Romero del Castillo, Valero, Casañas, & Costell, 2008).

Consumers generally believe that the flavor of fruits and vegetables has declined over the years (Bartoshuk & Klee, 2013). This perception is probably due to the dilution of key molecules as a consequence of increasing yields mainly through increasing carbohydrate and water content as well as of pleiotropic effects of breeding fruits and vegetables for longer shelf-life (Davis, 2009). However, these beliefs could also be partly due to psychological factors such as a nostalgic longing for "the good old days when everything was better" (Holbrook, 1993). Consumers perceive only the sensory phenotype, although like other traits, sensory traits result from genetic and environment effects as well as from the interaction between genetic and environment factors. Furthermore, perception also depends on consumers' own phenotype. The changes in genetic and environmental factors during the Green Revolution that brought about huge increases in yields had negative effects on sensory traits. As the main goal of scientific breeding programs was to increase production both directly and indirectly (e.g. by increasing resistance to stresses), the ideotypes failed to include other quality-related attributes, possibly because these traits often depend on multiple genes, making them difficult targets to work toward (Bell & Janick, 1990; Causse, Buret, Robini, & Verschave, 2003; Marsh, Paterson, Seal, & McNeilage, 2003; Quilot-Turion & Causse, 2014; Salazar et al., 2017). Consequently, yield and sensory quality tend to be negatively correlated both at the genetic and environmental levels. At the environmental level, the negative correlation can be explained by changes in farming practices to maximize yields (fertilization, irrigation, etc.) and harvest stage (Davis, 2009, 2011).

Tomatoes are a paradigmatic example of the loss of quality in horticultural products. Consumers rate the organoleptic quality of tomatoes poorly, and complaints about the sensory profile of commercial tomatoes have been noted for more than 40 years (Bruhn et al., 1991; Hobson, 1988; M. Kramer, 1980). All the factors discussed above have degraded the sensory and nutritional quality of tomatoes, including the use of wild varieties as donors of genes that confer resistance and the introgression of part of the wild-type genome into cultivated tomatoes (Causse et al., 2013). This topic has been debated extensively, and in addition to the references cited, more information is available in Morris and Sands (2006), Jenks and Bebeli (2011), Tieman et al. (2017), and Causse et al. (2020).

1.3. European Union geographical labels as a strategy to promote quality in horticultural products

To consolidate the market for a product beyond fads or fashions, we must target consumers' preferences, ensuring that the product has objective qualities that consumers value. It is difficult for agri-food companies to gain recognition for quality-related traits (nutritional, sensory, cultural, historical) in their products. After achieving a product that meets the objective quality criteria, producers must strive to guarantee that every lot of products that reaches consumers fulfills these criteria. Product labels should include detailed descriptions of their nutritional and sensory characteristics from rigorous analyses. The process of achieving products with quality traits that differentiate them from others and of defending these products in the market is expensive; to date, only wealthy companies have been able to accomplish this for a few select products (the main European brands of international distribution, with well-identified goods and easy traceability). An alternative approach is to seek recognition through quality designations conferred by public institutions. This approach is often the only option for associations of producers that work with a product with objectively differential traits but lack the financial resources to gain and maintain market recognition for it (Bardají, Iráizoz, & Rapún, 2009; Dias & Franco, 2018; Hajdukiewicz, 2014; Likoudis, Sdrali, Costarelli, & Apostolopoulos, 2016). The European Union has two broad categories of protected designation for food: "Quality Labels" and "Organic Certification". The most widely known are "Geographical Indications" in the Quality Labels category (European Commission, 2019b).

The European Union's geographical designations were created to promote rural development and territorial economic balance by recognizing products that can be considered special because of their historical value, particular management, adaptation to the local environment (low inputs), sensory quality, nutritional value, germplasm that has evolved together with the people who grow it over a long time (this aspect is difficult to quantify), and ties to the gastronomy and/or cuisine of a particular geographical zone. Thus, many added-value traits can be quantified to a certain degree. However, in general, these products often come from low-yielding varieties grown in extremely small areas, so producers cannot promote them or control their evolution by taking advantage of new technologies.

Agri-food products can aspire to various European quality labels and the demands that producers must meet to achieve these designations vary. The labels that place the greatest emphasis on the raw materials are Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI).

European Union regulation R 1151/2012 (European Commission, 2012) stipulates that a PDO identifies a product that: i) is produced in a determinate location, region, or, exceptionally, country; ii) owes its quality fundamentally or exclusively to a particular geographical environment comprising its inherent natural and human factors; and iii) is elaborated totally within the defined geographical area throughout all stages of production. The raw material must be produced within the designated area, preferably with autochthonous genetic material. For these reasons, most PDOs are based on one or more landraces.

The same European Union regulation (R 1151/2012) stipulates that a PGI identifies a product that: i) is produced in a determinate location, region, or country; ii) has a certain quality, reputation, or other characteristic that derives essentially from its geographic origin; and iii) is elaborated at, least partially, within the designated area. PGI designation does not require the product to be based on a landrace.

Each geographical designation is governed by a regulatory board made up of producers; in this way, the first benefit of the designation is to promote an alliance of producers that favors collaboration among small businesses in the primary sector. In a sense, producers become a sort of cooperative in which companies maintain their individuality but often share equipment, germplasm, marketing campaigns, or research and development projects funded with government grants. Moreover, geographical designation labels protect against intrusion from market competitors, who cannot use the proprietary name for their products. These labels also help to ensure consumer loyalty by guaranteeing the quality of the product. Finally, a quality label awarded by the European Union can improve access to international markets, at least within the Union itself.

All these benefits can increase producers' and processors' incomes and stimulate growth. For example, data from the Ministry of Agriculture in Spain show that the number of quality labels in Spain and resulting income have continued to grow (MAGRAMA, 2018). Between 1996 and 2013, the economic value of horticultural products that enjoy PDO status grew more than 8-fold more than the overall horticultural sector in Spain (Romero del Castillo, Simó, Casals, & Casañas, 2018). The mean increase in the entire European Union was less pronounced, but also notable; prices for products with quality labels are 50% higher than for those without quality labels, and sales increases are 8% higher (Hajdukiewicz, 2014).

Beyond direct economic benefits, geographical labels provide many indirect benefits such as helping to stop rural depopulation, promoting more equitable wealth sharing, guaranteeing the characteristics of the product for consumers, and providing consumers with objective guidance about the quality attributes of the product (Grunert & Aachmann, 2016; Likoudis et al., 2016), as well as favoring the recognition and prestige of quality agricultural products, the protection of low-input approaches that are well-adapted to local conditions, the survival of traditions by keeping them up to date, the prestige of traditional farming know-how and historical culture of rural areas, and the conservation of crop biodiversity through germplasm use (*in situ* conservation) (Casals et al., 2019; Dias & Franco, 2018).

1.4. Challenges and opportunities facing horticulture in Southern Europe

Nowadays, vegetables (and legumes normally grown in small plots) from Southern Europe must compete with products from countries outside the European Union where production costs are low (e.g., those in North Africa), as well as those from other countries within the European Union that use highly developed cultivation technologies to obtain extremely high yields (e.g., the Netherlands, where greenhouses yield 700-900 t/ha of tomatoes vs. 40-100 t/ha in open-air cultivation and 150-200 t/ha in greenhouse in Spain (Heuvelink, 2018)). As the costs of using the most advanced greenhouse technologies decreases (e.g., from using sunlight rather than gas to heat), greenhouses will become even more profitable. Moreover, advanced greenhouses can be placed near the areas where consumers are located, reducing transportation costs. Thus, if Southern European countries are to remain competitive in supplying horticultural products to the European Union, they must change production strategies to obtain products that will command higher prices.

