Review

Received: 30 January 2024 | Revised: 8 March 2024 | Accepted article published: 28 March 2024 | Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/jsfa.13492

Markers for meat provenance and authenticity with an account of its defining factors and quality characteristics – a review

Sara Wilhelmina Erasmus,[a*] Muhammad Sohaib,[a,b] Isabel Revilla,[c] Ana María Vivar-Quintana[c] and Sophia Jennie Giancoli[a]

Abstract

Provenance is becoming increasingly important in meat supply chains as it lends products higher perceived quality. However, its precise definition and interpretation along with its associated characteristics factors have remained somewhat elusive. This review meticulously defines meat provenance while dissecting the essential factors and associated quality attributes that constitute its essence and are subsequently employed to establish pertinent markers for provenance. Meat provenance emerges as a multi-dimensional construct stemming from the adept management of a constellation of factors relating to geographical origin, farm production system, traceability, and authenticity. Through intricate interactions, these factors unveil innate originality that not only forges a distinct reputation but also imparts a unique typicity to the meat product. Gaining insights into a meat product's provenance becomes attainable by scrutinizing its pertinent composition and organoleptic quality traits. Trace elements and stable isotopes stand out as provenance markers, forging a direct connection to both geographical origin and dietary sources. While somewhat less direct in linkage, other markers such as plant biomarkers, fatty acid composition, pH levels, flavour and aromatic compounds along with organoleptic characteristics contribute to the overall understanding of provenance. Additionally, the identification of animal species and breeds serves as key markers, particularly in the context of protected geographical indications. The study findings are useful for the various stakeholders of how the information for meat provenance can be linked with intrinsic and extrinsic factors for meat quality and protecting the integrity of the supply chain with special reference to traceability and authenticity.

Keywords: authenticity; designation of origin; meat markers; provenance; traceability; typicity

INTRODUCTION

The meat industry is continuously faced with the challenge of keeping up with the demands that consumers and manufacturers have to produce meat products of a certain quality.[1] Considering the consumers' expectations at purchase level, the demands are shifting towards products that are produced using animals with higher animal welfare, food safety compliance, traceability by appropriate and safe methods and are nutritious, while at the time of consumption, organoleptic quality characteristics such as flavour, taste, mouthfeel and texture are most important. In addition, consumers are becoming more concerned about the meat they eat, for ethical (i.e., animal welfare), as well as quality reasons.[2] However, the variability of raw materials and different production steps in product development makes it difficult to guarantee that the desired quality is consistent; consistency is sought to guarantee a constant intrinsic and extrinsic product quality for meat and meat-based products.[3] The intrinsic quality characteristics primarily ensure consumer satisfaction at product consumption, while extrinsic quality characteristics play a vital role during the product purchase decision by the consumer. Considering the higher consumers demand for safe, nutritious, healthy meat and meat products, the producers might make false claims regarding these quality characteristics, severing a product's authenticity. Ultimately, meat authentication is required to ensure that the consumer is informed correctly about the product and is not misled (e.g., through mislabelling), thereby also preventing meat fraud.[4]

* Correspondence to: SW Erasmus, Food Quality and Design, Wageningen University & Research, P.O. Box 17, 6700 AA, Wageningen, The Netherlands, E-mail: sara.erasmus@wur.nl

a Food Quality and Design, Wageningen University & Research, Wageningen, The Netherlands

b Department of Food Science and Human Nutrition, University of Veterinary and Animal Sciences, Lahore, Pakistan

c Food Technology Area, Universidad de Salamanca, Escuela Politécnica Superior de Zamora, Zamora, Spain

One highly relevant aspect in the current internationally growing meat industry is meat provenance considering the consumers demands with special reference to animal origin, authenticity, feeding regime as well as characteristics or claims like 'organic', 'grass fed', and so forth. Studies have shown that consumers often link meat provenance to certain quality characteristics of meat.[5] This agrees with research performed by Becker *et al.*[6] which shows that among consumers, meat origin and place of purchase are considered as some of the most important meat characteristics when assessing its quality. These findings suggest that meat provenance is a good indicator to assess meat quality, yet the opposite is also true as meat quality characteristics can also be a good indicator of provenance. Quality characteristics can differ greatly among different animal species. Hence, this review will focus on identifying which quality characteristics are integral to meat provenance of meat from livestock animals since most consumers are familiar with this meat type. There are currently limited studies addressing and defining the concept of 'meat provenance' with special reference to its characteristics on meat quality along with intrinsic and extrinsic factors that can influence the quality of meat and meat products, adding to the motivation of the current study to assess the research papers available on the topic. This study combines all relevant literature findings to produce a comprehensive description for 'meat provenance' together with the intrinsic and extrinsic factors and associated meat quality characteristics that are integral to it considering consumer demand along with meat supply chain integrity.

METHODOLOGY

A comprehensive literature review was undertaken to offer an assessment of research articles pertaining to the topic of 'meat provenance'. This review adhered to a structured methodology, following the five essential steps outlined by Khan *et al.*[7]: formulating the research question(s), identifying pertinent literature resources, critically evaluating the research's quality, synthesizing the available evidence, and conducting a thorough analysis and interpretation of the findings. This narrative will now delve into a detailed explanation of the initial three steps, with the latter two steps encompassing the summarization and interpretation of the study's results.

Framing the study research questions

The main research questions of the review were: What is meat provenance? Which factors and characteristics are linked to meat provenance? To give more structure to the review, the main research questions were addressed by discussing the following topics: the definition of meat provenance; the factors and characteristics influenced by meat provenance including reference to protected designation of origin (PDO) and protected geographical indication (PGI) specialty meat products.

Identifying pertinent literature

To identify literature that directly addressed the research question and related sub-topics, a stringent set of inclusion and exclusion criteria was employed to curate published papers. This process focused on selecting papers from reputable and accredited databases (i.e., Google Scholar, Scopus, and PubMed), primarily in English (a few in other languages followed by English translation), centred on papers published from 2005 (with some flexibility for earlier publications due to limited content on meat provenance) to 2023, specifically addressing research questions pertaining to meat provenance. However, the study excluded papers that discussed provenance in non-food context along with papers that describe research not linked to geographical origin, diet, or animals' characteristics in any way. Moreover, literature that did not conform to rigorous scientific standards or utilized concept of provenance outside realm of food-related contexts was deliberately omitted as this exclusion was deemed necessary to maintain focus and coherence of the review, as these materials fell outside the specified scope and did not meet the criteria of being both transparent and pertinent to the research objectives.

Assessing the research quality

The papers' relevance was evaluated through a sequential process. Initially, the title was examined for apparent alignment with the research questions. If deemed relevant, further scrutiny involved scanning the abstract and conclusion sections. Finally, the complete text was read if it passed the initial assessments. Any paper that did not meet the relevance criteria or violated any of the exclusion criteria as mentioned earlier was omitted from the review.