Biogeographical and historical factors have made the South of Europe a center of diversification for many horticultural species, such as lettuce, tomato, bean, or cabbage, among others

(Vetelainen, Negri, & Maxted, 2009). The genetic makeup of these species has evolved together with agro-ecosystems and human preferences, creating a panoply of landraces that are highly adapted to local cultivation conditions and figure prominently in local dishes (Casañas, Simó, Casals, & Prohens, 2017). Within this rich diversity of genetic resources, some genotype-by-environment combinations result in unique sensory and nutritional profiles (Casals et al., 2011; Sanchez, Sifres, Casañas, & Nuez, 2008) that confer singular gastronomic potential (Westling, Leino, Nilsen, Wennström, & Öström, 2019).

Moreover, thorough adaptation to local conditions is intertwined with other elements related to consumers' perception of quality, such as low inputs, preservation of natural resources (Smale, Bellon, Jarvis, & Sthapit, 2004), or cultural aspects (Jordan, 2007). Previous studies have shown that consumers are receptive to marketing strategies that include these elements (Brugarolas, Martinez-Carrasco, Martinez-Poveda, & Ruiz, 2009).

1.5. Objectives

In this context, we aimed to explore the following aspects of European geographic labels for horticultural products: i) The evolution of the PDO and PGI labels since their creation, ii) The stringency of the descriptions of the protected products as laid out in the documents filed with the European Union, iii) The extent to which PDO and PGI designations have achieved the objectives stipulated at their creation in 1992 (Council of the European Union, 1992), iv) The potential usefulness of PDO and PGI as tools for increasing profits and restoring territorial balance in the case of Spain.

2. Methods

2.1. Monitoring the European geographic labels

2.1.1. Characterization based on specifications in product registration

We analyzed horticultural products protected under a geographical quality label that are listed in the eAmbrosia database (European Commission, 2020a). Information for each product was obtained from registration specifications included in the "single document" (a detailed document summarizing the characteristics of each protected product) and from the webpages of the regulating boards, when available. Before characterization, a list of 35 attributes to be extracted from each study-case was prepared (Figure 1). The date of registration of each product was used to study the evolution of the number of European quality labels since their inception.

2.1.2. Survey

To obtain more information regarding each label, we surveyed the managers of the listed PDOs and PGIs to determine their level of knowledge about the regulations for the products that they manage and the actions that they take to ensure compliance with these regulations. The survey included questions regarding the varieties cultivated, the attributes that sustain the distinctiveness of the product, the certification of the quality attributes, and the impact the brand has had on the marketing of the product (Figure 2). We focused on sensory attributes, because consumers can easily check them to see whether the product has the characteristics that the label claims it has and because consumers are unlikely to choose a product based only on its chemical composition. We emailed the survey to the regulatory boards of the 166 labels in force in January 2020 on three successive occasions, clearly explaining the objectives of the study and assuring potential respondents that their anonymity was guaranteed and that we were only interested in the statistical value of their responses.

2.2. The case of Spain

Departing from the present map of Spanish geographic labels, we aimed to construct a new map with a list of potential candidates to be protected under a geographic quality label. To this end, we first compiled a list of candidate varieties by examining publications from the Regional Agriculture Councils of the Spanish Autonomous Communities, when available. We were aware that this first approach would probably be biased by the wide heterogeneity in the quantity and quality of activities to promote landraces in each region. To refine the list, we assembled a group of experts, including at least one representative of each region. Group members were chosen based on their expertise in horticultural production in their region. Assuring them that their contributions would be kept confidential, we invited 18 experts to propose up to five horticultural products from their regions that would be suitable candidates for protection under a European geographic quality label, using the following criteria: i) Objectively superior sensory value attributable to the combination of the varieties used and the environment and/or the cultivation method, ii) Historical recognition of the quality of the product (≥40 years), iii) A sufficient number of farmers who can work together to manage the brand, and iv) A collective memory of its existence (even if it is currently weak). No quantitative scoring of the different criteria for each candidate product was required to the experts. So, we received only a prioritized list of varieties for each region according to their expertise.

2.3. Statistical analyses

Data collected about each label from administrative documents and from the survey were arranged in an Excel spreadsheet. Presence/absence attributes were transformed into binary variables (0,1) to allow calculations. The data were summarized with descriptive statistics. Statistical analyses were performed with R (R core team, 2019), using the package "ggplot2" for producing the graphs. Maps were elaborated using ArcGIS® software by Esri.

3. Results and discussion

3.1. A successful strategy that favors the conservation of agrobiodiversity

The number of horticultural products that have been awarded quality labels has grown continuously, although growth for the more-demanding PDO label has been slower than for the PGI label (Figure 3). In 2020, a total of 43 horticultural products had achieved PDO recognition and 123 PGI recognition. Thirty years after these labels first became available, groups of farmers who grow products that could benefit from geographical labels continue to strive to achieve this recognition, despite the costs of preparing the applications and of controlling the protected product.

The distribution of the labels among territories and species is linked to each country's historical and climatic characteristics, as well as to its size (Figure 4). The number is highest in the regions of Southern Europe, such as Italy, Spain, and Greece, which also have the highest numbers of species and varieties within species (Shannon's diversity index (Figure 4) (Shannon & Weaver, 1963)). The number of protected products decreases with increasing latitude, with the exception of Germany, which despite its cold climate has a high diversity index and a high number of products that have been awarded quality labels.

Despite the lack of clear information about whether the germplasm specified in the registration documents of some protected products constitutes a landrace or commercial variety, many quality labels (especially PDOs) do protect one or more landraces (Figure 5) and the number of protected species is high (Figure 6). Furthermore, many of the improved commercial varieties included in the geographical designations have long been grown in the specified area and are thoroughly adapted to its environment, so that their relationships to the area are similar to those of traditional varieties. Thus, the quality schemes help ensure the survival of some landraces, as well as of “obsolete cultivars” which behave like traditional varieties, that would likely have disappeared from the market otherwise (Casals et al., 2019).

3.2. Variable commitment in the labels’ description of singularity

The European Union regulations’ terms and conditions specify that detailed information must be compiled about a series of items related to the protected product: i) The genotype: Genus, species, type of germplasm (landrace or improved modern variety). ii) The phenotype: External sensory attributes perceived through sight (shape, size, color), internal sensory attributes perceived through the tongue, taste buds, palate, etc. (odor, taste, flavor, texture, etc.), chemical composition related to nutritional and/or sensory attributes (pH, soluble solids, diverse organic and inorganic compounds considered important), iii) Environmental effects: Precise description of the geographical area and the characteristics considered most important in giving the protected product its unique character (soil characteristics, climate, historical growing techniques, local customs, etc.), iv) Interactions between the genotypes and environmental characteristics of the area, expressed through the links between the varieties and the geographical area, that contribute to the singular, superior characteristics of the product, and v) The regulations that are to govern the production, transformation (when necessary), packaging, identification, commercialization, etc.

In summary, these documents include an array of characteristics that should make it possible to perfectly understand the product’s objective differential qualities that make it worthy of protection under one of the European Union’s quality schemes. Our review of the European documents found that items i, iii, iv, and v are clearly stated for nearly all products; these findings show that the descriptors of morphology, geography, management, and commercial aspects have been thoroughly studied and defined. This type of information changes little over time, so a single measurement suffices for the preparation of the document specifying the conditions. The labels’ specifications for these aspects are demanding and the regulations for most protected products state them explicitly.

However, for item ii (phenotype), the emphasis placed on measuring attributes varies widely among the different documents analyzed (Figure 7). The level of detail required for the products’ visual appearance is very high; the documents for 70% to 90% of the products specify at least one visual attribute. At the other extreme, attributes related with chemical composition are mentioned in only half of the documents, and these mentions are sometimes very imprecise, for example, specifying only “high nutritional value”. The most important aspects defended are thus related to the products’ historical and cultural value. Aspects related to sensory value and chemical composition seem less important; in fact, our analysis shows that the documents for very few products specify precise measurements to characterize these attributes (content of sugars, acidity, flavor and texture, etc.) In fact, measurements of sensory attributes by a trained panel are rarely mentioned, being compulsory in only 4% of cases (Figure 7). Thus, the degree of rigor required in characterizing the protected products varies widely.

In summary, the level of detail required in the descriptions of the products is generally high with respect to morphological and geographical aspects, but less precise with respect to internal sensory and chemical attributes defining phenotypes that will reach consumers. Details are usually only required for visual descriptions, and even these specifications tend to be imprecise and often qualitative. Thus, the level of commitment to ensuring the singularity of the protected products varies widely.

3.3. The need to reinforce control over the product that reaches consumers, as a guarantee of quality

The strength of private and public brands of horticultural products depends on the degree to which they target consumer preferences and to which their quality is consistent (i.e., guaranteed). Guaranteeing quality requires i) delimiting the quality characteristics of the product explicitly and quantitatively and ii) establishing mechanisms to ensure that the product that uses the brand's label scrupulously fulfills these characteristics. Our first approach analyzed the specifications for different traits in European geographical designations and found wide variability in the degree to which the protected products' regulations (taken from documents approved by the European Union) specify the quality markers that should defend the labels, and that some of these markers are imprecisely described. In a second approach to analysis (i.e., survey), we sought to determine the degree of control regarding whether the products fulfilled the phenotypical criteria specified in the regulations.

The overall response rate to the survey was 40% (41% of PDOs and 39% of PGIs). Despite the possible selection bias that could be introduced by voluntary participation, we consider that the response rate is high enough to provide an approximate view of the situation (Table 1).

According to the responses, among the PDOs, only landraces are authorized in 88%, and only modern improved varieties are authorized in 12% (Table 1). By contrast, among the PGIs, landraces are authorized in 74%, modern improved varieties are authorized in 26%, and both landraces and modern improved varieties are authorized in some (Table 1). The results of the survey clarify the information in the official documents and specifications, in which it is sometimes difficult to discern whether the authorized varieties are landraces or modern improved varieties and in which the percentage of landraces seems to be underestimated (Figure 5). The high percentage of protected products that use landraces confirms that the strategy used in European geographical designations promotes the conservation of traditional germplasm through its use.

The results of the survey also confirm the importance of the role of historical and cultural aspects for promoting the label that was observed in the analysis of the official documents. This is especially evident in the PDOs, where about 90% of respondents considered these aspects important for defending the brand (Table 1). In fact, it is surprising that about 10% were unaware that these aspects were included in the official documents, since we found that nearly all of them state that compliance with historical and/or cultural aspects is essential for permission to use the label.

The respondents' perceptions regarding the other attributes that must be controlled (Table 1) are similar to those that we found in our analysis of the specifications in the official documents (Figure 7). The most important attribute is the product's external appearance with all its variants (size, shape, color), and the least important is its chemical composition. Internal sensory attributes such as texture or flavor are of intermediate importance. Regardless of the type of attribute, the managers' degree of commitment to ensuring compliance is less than that specified in the official documents (Table 2).

The level of control of the external appearance and chemical composition of protected products is in line with the specifications outlined in the regulations. In contrast, the control of the internal sensory attributes does not reach the level specified in the regulations. In their responses, 71% of the managers state that they are supposed to control for internal sensory attributes, although the percentages stating that they control for specific aspects of the internal sensory profile are lower (49% for texture, 38% for taste, and 30% for odor). Thus, the level of control of internal sensory attributes seems insufficient to ensure compliance with the label (Table 2). For texture and odor attributes, compliance with the regulations is better for products with PDO status than for those with PGI status (Table 1).

It is surprising how seldom sensory panels are used to control internal sensory attributes. Whereas 71% of respondents state that the label must be committed to ensuring compliance with the internal sensory attributes specified in the regulations, only 21% claim that they use trained panels for descriptive testing. This laxity is likely due, in part, to the difficulties involved in descriptive sensory analysis, which requires training panelists (Lawless & Heymann, 2010; Meilgaard, Civille, & Carr, 2007). Nowadays, descriptive sensory analysis is an established scientific discipline, and protocols have been developed to analyze various horticultural products (e.g., Romero Del Castillo et al. (2012) in common bean, Simó et al. (2012) in onions, Hongsoongnern & Chambers (2008) in tomatoes, Talavera-Bianchi et al. (2010) in leafy vegetables, Lespinasse et al. (2001) in lettuce, and Lespinasse et al. (2002) for fruits and horticultural products in general). However, the procedures are laborious, and the number of samples that can be analyzed is low. Much work remains to be done to develop, refine, and establish protocols to analyze some horticultural products. Moreover, as suggested by Pérez-Elortondo et al. (2018), steps should be taken to standardize the methods of control to avoid comparative grievances among brands.

It is logical for regulatory boards of products that enjoy protected geographical designation to verify the external sensory attributes. The United Nations Economic Commission for Europe also uses external sensory attributes to classify horticultural products into the categories Extra, Class I, and Class II (UNECE, 2020). So, failure to provide sufficient information about sensory attributes or failure to ensure that products that use the label meet the specifications for these attributes undermines the label and weakens its position among other European labels such as Organic Farming that demand rigorous controls of the key differential attributes (European Commission, 2020b).

To ensure that the European Union's protected geographical designations achieve the objectives for which they were created, the branding of the protected products must be at least as strong as that of the best private brands. Strong branding requires clear definitions and scrupulous control of the attributes of the protected products. Our survey shows that protected status increases consumers' awareness of the products, the homogeneity of the protected products, and sales and consequently profits (Table 1). It seems that the perceived benefits are greater for products that enjoy PDO status than for those that enjoy PGI status (81% of respondents stated that profits increased with PDO status vs. 61% of similar responses with respect to PGI status (Table 1)). To date, protected geographical status does not seem to have as great an impact on internationalization of sales (only 29% of respondents stated that exports of their products had increased after being awarded protected status), so this is one area with room for improvement. On the other hand, half of the respondents considered that protected status had made administrative management more difficult (Table 1), but this drawback is inherent in all regulations.

3.4. Descriptive sensory analysis: a bottleneck in quality control that must be resolved

Assessing the appearance of horticultural products is relatively easy. Size, weight, shapes, and colors can be measured instrumentally. Moreover, visual impressions are also very important in European consumers' decisions (Moser et al., 2011), especially for their first purchase of a horticultural product. Thus, it is not surprising that external sensory attributes are the most used to control the acceptability of materials under the geographical designations. However, unless they correlate with other quality-related attributes, these external attributes represent generic qualities that are insufficient to define the protected products.

Internal sensory attributes constitute an essential component of a food quality, and these attributes provide added value to protected products. However, assessing internal sensory attributes is much more difficult because it requires descriptive analysis by a trained panel.

Sensory analysis by trained panels is slow and laborious, making this approach unfeasible for analyzing the large number of samples required for quality control of a label (Costa et al., 2011; Magwaza & Opara, 2015; Plans et al., 2014). Moreover, sensory panels may suffice for some seasonal products for which all lots are elaborated from the same raw materials (e.g., food products such as nougat, wine, oil, etc.), but they cannot be applied to horticultural products that can change over the production period because that would require many assessments to ensure that the products meet the quality criteria established in the regulations.

Consequently, other approaches must be sought to streamline the assessment of internal sensory attributes. Establishing correlations between chemical/physical parameters and sensory attributes can make it easier to assess large numbers of samples for quality control. Correlations with soluble solids content have proven useful in determining sweetness in horticultural products, as have various indices that use soluble solids content together with titratable acidity (Magwaza & Opara, 2015). Many techniques for sensory phenotyping have been tested, including visible/near-infrared spectroscopy; Raman spectroscopy; nuclear magnetic resonance spectroscopy; spectral imaging; time resonance spectroscopy; fluorescence; hyperspectral backscattering imaging; hyperspectral and multispectral imaging; ultrasonic, acoustic, and force impulse response; and the electronic tongue (Cakmak, 2019; Magwaza & Opara, 2015). The results achieved with most of these techniques generally do not correlate well with those of sensory panel analyses. The best results have been obtained with near-infrared spectroscopy (Chapman et al., 2019), and this technique has yielded good correlations with sensory panels for some attributes, as found in several studies such as those of Németh et al. (2019) in melons, Plans et al. (2014) in beans, Sans et al. (2020) in “calçots” (onion), Belie et al. (2003) in carrots, Escribano et al. (2017) in sweet cherries, Ferrer-Gallego et al. (2013) in grapes, François et al. (2008) in chicory, Kjolstad et al. (1990) in peas, Mehinagic et al. (2003) in apples, Valente et al. (2011) in mango, Van Dijk et al. (2002) in potatoes, or Peirs et al. (2003) in tomatoes.