MEAT PROVENANCE

The definition of 'place of provenance' given by the European Union (EU) in Council Regulation (EEC) No. 1169/2011 on the *Provisions of Food Information to Consumers*, is 'any place where a food is indicated to come from, and that is not the "country of origin"'. This means that according to the EU, the place of provenance could be several geographical areas or countries where at least one food production step occurred. In the realm of food, especially when it comes to meat, the concept of provenance encompasses various key factors, including its geographical origin, the methods employed in its production on the farm, and a comprehensive account of its path from the farm to the consumer's table (*farm to fork*). Therefore, the following definitions of provenance, are focused on meat, but can also be applied to other food products such as cheese, wines/spirits, olive oils, salts, and so forth, that originate from a certain area or region of origin.

Although provenance is often considered as simply being a place, its concept is more complex. In fact, provenance consists of multiple dimensions including 'spatial dimension (its place of origin), a social dimension (its methods of production and distribution), and a cultural dimension (its perceived qualities and reputation) for the described product'.[8] A similar definition of provenance is also given by Monahan *et al.*[9] who identified provenance, and meat provenance in particular, as a combination of geographical origin, farm production system along with traceability of the meat and meat products. Taking both studies into account, one can say that meat provenance is a multi-dimensional function of management of multiple factors relating to geographical origin, farm production system, as well as traceability and authenticity, as illustrated in Fig. 1. More details on these specific factors are provided in the next sections.

From these findings, it can be concluded that meat provenance is, among others, a suitable indicator to assess meat quality, but vice versa also applies as certain meat quality characteristics can be used to indicate provenance for meat. This highlights both the consumer-oriented (cultural dimension) as well as the more technical side (social dimension) of meat provenance. Consumers are most interested in the perceivable quality that is a result of the effects of certain technical influences. Quality characteristics can be broken down into intrinsic and extrinsic quality characteristics.

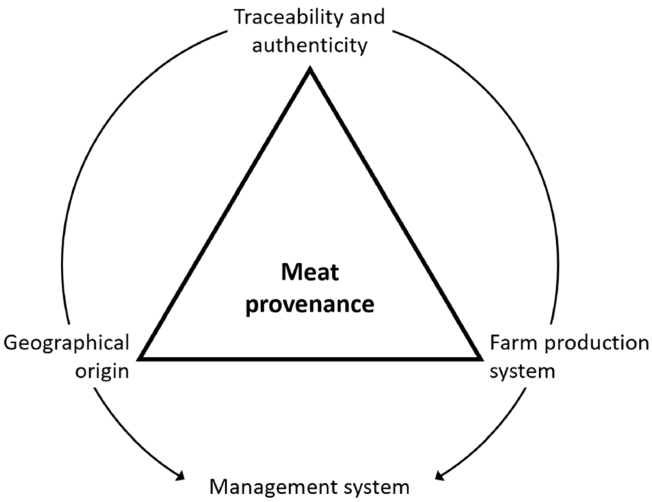

Figure 1. Graphic depiction illustrating the term 'meat provenance' and the relation between all factors.

One of the researcher groups referred to intrinsic quality characteristics as being part of the product; not being able to change them without changing the product itself. These intrinsic characteristics are organoleptically perceivable by the consumers and include aspects such as colour, texture, flavour, and aroma. Conversely, extrinsic quality characteristics are also related to the product but are not physically part of it, yet they may still play a pivotal role in the decision-making process of consumers for that particular food.[10,11]

In the case of meat provenance, the intrinsic and extrinsic quality characteristics are influenced by several intrinsic and extrinsic factors. The extrinsic factors include the place of origin, feed, and farming system for animals rearing and these factors can influence intrinsic factors, which characterize the animal's growth, age at slaughter and also directly affect meat composition.[12] Among different studies, there is conflicting opinion when assigning the animal breed and species to a certain category. Breed is often considered to be an intrinsic factor[12,13] while others consider it to be an extrinsic factor.[14] This review will assume that animal breed, species and age at slaughter are intrinsic factors since they are physically related to the product and can directly influence its composition.

There is a strong interaction between the intrinsic and extrinsic factors that can influence characteristics of the meat and meat-based products.[15] Although they are separated into two distinct groups, they remain closely linked considering the growth and animal production patterns and their influence on meat quality characteristics. Additionally, consumer experience for different meat and its products may depends on intrinsic and extrinsic characteristics for the meat along with personal choice/preference that can influence intrinsic meat characteristics[16] as well as linked with the factors related to meat provenance as shown in Fig. 2. Considering provenance from a more technical viewpoint, the intrinsic and extrinsic factors along with organoleptic quality characteristics are fundamental as they can be quantified, identified, and used as provenance markers as summarized in Table 1. Thus, in this review the influences of provenance on meat quality characteristics that can affect meat acceptability based on consumer decision-making will be addressed.

Geographical origin

In the contemporary food landscape, the geographical origin of food holds a prominent position as a pivotal determinant influencing consumer preference. This is attributed to the fact that locally sourced food products such as meat are commonly linked to a perception of superior quality due to reduced transportation times and enhanced animal welfare practices within the production system. Thus, there is an increasing need for official signs of quality to correlate the composition/quality of meat with its spatial dimension or geographical origin.[17] This is substantiated by research in five European countries including France, England, Spain, Scotland and Italy, which has shown that beef and lamb consumers tend to give higher importance to animal origin along with subjected feeding system mainly owing to their link with animal health, meat safety and convenience for meat products along with ethical issues linked with rearing of animals. Although the significance of environment-friendly animal production and welfare systems is widely acknowledged, consumers still place a higher emphasis on factors such as animal origin and feeding regimen when evaluating meat quality characteristics.[18] Moreover, the alarming surge in fraudulent activities within the global market necessitates a critical focus on instances like species substitution of Australian beef being illicitly sold as another in China or the deceitful assignment of certified origin labelling to products like *Prosciutto di Parma* and *San Daniele ham*. These fraudulent occurrences serve as stark reminders of paramount significance in establishing a fool proof mechanism to accurately trace the origin of every food product with special reference to meat.[19] The claimed products disguised as the products with superior characteristics, while having an inferior quality, will cause a significant loss of the reputation of products whose quality and prestige are determined by the origin that can have impact on the quality of food.[20]

Due to this perceived increasing cultural quality value connected to products from certain regions, a broad range of trademarks concerning product origin exist.[8] Within the EU, a safeguarding mechanism is in place for these products known as geographical indications (GIs). In this context, a GI serves as a unique symbol employed to designate a product whose distinct qualities, prestige, or other defining attributes are intricately tied to its geographic origin. This protection ensures that only products genuinely originating in a specific region are identified as such; thereby, promoting rural and agricultural activity, and preventing imitation and misuse. The legislation on the *Protection of Geographical Indications and Designations of Origin for Agricultural Products and Foodstuffs* was put into place by the European Community in 1992 (EEC. No. 2081/92); describing the definitions of products with a PDO, PGI or Traditional Speciality Guaranteed (TSG), and the requirements that need to be met to use the protected name.