In our opinion, it is essential to take three aspects into account when using these indirect techniques to predict sensory attributes: i) it is extremely important to have solid reference data; in other words, we need a good system for sampling the product, we need to include data from the whole range of variability that will be found later when we use indirect measures (we are not interested in general models; rather we are interested in models based on the rank of variation that we expect to find in the product to be evaluated). If we want to increase the robustness of the models (which might be interesting in breeding programs that work with a wide range of variability), we will decrease the precision of the models (whereas precision is what interests us in quality control). ii) The panel must be well trained to work within the interval of variation for the attributes. The more imprecise the panel’s evaluations are, the worse the model will be. iii) The parameters for measuring the models’ goodness of fit must be chosen carefully. We propose using relative ability of prediction estimators, which take into account both the imprecision of the model and the imprecision of the reference method (Martens & Naes, 1992). Only after comparing several series of estimated values against values obtained by the reference method can we propose cutoffs that would be acceptable for our purposes. So far, we have used this approach to document the sensory value of large collections of bean germplasm (Rivera et al., 2016) and for quality control of geographic labels (Plans et al., 2014; Sans et al., 2020).

3.5. The key role of public administrations in ensuring honesty in the implementation of policies for geographic quality labels

Our years of experience in working with protected geographical designations in Spain have convinced us that public administrations should work with cooperatives and associations of producers, leading initiatives for this type of recognition, especially for products that have slim profit margins, as is the case for raw materials. Public administrations should lead the process of identifying potential brands and should guide producers through the process of obtaining protected geographical status. Afterwards, they should oversee the management of the label until it can generate enough added value to enable it to hire its own staff for this purpose. Once the quality label has been achieved and consolidated, public administrations should continue to provide support to: i) help in the controlled multiplication of the germplasm of the landraces promoted by the quality label (owing to the low quantity of the seeds or propagules used, seed companies are uninterested because they see little opportunity for profits), ii) foster the evolution of the landraces; in other words, promote breeding programs to make the landraces more resistant to new pests and diseases as well as to improve their sensory and nutritional value, if necessary, and meet the demands of producers and consumers (Casañas et al., 2017), iii) improve management techniques, incorporating new technologies that optimize crop efficiency, iv) undertake marketing campaigns to promote protected geographical designation labels in general as well as particular labels, explaining what the labels mean and what they protect, and v) guarantee the labels. This point is especially important. The guarantee must be effective so that consumers can trust these types of labels. Consumers' trust can only be gained by unifying and strengthening the quality control criteria so that the degree of compliance required is the same for all European labels, thus ensuring fairness (Pérez-Elortondo et al., 2018).

3.6. The potential of European geographic labels for increasing profits and restoring territorial balance: the case of Spain

Spain's horticultural sector has the lowest mean profit margin of all countries in the European Union and one of the lowest in the world (Galdeano-Gómez, Céspedes-Lorente, & Rodríguez-Rodríguez, 2006; Iráizoz, Rapún, & Zabaleta, 2003). The depopulation of rural areas is also an important problem in Spain (Collantes & Pinilla, 2011). Expanding the market for horticultural products can help small-scale producers and thus mitigate the decline in the rural population.

At present, 35 European geographical labels protect Spanish horticultural products. These are distributed unevenly throughout Spain's autonomous regions, probably because some regional administrations promote European quality schemes more than others (Supplementary Figure 1). There is, however, much room for growth. We consulted specialists in all the regions, and they have proposed 82 products that could be candidates for protected geographical status (Figure 8), according to the criteria set out in 2.2 section. Despite the tendency for these areas to be concentrated in certain regions, the map includes the 82 proposals distributed in 71 epicenters. Obviously, the lack of traditional horticulture in many areas due to the environmental conditions limits the possibilities. Nevertheless, even focusing only on the labels for horticultural products, there is much that can be done to revitalize Spanish horticulture and to bring it up to date in terms of sensory quality and proximity.

4. Conclusions

The European Union's protected geographical designations were devised to foster economic and social growth in rural communities. This objective is especially relevant for labels that protect horticultural products. Our analysis of the situation revealed that these objectives have been achieved only in part, because the degree of control exercised over quality attributes beyond those related to the products' historical and cultural value is clearly insufficient, and many products that could potentially benefit from quality labels have failed to apply for protected status (at least in Spain, which we have used as a case study). Moreover, the use of landraces, another potential strength of these quality schemes (conserving agrobiodiversity through use), can be improved, as is demonstrated by the smaller number of PDO labels (which place a greater emphasis on using landraces) than PGI labels. Thus, existing labels for horticultural products must be strengthened, and efforts to establish new labels for other products must be encouraged, especially in Southern Europe where bioclimatic and historical conditions are most favorable. These efforts should include: i) encouraging the use of landraces and promoting their evolution toward higher-quality products; ii) including sensory attributes in the descriptions of the horticultural products that achieve protected geographical status, providing descriptions of the most important attributes through numerical scales and guaranteeing the absence of determinate sensory defects; iii) agreeing on and developing standardized methods for the sensory analysis of each kind of horticultural product that could provide reference values for the European Union; iv) advancing toward indirect technologies that would permit routine screening for products that are clearly outside the acceptable limits for the labels; and v) persuading public administrations to take the lead in European quality schemes.

Acknowledgements

We thank the local agents involved in managing the European quality labels for horticultural products (supervisory boards, regulatory bodies, etc.) for responding to the questionnaire and to our questions. We also thank the people in the different regions of Spain who helped by sharing their profound knowledge of local particularities in proposing new protected geographical designations for horticultural products. Without all their help, this study would not have been possible.

Author Contributions

Roser Romero del Castillo: Conceptualization, Formal analysis, Data curation, Original draft, Writing–review & editing. **Silvia Sans**: Conceptualization, Data curation, Funding acquisition. **Francesc Casañas**: Conceptualization, Formal analysis, Data curation, Original draft. **Salvador Soler**: Conceptualization, Data curation, Writing –review & editing. **Jaime Prohens**: Conceptualization, Data curation, Writing–review & editing. **Maria José Diez**: Conceptualization, Data curation, Writing–review & editing. **Joan Casals**: Conceptualization, Formal analysis, Funding acquisition, Writing–review & editing.

Funding sources

This work was supported by the "Departament d'Agricultura de la Generalitat de Catalunya".

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Table 1.- Statistical summary of the responses to the questionnaire sent to the regulatory boards and certifying bodies. They were asked about the kind of varieties accepted in each label, the quality attributes they remembered were present in the specifications, the attributes that are actually verified, and the perceived socioeconomic effects of the product's protection under the label. Data are expressed as percentages of the completed questionnaires.

	All labels	PDO	PGI
	Varieties accepted according to managers' knowledge		
Landraces	78	88	74
Modern improved	27	12	33
	Attributes present in the rules according to managers' knowledge		
Historical	84	94	81
Cultural	75	88	70
External appearance (morphology)	83	94	78
Sensory	71	71	72
Chemical	38	47	35
	Attributes actually controlled according to managers' knowledge		
Size	76	82	74
Shape	79	88	76
Color	79	82	78
Texture	49	71	41
Smell	30	53	22
Taste	38	47	35
Chemical composition	40	53	35
	Sensory attributes scored by a sensory panel, according to managers' knowledge		
None	21	24	20
	Socioeconomic consequences of the label		
More advertising	67	94	74
Sales increase	63	94	69
Market internationalization	29	47	29
More homogeneity	58	75	63
Increased profit	61	81	67
Administrative drawbacks	39	50	44

Table 2. The percentage of labels that control compliance with aspects related with the three groups of attributes according to the official documents, the percentage of labels for which the respondents remember are defined in the official documents, and the percentage of labels that the respondents claim they actually control.