Currently, there are over 400 registered and protected meat and meat products including fresh meat and offal ($n = 192$), and meat products including cooked, salted, smoked, and so forth ($n = 219$) in the EU (eAmbrosia – the EU geographical indications register). Within the PGI and PDO scheme requirements, various categories of meat animals are crucial, encompassing beef ($n = 56$), sheep ($n = 54$), poultry ($n = 48$), pork ($n = 18$), goat ($n = 11$) and game ($n = 2$) as outlined in Table 2. These animals are specifically selected to yield fresh meat that embodies the distinct characteristics necessary to ensure the attributes accountable for unique qualities of meats aligned with specific scheme standards. The

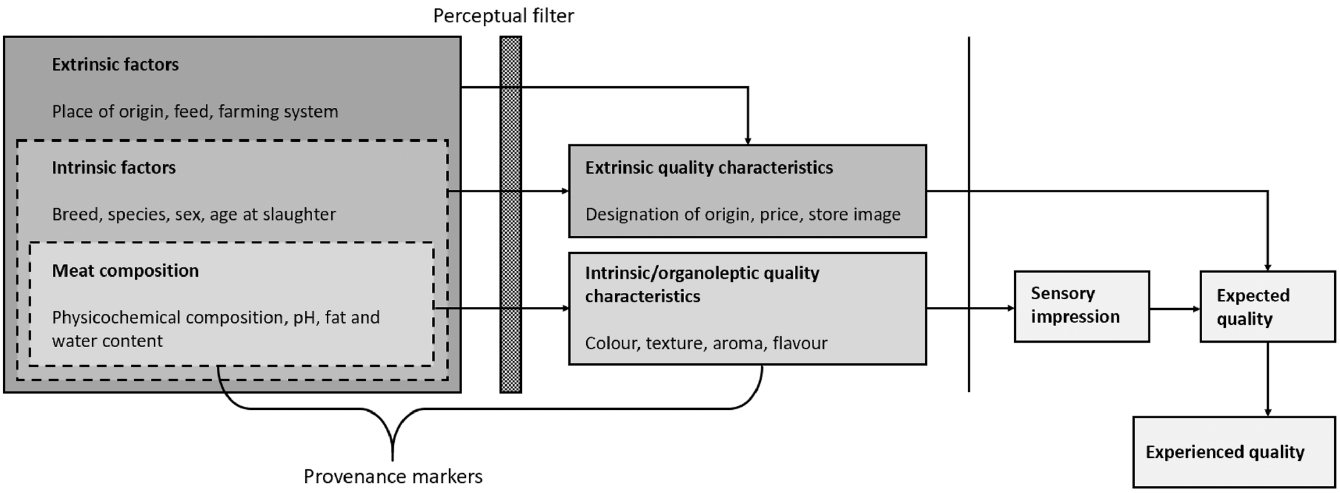

Figure 2. Perception of quality linked to the provenance of meat and meat-based products.

Table 1. The meat quality and organoleptic quality characteristics most relevant to meat provenance as related to intrinsic and extrinsic factors

Factors		Provenance markers
Intrinsic factors (animal characteristics)	Species	Protein, fatty acids, amino acid composition
	Breed	Volatiles
		Texture
		Sensory attributes: aroma, flavour
	Sex	Fatty acids
		Volatiles
	Age at slaughter	Fatty acids
		Colour: L^*, a^*, b^*, chroma, hue
		texture
		Sensory attributes; aroma, flavour
Extrinsic factors (environmental characteristics)	Place of origin	Trace elements (Se, Rb, Fe)
	Feed/diet	Stable isotopes (δ^{13}C, δ^{2}H, δ^{18}O, δ^{15}N, δ^{87}Sr)
	Farming system	
	Feed/diet	Plant biomarkers (antioxidants, terpenes, animal metabolites)
	Place of origin	pH
	Farming system	Colour: L^*, a^*, b^*, chroma, hue
		Volatiles
		Sensory attributes aroma, flavour

allocation of PGI or PDO status to different animal categories considers essential intrinsic factors such as animal species, breed, sex, and the age of the animal at the time of slaughter, complemented by extrinsic attributes including the animal's place of origin, the farming system it was raised in, and the composition of its feed or diet. Moreover, specific attributes such as meat colour, texture, as well as distinctive aroma and flavour, hold significant importance in determining the status of animals within their respective organoleptic requirements categories.

The quality attributes of PDO and PGI products are determined by the inherent natural and human components that are involved in the production, processing, and preparation of the products; all taking place in a specific geographical area or region of origin. The TSG products only highlight the traditional aspects that involves how the product is made or its composition with no link to the origin of products. For PDO products, every part of the production process needs to take place in one geographical area of origin whereas, at least one of the stages of the process needs to take place in the defined origin for PGI products. Ultimately, what gives these products their unique characteristics and quality, is the combination of localized cultures together with the unique environmental conditions involved in their production.[21]

Creating an indication of quality by origin for meat products requires the identification of territorial elements that provide the product with its certain quality. The French have a long history of making products from specific areas and are very proud of their heritage products. This has led them to be ahead of many other countries when it comes to identifying and defining terms related to provenance and geographical origin. Two French terms often used regarding wine and geographical origin are 'terroir' and 'typicity', but these terms can also be applied to any general or protected meat products. A rough translation of the definition of terroir given by multiple French scientists[22] is defined as geographical space in which there is an interaction between

Table 2. Overview of the fresh meat, Class 1.1 Fresh meat (and offal), protected designation of origin (PDO) and protected geographical indication (PGI) products ($n = 189$) in the European Union (sourced from the eAmbrosia geographical indications register and https://www.qualigeo.eu/en/)

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics)			
			Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Beef ($n = 56$)						
Bayerisches Rindfleisch/ Rindfleisch aus Bayern	PGI	Germany	Beef from cattle (*Bos taurus*)	Bavarian breeds (dual-purpose) of Fleckvieh, Braunvieh, Gelbvieh, Pinzgau, Allgau Braunvieh, Franconian Gelbvieh and Murau-Werdenfels	Male/female	Calves maximum 8 months (120–220 kg); adult bovine (male/female) 8–12 months (220–430 kg); cows maximum 7 years (220–450 kg)
Bœuf charolais du Bourbonnais	PGI	France	Beef from cattle (*Bos taurus*)	Charolais breed	Male/female	Minimum 28 months and maximum 8 years
Bœuf de Bazas	PGI	France	Beef from cattle (*Bos taurus*)	Bazadaise and Blonde d'Aquitaine breeds and their crossbreeds	Male/female	Heifers minimum 30 months (300 kg); cows minimum 36 months (300 kg); bullocks minium 36 months (380 kg)
Bœuf de Chalosse	PGI	France	Beef from cattle (*Bos taurus*)	Blonde d'Aquitaine, Limousine and Bazadaise cattle breeds	Male/female	Heifers and cows 30 months; males 32 months; maximum age 9 years
Bœuf de Charolles	PDO	France	Beef from cattle (*Bos taurus*)	Charolais breed	Male/female	Minimum 28–30 months
Boeuf de Vendée	PGI	France	Beef from cattle (*Bos taurus*)	Rouge des Prés (Maine-Anjou) breed	Male/female	Male minimum 30 months (360 kg for castrated males); female maximum 10 years (minimum 320 kg)
Bœuf du Maine	PGI	France	Beef from cattle (*Bos taurus*)	Blonde d'Aquitaine, Limousine, Charolaise and Rouge des Prés cattle breeds and their crossbreeds	Male/female	Cows 10 years old which calved at least once (minimum 380 kg); oxen minimum 30 months (400 kg)
Carn d'Andorra	PGI	Andorra	Beef from cattle (*Bos taurus*)	Bruna d'Andorra breed or crosses between female Bruna breed and male Charolais, Limousine and Gasconne breeds	Male/female	Minimum 8 months
Carnalentejana	PDO	Portugal	Beef from cattle (*Bos taurus*)	Alentejana breed	Male/female	Vitela cows 6–9 months (maximum 150 kg); Novilho cows 12–29 months (maximum 300 kg); Novilho bulls 14–24 months (minimum 200 kg)
Carne Arouquesa	PDO	Portugal	Beef from cattle (*Bos taurus*)	Arouquesa breed	Male/female	Veal (male/female) 5–9 months (70–135 kg); Novilho (male/female) 9–24 months (135–230 kg); Vaca cows 2–4 years (minimum 150 kg); Boi castrated bulls 2–5 years (minimum 150 kg)
Carne Barrosã	PDO	Portugal	Beef from cattle (*Bos taurus*)	Barrosã breed	Female	Vitela cows 5–9 months (70–130 kg); Novilho cows 9–36 months (minimum 130 kg); Vaca cows 3–4 years (minimum 130 kg)
Carne Cachena da Peneda	PDO	Portugal	Beef from cattle (*Bos taurus*)	Cachena breed	Male/female	Vitela bulls and cows 4–9 months (70–120 kg); Novilho cows 9–24 months (120–210 kg)
Carne da Charneca	PDO	Portugal	Beef from cattle (*Bos taurus*)	Preta breed (also known as Gado da Terra)	Female	Vitela cows weighing 120–200 kg; Novilho cows weighing 200–400 kg
Carne de Ávila	PGI	Spain	Beef from cattle (*Bos taurus ibericus*)	Avileña-Negra Ibérica breed	Male/Female	Ternero calves maximum 10 months; Añojo veal calves 12–24 months; Novillo beef 18–36 months
Carne de Bovino Cruzado dos Lameiros do Barroso	PGI	Portugal	Beef from cattle (*Bos taurus*)	Traditional, extensively reared breed	Female	Vitela cows maximum 8 months (maximum 180 kg); Novilho cows 9–24 months (minimum 180 kg); Vaca cows minimum 2 years (minimum 180 kg)
Carne de Bravo do Ribatejo	PDO	Portugal	Beef from cattle (*Bos taurus*)	Brava de Lide breed	Male/female	Novilha Brava de Lide heifers 18–30 months (100–200 kg); Novilho Bravo de Lide young bulls 18–30 months (150–250 kg); Vaca Brava de Lide cows 31–60 months (100–250 kg); Toiro Bravo de Lide from bulls 31–60 months (maximum 200 kg)

Table 2. Continued

Name	Type (PDO/ PGI)	Country	Intrinsic factors (animal characteristics)			
			Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Carne de Cantabria	PGI	Spain	Beef from cattle (*Bos taurus*)	Tudanca, Monchina and Asturiana breeds, Bruna Alpina, Limosina and relative cross breeds	Male/female	Ternera cattle maximum 12 months; Añojo cattle 12–24 months; Novillo cattle 24–40 months; Buey castrated males minimum 24 months (of which minimum 14 months spent in pasture)
Carne de la Sierra de Guadarrama	PGI	Spain	Beef from cattle (*Bos taurus*)	Avileña Negra Ibérica, Limosina, Charolaise breed and relative cross breeds	Male/female	Ternera female maximum 14 months (after 3 months fattening, minimum 150 kg); Añojo 16 months (after 3 months fattening, 225 kg); Cebón male castrated at minimum 18 months
Carne de Salamanca	PGI	Spain	Beef from cattle (*Bos taurus*)	Morucha breed or crosses between cows of Morucha breed and bulls of Charolais and Limousine breeds	Male/female	Ternera 8–12 month, Añojo 12–24 months and Cebón bull/heifer 24–48 months
Carne de Vacuno del País Vasco/Euskal Okela	PGI	Spain	Beef from cattle (*Bos taurus*)	Pirenaica, Limousine, Alpine Bruna, Blonda breeds and relative cross breeds	Male/female	Txahala 8–20 months (males 210 kg and females 160 kg); Zaharra 21–84 months (275 kg); Idia 21–59 months (minimum 275 kg)
Carne dos Açores	PGI	Portugal	Beef from cattle (*Bos taurus*)	Do not belong to any particular breed	Female	Vitela cows 5–9 months (maximum 180 kg); Novilho cows 2 years (maximum 180 kg); Vaca cows minimum 200 kg
Carne Marinhoa	PDO	Portugal	Beef from cattle (*Bos taurus*)	Marinhoa breed	Male/female	Vitelo(a) (male/female) 6 months (maximum 120 kg); Vitelão (Novilho) (male/female) 6–24 months (120–300 kg)
Carne Maronesa	PDO	Portugal	Beef from cattle (*Bos taurus*)	Maronesa (Maronês) breed	Male/Female	Vitela cows 5–9 months (75–130 kg); Novilho 9–24 months (maximum 130 kg); Vaca 2–4 years (maximum 300 kg)
Carne Mertolenga	PDO	Portugal	Beef from cattle (*Bos taurus*)	Mertolenga breed	Female	Vitela cows 6–10 months (90–120 kg); Novilho cows 15–30 months (180–250 kg)
Carne Mirandesa	PDO	Portugal	Beef from cattle (*Bos taurus*)	Mirandesa breed	Male/female	Vitela cows 5–9 months; Novilho 10–18 months
Carne Ramo Grande	PDO	Portugal	Beef from cattle (*Bos taurus*)	Ramo Grande breed	Male/female	Veal (male/female) 8–12 months (minimum 110 kg); heifers (male/female) 12–24 months (minimum 120–130 kg); bulls (entire males) minimum 24 months (minimum 200 kg); castrates (males) minimum 12 months (minimum 130 kg); beef (females) minimum 200 kg
Charolais de Bourgogne	PGI	France	Beef from cattle (*Bos taurus*)	Charolais breed	Male/female	Bovine 14–24 months (minimum 320 kg); heifers minimum 24 months (minimum 280 kg); cows maximum 10 years (minimum 330 kg)
Fin Gras/Fin Gras du Mézenc	PDO	France	Beef from cattle (*Bos taurus*)	Mezine, Aubrac, Salers, Charolaise and Limousine breeds	Male/female	Heifers minimum 24 months; bulls minimum 30 months
Génisse Fleur d'Aubrac	PGI	France	Beef from cattle (*Bos taurus*)	Crossbreed between female Aubrac breed and male Charolais breed	Female	Minimum 24–42 months
Irish Grass Fed Beef	PGI	Ireland, United Kingdom	Beef from cattle (*Bos taurus*)	Crossing traditional breeds (i.e., Hereford, Angus, Shorthorn) with both dairy breeds and European breeds (i.e., Limousin, Charolais, Simmental)	Male/female	Steers and heifers minimum 36 months; cows maximum 120 months
Magyar szürkemarha hús	PGI	Hungary	Beef from cattle (*Bos taurus*)	Hungarian Grey breed	Male/female	Not specified
Maine-Anjou	PDO	France	Beef from cattle (*Bos taurus*)	Rouge des Prés breed	Male/female	Males (neuters) minimum 30 months; cows maximum 10 years (calved at least once)