	Attributes that are controlled according to official documents	Respondents' memory of attributes controlled according to the documents	Attributes that respondents claim are controlled
External appearance	95	83	79
Internal sensory attributes	73	71	41 (21 by descriptive analysis by panel)
Chemical composition	50	38	40

Figure captions

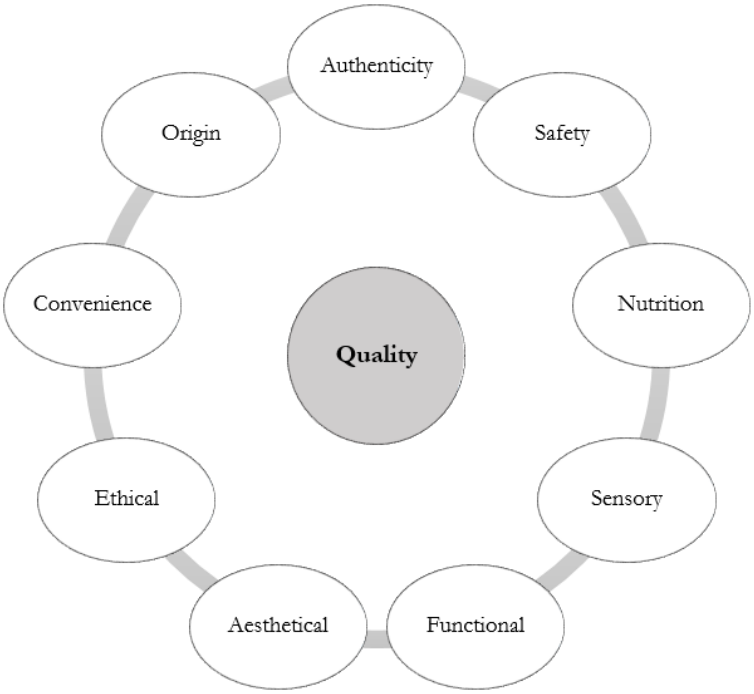


Figure 1. Components of food quality (modified from European Commission, 2020a)

Figure 2. The logos of the two main geographical labels awarded by the European Union that mainly protect the raw materials (R 1151/2012 (OJEU, 2012))

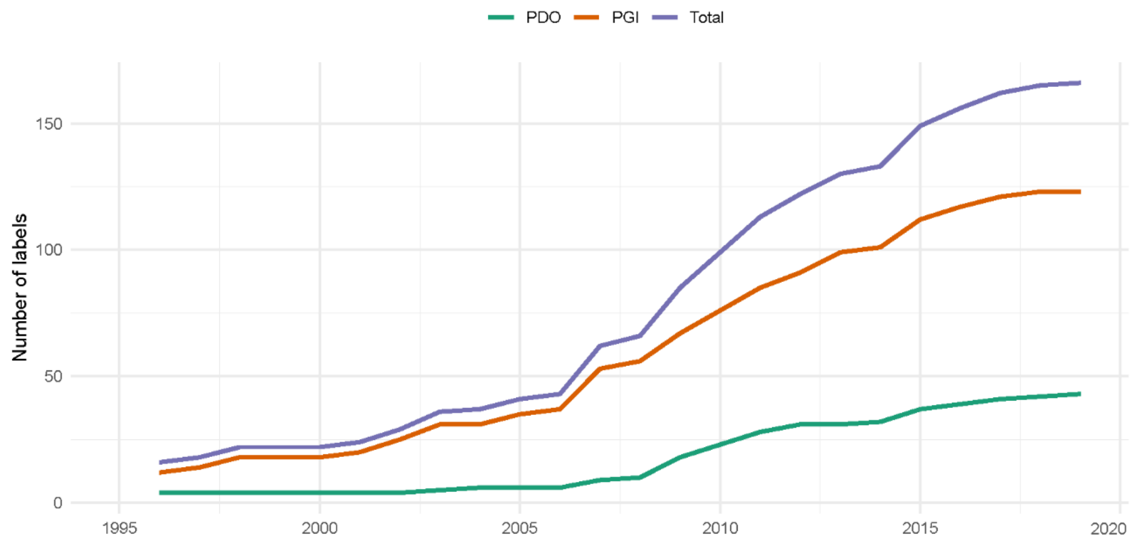


Figure 3. Evolution of the number of PDOs, PGIs and total labels, for horticultural products since the creation of these quality awards.

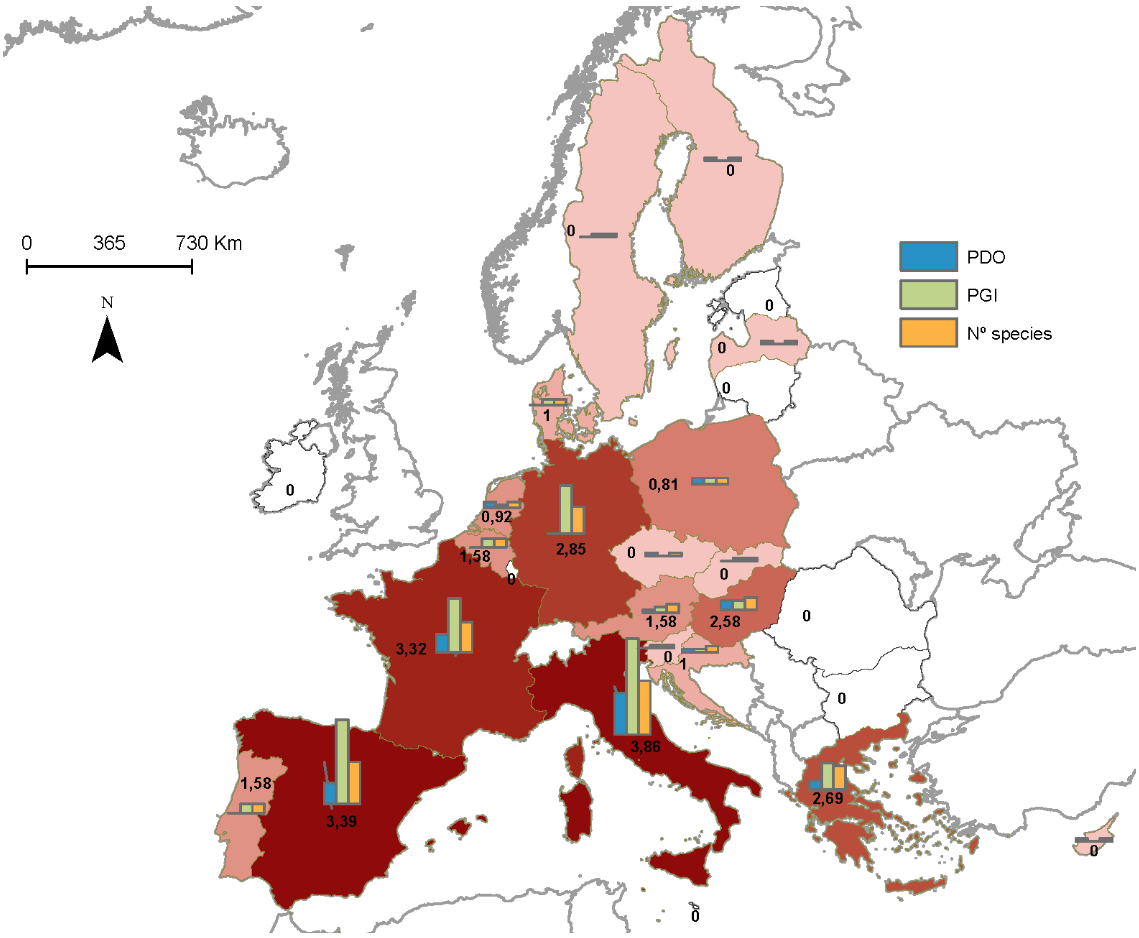


Figure 4. Map showing the number of geographical quality labels (PDO and PGI) for horticultural products awarded to countries in the European Union, the number of different species involved, and the Shannon-Weaver diversity index (1963), which provides information about the diversity of horticultural products protected with the geographical quality labels in each country, calculated as H=-$\sum p_i \log_2 p_i$, where p_i is the probability of the occurrence

of a variety into a species $_i$, and $\sum p_i=1$. The shading of each country reflects the number of total labels of each country (white=0 labels; increasingly darker shades=increasingly more labels).