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics): Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Meso istarskog goveda - boškarina/Meso istrskega goveda - boškarina	PDO	Croatia, Slovenia	Beef from cattle (*Bos taurus*)	Boškarin (Istrian cattle) breed	Male/female	Not specified
Orkney beef	PDO	United Kingdom	Beef from cattle (*Bos taurus*)	Aberdeen Angus and Shorthorn/Blue Grey cows	Male/female	Not specified
Rosée des Pyrénées Catalanes	PGI	Spain, France	Beef (veal) from cattle (*Bos taurus*)	Bruna des Pyrénées, Aubrac or Gasconne rustic breeds or crossing females of same rustic breeds with males of Charolaise, Limousine or Blonde d'Aquitaine breeds	Male/female	Calves (unweaned) 5–8 months (minimum 110 kg)
Scotch Beef	PGI	United Kingdom	Beef from cattle (*Bos taurus*)	Crosses of traditional Scottish breeds such as Galloway, Aberdeen Angus, Shorthorn and Highland breeds	Male/female	Not specified but animal must spend minimum 3 months in Scotland pastures before slaughter
Taureau de Camargue	PDO	France	Beef from cattle (*Bos taurus*)	Raço de Biou and De Combat breeds or their crossbreeds	Male/female	Minimum 100 kg; heifers 18–30 months (minimum 85 kg)
Ternera Asturiana	PGI	Spain	Beef from cattle (*Bos taurus*)	Asturiana de los Valles and Asturiana de la Montaña breeds and their crosses	Male/female	Ternera maximum 12 months; Añojo 12–18 months
Ternera de Aliste	PGI	Spain	Beef (veal) from cattle (*Bos taurus*)	Breeds bred for meat production	Male/female	Calves 8–12 months
Ternera de Extremadura	PGI	Spain	Beef from cattle (*Bos taurus*)	Autochthon Retinta, Avileña-Negra Ibérica, Morucha, Blanca Cacereña and Berrendas breeds and crosses with Charolaise, Limousine and autochthon breeds	Male/female	Ternera 7–12 months; Añojo 12–16 months; Novillo 16–36 months
Ternera de los Pirineos Catalanes/Vedella dels Pirineus Catalans/Vedell des Pyrénées Catalanes	PGI	Spain, France	Beef (veal) from cattle (*Bos taurus*)	Rustic Bruna dei Pirenei, Aubrac or Gasconne breeds or crossing females of same breeds with males of Charolaise, Limousine or Blonde breeds 'Aquitaine'	Male/female	Calves 8–12 months
Ternera de Navarra/Nafarroako Aratxea	PGI	Spain	Beef (veal) from cattle (*Bos taurus*)	Pirenaica, Bruno-Alpina, Blonde de Aquitaine, Charolaise breeds and crossbreeds	Male/female	Ternera females 8–12 months; Ternero males 9–13 months
Ternera Gallega	PGI	Spain	Beef from cattle (*Bos taurus*)	Rubia Gallega and Morenas del Noroeste breeds, pure-bred or crossed with Frisona and Pardo Alpina breeds	Male/female	Ternera heifers maximum 10 months; Añojo calves 10–18 months; Cebón (male/female) 18–30 months
Vaca de Extremadura	PGI	Spain	Beef from cattle (*Bos taurus*)	Avileña-Negra Ibérica, Retinta, Morucha, Blanca Cacereña, Berrenda en Negro, Berrenda en Colorado breeds, pure-bred or crossed with Charolaise, Limousine and Blonde d'Aquitaine breeds	Male/female	Vaca cows minimum 48 months with reproductive maturity age
Vaca Gallega – Buey Gallego	PGI	Spain	Beef from cattle (*Bos taurus*)	Galician cows and steers of Bionda Galiziana, Bruna Galiziana, Asturiana de los Valles, Limosina, Bionda di Aquitania, Friesian and Alpine Brown breeds, purebred or crossbreeds	Male/female	Cows minimum 48 months (given birth at least once); steers minimum 48 months (males castrated before 1 year old)
Vadehavsstude	PGI	Denmark	Beef from cattle (*Bos taurus*)	Danish Holstein breed	Male	Castrates (male) 18–30 months (200–380 kg)

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics)			
			Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Veau d'Aveyron et du Ségala	PGI	France	Beef (veal) from cattle (*Bos taurus*)	Limousine and Blonde d'Aquitaine breeds and their crossbreeds	Male/female	Calves 10 months (170–250 kg)
Veau du Limousin	PGI	France	Beef (veal) from cattle (*Bos taurus*)	Pure Limousine or Charolais breed or crossbreeds, also with Limousine-Salers breed	Male/female	Calves 3–5 months (85–150 kg)
Viande de Blanc-Bleu Belge/Belgisch Witblauw Vlees	PGI	Belgium	Beef from cattle (*Bos taurus*)	Belgian Blue breed	Male/female	Not specified and cattle are dual purpose for meat and milk
Vitela de Lafões	PGI	Portugal	Beef (veal) from cattle (*Bos taurus*)	Arouquesa and Mirandesa breeds or their crossbreeds	Male/female	Calves 5–7 months
Vitellone Bianco dell'Appennino Centrale	PGI	Italy	Beef from cattle (*Bos taurus*)	Chianina, Marchigiana and Romagnola breeds 'white breeds from central Apennines'	Male/female	Minimum 12–24 months
Vitelloni Piemontesi della Coscia	PGI	Italy	Beef from cattle (*Bos taurus*)	Piedmontese breed	Male/female	Minimum 12 months (minimum 260 kg for category E; minimum 320 kg for category C; minimum 360 kg for category A)
Vlees van het rood ras van West-Vlaanderen	PDO	Belgium	Beef from cattle (*Bos taurus*)	West Flanders red breed	Male/female	Cows 3½–8 years; steers 2–3½ years
Weideochse vom Limpurger Rind	PDO	Germany	Beef from cattle (*Bos taurus*)	Limpurger Rind breed	Male/female	Minimum 31 months
Welsh Beef	PGI	United Kingdom	Beef from cattle (*Bos taurus*)	Wales breed	Male/female	Minimum 24–48 months
West Country Beef	PGI	United Kingdom	Beef from cattle (*Bos taurus*)	Devon breed	Male/female	Not specified (200–500 kg)
Sheep (n = 54)						
Abbacchio Romano	PGI	Italy	Lamb (suckling) from sheep (*Ovis aries*)	Sarda, Comisana, Sopravissana, Massese and Merinizzata Italiana and relative crossbreeds	Male/female	Minimum 28–40 days (maximum 8 kg)
Agneau de l'Aveyron	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Lacaune breed	Male/female	Minimum 60–120 days (about 17 kg)
Agneau de Lozère	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Blanche du Massif Central breed	Male/female	Maximum 130 days (7–19 kg)
Agneau de Pauillac	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Lacaune, Tarasconnaise and Blanche du Massif Central crossbreeds with Bérischon du Cher, Charollais, Suffolk and Rouge de l'Ouest breeds	Male/female	Maximum 75 days (11–15 kg)
Agneau de Sisteron	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Mérinos d'Arles, Préalpes du Sud and Mourérous breeds	Male/female	Minimum 70–150 days (13–19 kg)
Agneau des Pyrénées	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Manech Red head, Manech Black head and Basque-Béarnaise breeds	Male/female	Maximum 45 days (9–16 kg)
Agneau du Bourbonnais	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Charollais, Ile de France, Texel, Suffolk and Charmoise breeds	Male/female	Minimum 90–210 days (14–23 kg)
Agneau du Limousin	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Breeds for slaughter and their crossbreeds	Male/female	Minimum 5–10 months (13–22 kg)

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics): Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Agneau du Périgord	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Crossbreeds with rams from Berrichon, Charollais, Ile de France, Rouge de l'Ouest, Suffolk and Texel breeds and ewes from pure or semi-hardy breeds (Lacaune viande, Blanche du Massif Central, INRA 401)	Male/female	Minimum 80–180 days (15–21 kg)
Agneau du Poitou-Charentes	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Ile de France, Mouton Charollais, Mouton Vendéen, Rouge de l'Ouest, Suffolk and Texel breeds	Male/female	Maximum 10 months (14–22 kg)
Agneau du Quercy	PGI	France	Lamb (suckling) from sheep (*Ovis aries*)	Caussenade du Lot breed, only some parts Blanche du Massif Central and Lacaune breeds	Male/female	Minimum 5 months (17.5 kg)
Agnello del Centro Italia	PGI	Italy	Lamb (suckling) from sheep (*Ovis aries*)	Central Italy breeds	Male/female	Agnello Leggero maximum 12 months (8.01 to 13 kg); Agnello Pesante maximum 12 months (13.01–20 kg)
Agnello di Sardegna	PGI	Italy	Lamb (suckling) from sheep (*Ovis aries*)	Sardinian breeds	Male/female	Leggero maximum 150 days (4.5–8.5 kg); da Taglio (spring lamb) maximum 150 days (8.5–10 kg)
Αρνάκι Ελασσόνας/Arnaki Elassonas	PDO	Greece	Lamb (suckling) from sheep (*Ovis aries*)	Karagouniki, Vlahiki, Sarakatsaniki and Boutsiko, or crossbred with Greek Hiotiko, Serres, Mytilini and Frizarta breeds	Male/female	Minimum 30–45 days (6½–10½ kg)
Αρνάκι Λήμνου/Arnaki Limnou	PGI	Greece	Lamb (suckling) from sheep (*Ovis aries*)	Indigenous Greek breeds	Male/female	Minimum 60–120 days (minimum 10 kg)
Barèges-Gavarnie	PDO	France	Mutton from sheep (*Ovis aries*)	Barégeoise breed	Male/female	Minimum 2–6 years while Doublons are older than 18 months (22–23 kg)
Borrego da Beira	PGI	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	Cross bred of Churra do Campo or Marialveira, Churra Mondegueira and Merino da Beira Baixa breeds	Male/female	Not specified (12 kg live weight)
Borrego de Montemor-o-Novo	PGI	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	White Merino breed	Male/female	Minimum 90–120 days (9–12 kg)
Borrego do Baixo Alentejo	PGI	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	Crossbred of Campaniça and White Merino breeds	Male/female	Minimum 3–4 months (8–13 kg)
Borrego do Nordeste Alentejano	PGI	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	White Merino or crosses with other breeds called melhoradoras (improvers)	Male/female	Minimum 90–120 days (8–14 kg)
Borrego Serra da Estrela	PDO	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	Bordaleira breed	Male/female	Maximum 30 days (12 kg)
Borrego Terrincho	PDO	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	Churra da Terra Quente breed	Male/female	Minimum 3–4 weeks (5–8 kg)
Comeragh Mountain Lamb	PGI	Ireland	Lamb from sheep (*Ovis aries*)	Blackface breed	Male/female	Not specified
Connemara Hill Lamb/Uain Sléibhe Chonamara	PGI	Ireland	Lamb from sheep (*Ovis aries*)	Blackface breed	Male/female	Minimum 10–14 weeks (10 kg)
Cordeiro Bragançano	PDO	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	Churra Galega Bragançana breed	Male/female	Minimum 30–90 days (8–12 kg)
Cordeiro de Barroso/Anho de Barroso/Cordeiro de leite de Barroso	PGI	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	Churra Galega and Bordaleira de Entre Douro e Minho breeds	Male/female	Minimum 1–4 months (4–12 kg)