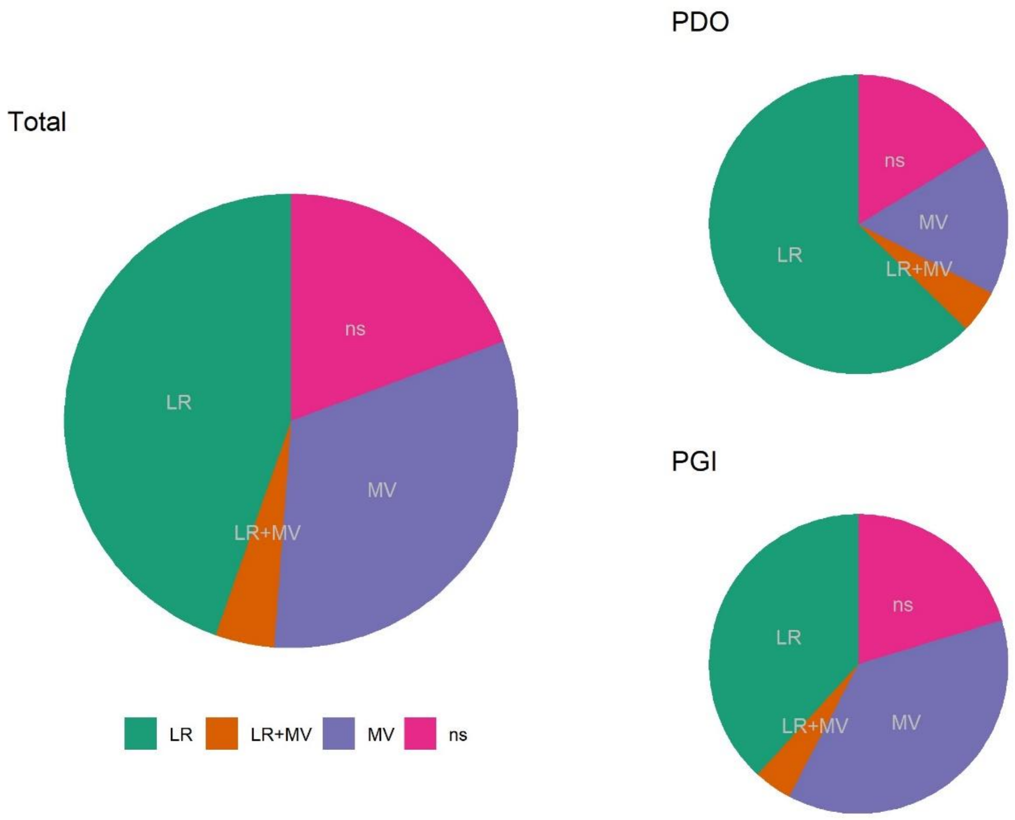


Figure 5. Type of germplasm used in the European Union's quality labels: PDOs, PGIs, and total labels. (LR: Landraces; MV: Modern Varieties, LR+MV: landraces + Modern Varieties; ns: not clearly specified).

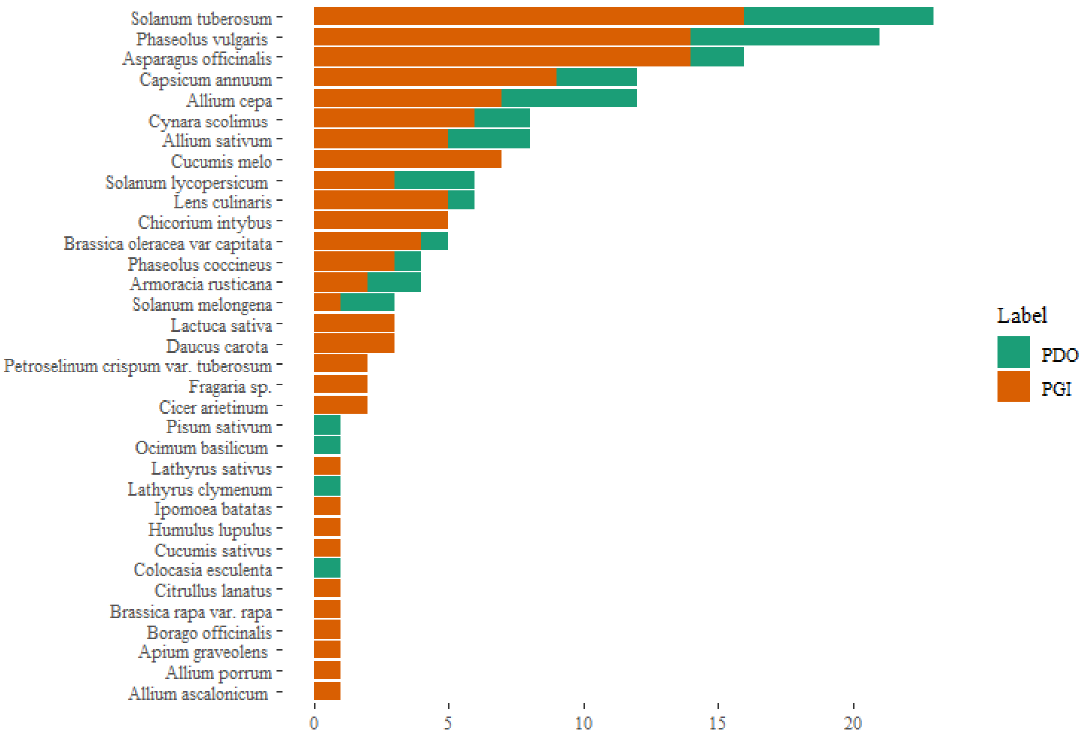


Figure 6. Number of PDOs and PGIs in which each species appears in the registration specification of the European Labels.

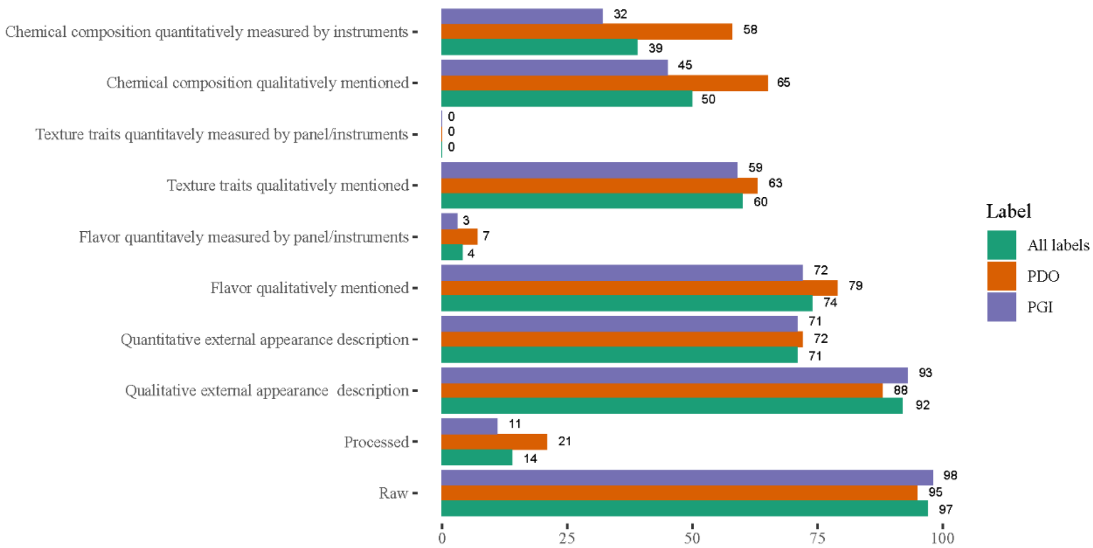


Figure 7. Proportion of the label register documents that require specification for quality items for all labels and for PGIs and PDOs separately. Proportion of labels dealing with raw or transformed products.