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics): Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Cordeiro Mirandês/Canhono Mirandês	PDO	Portugal	Lamb (suckling) from sheep (*Ovis aries*)	Churra Galega Mirandesa breed	Male/female	Maximum 4 months
Cordero de Extremadura	PGI	Spain	Lamb (suckling) from sheep (*Ovis aries*)	Merino, Ille de France and Merino Fleischschaf breeds	Male/female	Maximum 100 days (< 14 kg for females and < 16 kg for males)
Cordero Manchego	PGI	Spain	Lamb (suckling) from sheep (*Ovis aries*)	Manchega breed	Non-castrated male/female	Minimum 60–90 days
Cordero de Navarra/Nafarroako Arkumea	PGI	Spain	Lamb (suckling) from sheep (*Ovis aries*)	Navarra (Lechal and Ternasco lamb) and Lacha (Lechal lamb) breeds	Male/female	Not specified (9–12 kg)
Cordero Segureño	PGI	Spain	Lamb (suckling) from sheep (*Ovis aries*)	White and Rubissca Segureño breeds	Male/female	Not specified (9–13 kg)
Dalmatinska janjetina	PDO	Croatia	Lamb from sheep (*Ovis aries*)	Dalmatinska Pramenka breed	Male/female	Minimum 70–130 days
Diepholzer Moorschnucke	PDO	Germany	Lamb or mutton from sheep (*Ovis aries*)	Diepholzer Moorschnucke breed	Male/female	Not specified
Gower Salt Marsh Lamb	PDO	United Kingdom	Lamb from sheep (*Ovis aries*)	No restriction regarding the breeds (or cross-breeds)	Male/female	Minimum 4–10 months (16–23 kg)
Hånnlamb	PDO	Sweden	Lamb or mutton from sheep (*Ovis aries*)	Gutefår breed	Male/female	Not specified (15–25 kg, body should be fully developed)
Isle of Man Manx Loaghtan Lamb	PDO	United Kingdom	Lamb from sheep (*Ovis aries*)	Manx Loaghtan breed	Male/female	Maximum 6–15 months (13–18 kg)
Íslenskt lambakjöt	PDO	Iceland	Lamb from sheep (*Ovis aries*)	Purebred Icelandic sheep	Male/female	Maximum 4–6 months (15–17 kg)
Jagnięcina podhalańska	PGI	Poland	Lamb (suckling) from sheep (*Ovis aries*)	Polska Owca Górska, Polska Owca Górska Odmiany Barwnej and Cakiel Podhalanski breeds	Male/female	Maximum 60 days (4–8 kg)
Keleméri bárányhús	PGI	Hungary	Lamb (suckling) from sheep (*Ovis aries*)	Île-de-France or Suffolk breeds (rams)	Male/female	Maximum 120 days
Lakeland Herdwick	PDO	United Kingdom	Lamb or mutton from sheep (*Ovis aries*)	Herdwick breed	Male/female	Minimum 8–12 months (14–22 kg)
Lechazo de Castilla y León	PGI	Spain	Lamb (suckling) from sheep (*Ovis aries*)	Churra, Castilian and Ojalada breeds	Male/female	Maximum 35 days (4.5–7 kg)
Lička janjetina	PGI	Croatia	Lamb (suckling) from sheep (*Ovis aries*)	Lička Pramenka breed	Male/female	Minimum 90–160 days (12–18 kg)
Lofotlam	PGI	Norway	Lamb (suckling) from sheep (*Ovis aries*)	Norwegian white sheep	Male/female	Not specified (16 kg)
Lüneburger Heidschnucke	PDO	Germany	Lamb or mutton from sheep (*Ovis aries*)	Heidschnucke breed	Male/female	Not specified
Orkney Lamb	PDO	United Kingdom	Lamb from sheep (*Ovis aries*)	North Ronaldsay breed	Male/female	Maximum 8–12 months
Paška janjetina	PDO	Croatia	Lamb (suckling) from sheep (*Ovis aries*)	Not specified	Male/female	Maximum 45 days (13 kg)
Prés-salés de la baie de Somme	PDO	France	Lamb from sheep (*Ovis aries*)	Suffolk, Hampshire, Roussin, Ile de France, Rouge de l'Ouest, Boulonnais and Vendéen breeds	Male/female	Maximum 12 months
Prés-salés du Mont-Saint-Michel	PDO	France	Lamb from sheep (*Ovis aries*)	Suffolk, Roussin, Rouge de l'Ouest, Vendéen, Cotentin, Avranchin and Charollais breeds	Male/female	Maximum 12 months
Scotch Lamb	PGI	United Kingdom	Lamb or mutton from sheep (*Ovis aries*)	Scottish Blackface, Cheviots, Scotch Mule, Texel and Shetland breeds	Male/female	Not specified

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics) Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Shetland Lamb	PDO	United Kingdom	Lamb from sheep (*Ovis aries*)	Shetland or Shetland/Cheviot cross breeds	Male/female	Maximum 12 months (pure bred Shetland 7–14 kg; cross breeds 20 kg)
Ternasco de Aragón	PGI	Spain	Lamb (suckling) from sheep (*Ovis aries*)	Rasa Aragonesa, Ojinegra de Teruel and Castellana breeds	Male/female	Minimum 70–90 days (8–12.5 kg)
Vadehavslam	PGI	Denmark	Lamb from sheep (*Ovis aries*)	Texel breed or crossed with males of Suffolk or Gotland breeds	Male/female	Not specified (live weight 19–25 kg)
Welsh Lamb	PGI	United Kingdom	Lamb from sheep (*Ovis aries*)	Wales breed	Male/female	Maximum 12 months
West Country Lamb	PGI	United Kingdom	Lamb from sheep (*Ovis aries*)	Polled Dorset and Dorset Horn breeds	Male/female	Maximum 12 months (9–26 kg)
Poultry ($n = 48$)						
Canard à foie gras du Sud-Ouest (Chalosse, Gascogne, Gers, Landes, Périgord, Quercy)	PGI	France	Duck (*Cairina moschata domestica; Anas platyrhynchos domesticus*)	Barbarie/Muscovy and Mulard breeds	Male	Minimum 3 months
Capão de Freamunde	PGI	Portugal	Chicken (*Gallus gallus domesticus*)	Slow-growing; Pedrês Portuguesa, Preta Lusitanica and Amarela breeds	Male/female	Minium 10–11 months
Capón de Vilalba	PGI	Spain	Chicken (*Gallus gallus domesticus*)	Slow-growing; Galiña de Mos breed	Male	Minimum 150 days (2.5 kg)
Chapon du Périgord	PGI	France	Chicken (*Gallus gallus domesticus*)	Slow-growing genetic types of naked neck breed	Male	Minimum 150 days
Dinde de Bresse	PDO	France	Turkey (*Meleagris gallopavo domesticus*)	Slow-growing; Bresse breed	Male/female	Minimum 6 months (females 3 kg; males 5½ kg)
Gall del Penedès	PGI	Spain	Chicken (*Gallus gallus domesticus*)	Slow-growing; Penedesenca Negra breed	Male	Minimum 98 days (1.5 kg)
Oie d'Anjou	PGI	France	Goose (*Anser anser*)	White Rhine geese breed	Female	Minimum 175 days (2.5 kg)
Pintade de l'Ardèche	PGI	France	Guinea fowl (*Numida meleagris*)	Slow-growing breed	Male/female	Minimum 94 days
Pintadeau de la Drôme	PGI	France	Guinea fowl (*Numida meleagris*)	Slow-growing breed	Male/female	Maximum 87–100 days (minimum 850 g)
Pollo y Capón del Prat	PGI	Spain	Chicken (*Gallus gallus domesticus*)	Prat breed	Male/female	Minimum 77–182 days
Poularde du Périgord	PGI	France	Chicken (*Gallus gallus domesticus*)	Slow-growing genetic types of naked neck	Female	Minimum 120 days
Poulet de l'Ardèche/ Chapon de l'Ardèche	PGI	France	Chicken (*Gallus gallus domesticus*)	Slow-growing rustic breeds	Male/female	Minimum 81–150 days (1.3–2.9 kg)
Poulet des Cévennes/ Chapon des Cévennes	PGI	France	Chicken (*Gallus gallus domesticus*)	Slow-growing breed	Male/female	Chickens 84 days; capons 150 days
Poulet du Bourbonnais	PDO	France	Chicken (*Gallus gallus domesticus*)	Crossbreed of Bourbonnais cock and Bourbonnais hen (or another breed)	Male/female	Minimum 101 days (1.4 kg)
Poulet du Périgord	PGI	France	Chicken (*Gallus gallus domesticus*)	Slow-growing genetic types of naked neck (yellow) and/or non-naked neck (white)	Male/female	Poulard du Périgord 81 days; poularde du Périgord 120 days; capon du Périgord 150 days