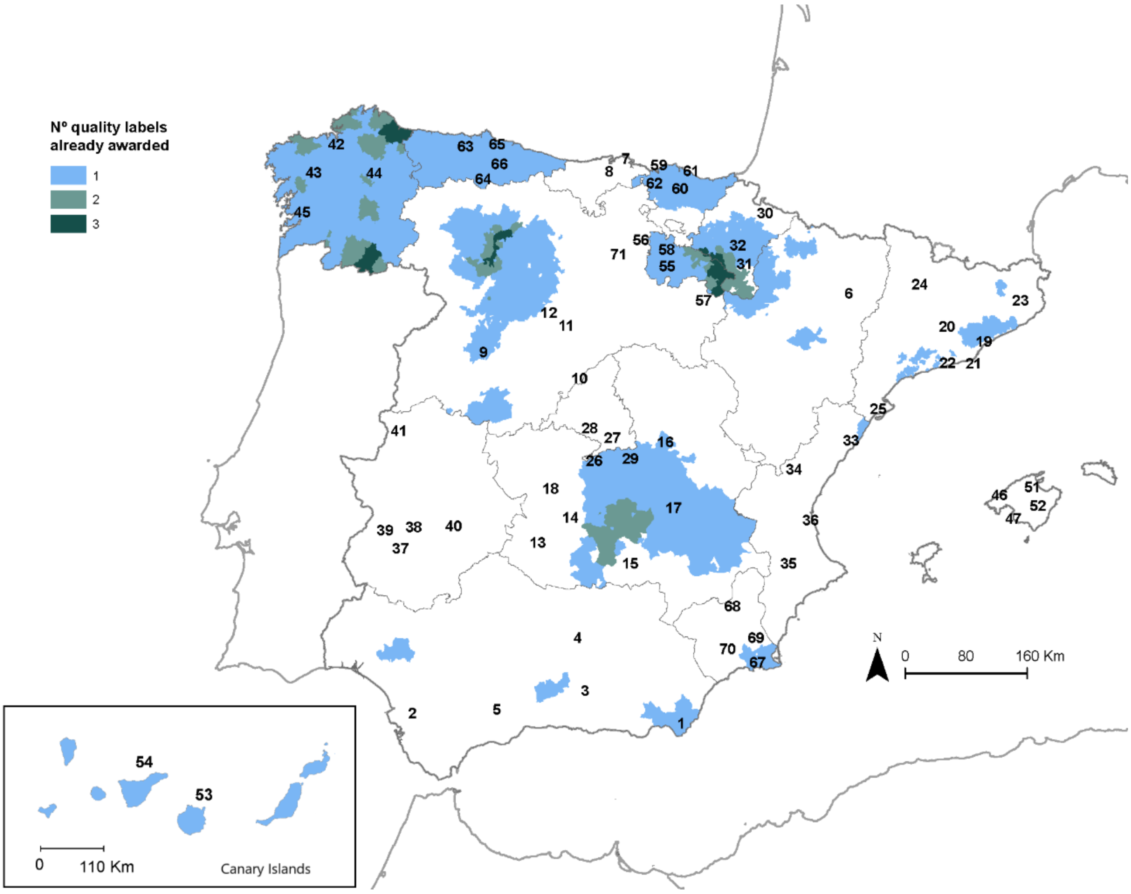
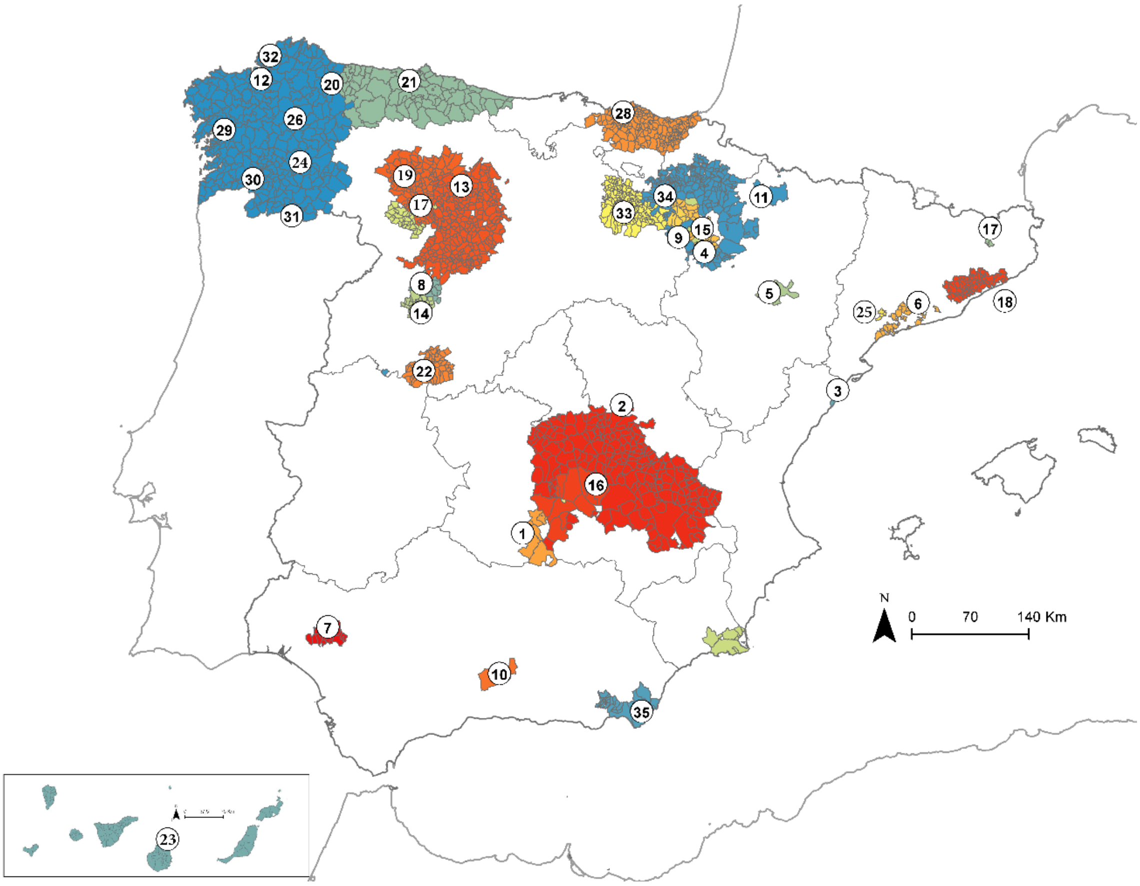


Figure 8. Distribution of territories with protected geographical designations for horticultural products (color-coded for the number of labels already awarded in each area; see complementary figure for the label's names) and epicenters of possible new labels (some epicenters have more than 1 candidate label). 1. Tomate RAF de la Cañada-Nijar (*Solanum lycopersicum* L.); 2. Tomate roteño (*Solanum lycopersicum* L.); 3. Tomate de la vega de Granada (*Solanum lycopersicum* L.); 4.Melones de Grañena (*Cucumis meló L.*) ; 5.Melones de Ardales (*Cucumis meló* L.); 6.Tomate Rosa de Barbastro (*Solanum lycopersicum* L.) ; 7.Pimiento de Isla (*Capsicum annuum* L.); 8.Carico montañés (*Phaseolus vulgaris* L.); 9.Garbanzo de Pedrosillo (*Cicer arietinum* L.); 10.Judión de la Granja (*Phaseolus coccineus* L.); 11.Ajo de Vallelado (*Allium sativum* L.); 12.Espárrago de Tudela de Duero (*Asparagus officinalis* L.); 13.Cebolla de la Mancha (*Allium cepa* L.); 14.Judía Pinesa de Malagon (*Phaseolus coccineus* L.); 15.Pimiento de Villanueva de los Infantes (*Capsicum annuum* L.); 16.Pepino de Huete (*Cucumis sativus* L.); 17.Pimiento de San Clemente (*Capsicum annuum* L.); 18.Tomate Moruno de San Pablo de los Montes (*Solanum lycopersicum* L.); 19.Tomàquet de Penjar de Catalunya (*Solanum lycopersicum* L.); 20.Mongeta de Castellfollit del Boix (*Phaseolus vulgaris* L.); 21.Carxofa del Prat de Llobregat (*Cynara scolimus* L.); 22.Espigalls del Garraf (*Brassica oleracea* L.); 23.Tomaquet Pera de Girona (*Solanum lycopersicum* L.); 24.Ceba de Coll de Nargó (*Allium cepa* L.); 25.Ceba Morada d'Amposta (*Allium cepa* L.); 26.Fresas de Aranjuez (*Fragaria sp*); 27.Ajo fino de Chinchón (*Allium sativum* L.); 28.Acelgas de Fuenlabrada (*Beta vulgaris* L.); 29.Espárragos de Villaconejos (*Asparagus officinalis* L.); 29.Melones de Villaconejos (*Cucumis melo* L.); 30.Patata del Pirineo Navarro (*Solanum tuberosum* L.) ; 31.Cardos rojos y blancos de Corella y Peralta (*Cynara cardunculus* L.); 32.Ajo de Falces (*Allium sativum* L.); 33.Tomata de Penjar de Castelló (*Solanum lycopersicum* L.); 34.Peladilla de Viver (*Phaseolus vulgaris* L.); 35.Meló d'Or d'Ontinyent (*Cucumis melo* L.); 36.Tomata valenciana (*Solanum lycopersicum* L.); 36.Garrofó de de València (*Phaseolus lunatus* L.); 37.Ajo de Aceuchal (*Allium sativum* L.); 38.Melon de Almendralejo (*Cucumis melo* L.); 39.Tomate de Talavera la Real (*Solanum lycopersicum* L.); 40.Sandia de Villanueva de la Serena (*Citrullus lanatus* (Thunb.) Mastsum. & Nakai.); 41.Pepinos de Moraleja (*Cucumis sativus* L.); 42.Repollo de Betanzos (*Brassica oleracea* L.); 43.Berza Rizada de Galicia (*Brassica oleracea* L.); 43.Faba do Caldo de Galicia (*Phaseolus vulgaris* L.); 44.Faba do Marisco de la Marina Lucense (*Phaseolus vulgaris* L.); 45.Nabicol de las Rias Baixas (*Brassica napobrassica* Mill.); 45.Faba de ollo de pita de Pontevedra (*Phaseolus vulgaris* L.); 46.Tomàtiga de Ramellet de Mallorca (*Solanum lycopersicum* L.); 47.Pebre tap de cortí de l'horta de Palma (*Capsicum annum* L.); 48.Pebre Ros de Mallorca (*Capsicum annuum* L.); 49.Col borratxó de Mallorca (*Brassica oleracea* L.); 50.Pastanaga negra de Mallorca (*Daucus carota* L.); 51.Rave de Mallorca (*Raphanus sativus* L.); 52.Meló eriçó de Vilafranca de Bonany (*Cucumis melo* L.); 53.Batata de Canarias (*Ipomoea batatas* L.); 53.Bubangos de Canarias (*Cucurbita pepo* L.); 53.Tomate de Canarias (*Solanum lycopersicum* L.); 53.Pimientas de Canarias (*Capsicum annuum* L.); 54.Cebollas de Tenerife (*Allium cepa* L.) ; 55.Caparron de Anguiano (*Phaseolus vulgaris* L.); 56.Caparron del río Oja (*Phaseolus vulgaris* L.); 57.Cardo rojo del

valle de Alhama (*Cynara cardunculus* L.); 58.Pimiento de Nájera (*Capsicum annuum* L.); 59.Acelga amarilla enana de Derio (*Beta vulgaris* L.); 60.Puerro de Durango (*Allium porrum* L.); 61.Nabo de Nabarniz (*Brassica rapa* L.); 62.Cebolla roja de Zalla (*Allium cepa* L.); 63.Fresa de Candamo (*Fragaria sp*); 64.Guisantes de Llano de Someron (*Pisum sativum* L.); 65.Maiz de Asturias (*Zea mays* L.); 65.Berza de Asturias (*Brassica oleracea* L.); 66.Nabos de San Martin (*Brassica rapa* L.); 67.Pimiento Morro de Vaca del Campo de Cartagena (*Capsicum annuum* L.); 68.Berengena de Cieza (*Solanum melongena* L.); 69.Tomate Verdal de Murcia (*Solanum lycopersicum* L.); 69.Tomate Flor de Baladre de Murcia (*Solanum lycopersicum* L.); 69.Pimiento Ñora de Murcia (*Capsicum annuum* L.); 69.Lechuga perdices de Murcia (*Lactuca sativa* L.); 70.Calabaza de Totana (*Cucurbita pepo* L.); 71.Lechuga de Medina de Pomar (*Lactuca sativa* L.).



Supplementary Figure. Distribution of the awarded European Geographic labels in the different Spanish regions. Numbers in the figure correspond to the name of the label, scientific name of the varieties involved, and level of the label. 1. PGI Berengena de Almagro (*Solanum melongena* L.). 2. PGI Ajo morado de Las Pedroñeras (*Allium sativum* L.). 3. PDO Alcachofa de Benicarló (*Cynara scolimus* L.). 4. PGI Alcachofa de Tudela (*Cynara scolimus* L.). 5. PDO Cebolla Fuentes de Ebro (*Allium cepa* L.). 6. PGI Calçots de Valls (*Allium cepa* L.). 7. PGI Garbanzo de Escacena (*Cicer arietinum* L.). 8. PGI Garbanzo de Fuentesauco (*Cicer arietinum* L.). 9. PGI Coliflor de Calahorra (*Brassica oleracea* L.). 10. PGI Espárrago de Huetor-Tajar (*Asparagus officinalis* L.). 11. PGI Espárrago de Navarra (*Asparagus officinalis* L.). 12. PGI Grelos de Galicia (*Brassica rapa* L.). 13. PGI Lenteja de Tierra de Campos (*Lens culinaris* Medik.). 14. PGI Lenteja de la Armuña (*Lens culinaris* Medik.). 15. PGI Melon de Torre Pacheco (*Cucumis melo* L.). 16. PGI Melón de la Mancha (*Cucumis melo* L.). 17. PDO Fesols de Santa Pau (*Phaseolus vulgaris* L.). 18. PDO Mongeta del Ganxet (*Phaseolus vulgaris* L.). 19. PGI alubia de la Bañeza-Leon (*Phaseolus vulgaris* L.). 20. PGI Faba de Lourenza (*Phaseolus vulgaris* L.). 21. PGI Faba Asturiana (*Phaseolus vulgaris* L.). 22. PGI Judías del Barco de Avila (*Phaseolus vulgaris* L.). 23. PDO Papas antiguas de Canarias (*Solanum tuberosum* L.). 24. PGI Pataca de Galicia (*Solanum tuberosum* L.). 25. PGI Patates de Prades (*Solanum tuberosum* L.). 26. PGI Pimiento de Mougan (*Capsicum annuum* L.). 27. PGI Pimiento de Fresno-Benavente (*Capsicum annuum* L.). 28. PGI Pimiento de Guernica (*Capsicum annuum* L.). 29. PDO Pemento de Herbon (*Capsicum annuum* L.). 30. PGI Pemento de Arnoia (*Capsicum annuum* L.). 31. PGI Pemento de Oimbra (*Capsicum annuum* L.). 32. PGI Pemento de Couto (*Capsicum annuum* L.). 33. PGI Pimiento riojano (*Capsicum annuum* L.). 34. PDO Pimiento del Piquillo de Lodosa (*Capsicum annuum* L.). 35. PGI Tomate La Cañada (*Solanum lycopersicum* L.).