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics)			
			Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Volaille de Bresse/ Poulet de Bresse/ Poularde de Bresse/ Chapon de Bresse	PDO	France	Chicken (*Gallus gallus domesticus*)	Slow-growing; Gauloise or Bresse breeds	Male/female	Chickens 16 weeks (1.3 kg); pullets 20 weeks (1.8 kg); capons 32 weeks (3 kg)
Volailles d'Alsace	PGI	France	Alsace poultry (guinea hens; turkeys; capons; guinea-hen capons; pullets)	Pure/crossbred and slow-growing breeds	Male/female	Close to sexual maturity
Volailles d'Ancenis	PGI	France	Ancenis poultry (white, yellow, black chickens; guinea hens; turkeys; white, yellow capons; guinea-hen capons; geese; pullets)	Slow-growing breed and their crossbreeds	Male/female	Close to sexual maturity; chickens 81 days; capons 150 days
Volailles d'Auvergne	PGI	France	Auvergne poultry (fowl; guinea hens; capons; pullets)	Slow-growing breed and their crossbreeds	Male/female	Close to sexual maturity
Volailles de Bourgogne	PGI	France	Bourgogne poultry (partridges; ducks; quails; capons; pullets; partridge capons)	Slow-growing, rustic breed and their crossbreeds	Male/female	Close to sexual maturity
Volailles de Bretagne	PGI	France	Bretagne poultry (chickens; capons, pullets; guinea hens; geese; turkeys)	Slow-growing breed and their crossbreeds	Male/female	Close to sexual maturity
Volailles de Challans	PGI	France	Challans poultry (chickens; pullets; young hens; capons; guinea hens/capons; ducks; geese; quails; turkeys)	Slow-growing breeds	Male/female	Close to sexual maturity
Volailles de Cholet	PGI	France	Cholet poultry (white, black chickens; capons; pullets; turkeys; guinea hens)	Pure/crossbred and slow-growing breeds	Male/female	Close to sexual maturity
Volailles de Gascogne	PGI	France	Gascogne poultry (chickens; pullets; Blanche, Jaune or Noire breed capons)	Slow-growing breed and their crossbreeds	Male/female	Chickens 81–91 days (1.2 kg), pullets 120 days (1.8 kg); capons 150 days (3 kg)
Volailles de Houdan	PGI	France	Houdan poultry (fowl; chickens; pullets; capons)	Houdan breed	Male/female	Minimum 105 days
Volailles de Janzé	PGI	France	Janzé poultry (fowl; chickens; pullets; capons)	Slow-growing breed and their crossbreeds	Male/female	Chickens minimum 81 days (2 kg); guinea hen 94 days; capons 6 months (4.5 kg)
Volailles de la Champagne	PGI	France	Champagne poultry (turkeys; capons)	Slow-growing, rustic breeds	Male/female	Close to sexual maturity
Volailles de la Drôme	PGI	France	Drôme poultry (yellow capons; bare-neck yellow, blue-claw chickens; turkeys; pullets)	Slow-growing breeds	Male/female	Close to sexual maturity
Volailles de l'Ain	PGI	France	Ain poultry (chickens; capons; guinea hens; turkeys)	Slow-growing breed	Male/female	Maximum 81 days
Volailles de Licques	PGI	France	Licques poultry (white, yellow chickens; pullets; guinea hens; capons; turkeys)	Pure/crossbred and slow-growing breeds	Male/female	Females 98 days; males 126 days

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics)			
			Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Volailles de l'Orléanais	PGI	France	l'Orléanais poultry (white, black chickens; turkeys, capons; pullets)	Slow-growing pure breed and their crossbreeds	Male/female	Close to sexual maturity
Volailles de Loué	PGI	France	Loué poultry (white, black, yellow chickens; turkeys; guinea-fowl; ducks; geese; capon; hens; guinea-fowl capon)	Slow-growing pure breed and their crossbreeds	Male/female	Close to sexual maturity
Volailles de Normandie	PGI	France	Normandie poultry (turkeys; guinea hens; white, yellow, naked neck chickens; naked neck, black capons)	Slow-growing pure breed and their crossbreeds	Male/female	Close to sexual maturity
Volailles de Vendée	PGI	France	Vendée poultry (different winged animals)	Slow-growing breeds	Male/female	Close to sexual maturity
Volailles des Landes	PGI	France	Landes poultry (quails; guinea hens; chicken capons; turkeys; pullets; white, black, yellow, naked neck chickens)	Slow-growing pure breed and their crossbreeds	Male/female	Close to sexual maturity
Volailles du Béarn	PGI	France	Béarn poultry (chicken; guinea hens/capons; turkeys)	Slow-growing pure breed and their crossbreeds	Male/female	Close to sexual maturity
Volailles du Berry	PGI	France	Berry poultry (fowl; chickens)	Malvoisine breed or other slow-growing breeds	Male/female	Close to sexual maturity (hen 2.8–3.5 kg; cock 3.5–4 kg)
Volailles du Charolais	PGI	France	Charoláis poultry (naked neck and refined fowl)	Slow-growing, rustic breeds	Male/female	Close to sexual maturity
Volailles du Forez	PGI	France	Forez poultry (poultry; capons; turkeys)	Slow-growing, rustic breeds and their crossbreeds	Male/female	Close to sexual maturity
Volailles du Gatinais	PGI	France	Chicken (*Gallus gallus domesticus*)	Gâtinaise breed	Male/female	Minimum 81 days (hen 2.5–3 kg; cock 3.5–4 kg)
Volailles du Gers	PGI	France	Gers poultry (chicken; pullets; grey, red, white, black capons; black turkeys; guinea hens/capons)	Slow-growing breeds	Male/female	Close to sexual maturity
Volailles du Languedoc	PGI	France	Languedoc poultry (fowl)	Malvoisine breed and crossbreeds	Male/female	Minimum 81 days (live weights: 3.5–4 kg)
Volailles du Lauragais	PGI	France	Lauragais poultry (fowl)	Pure or cross-bred slow-growing breeds	Male/female	Minimum 81 days (live weights: 3.5–4 kg)
Volailles du Maine	PGI	France	Maine poultry (fowl; chicken; turkey)	Pure, crossbred and slow-growing rustic breeds	Male/female	Close to sexual maturity
Volailles du plateau de Langres	PGI	France	Langers plateau poultry (fowl; chicken; turkey)	Pure, crossbred and slow-growing rustic breeds	Male/female	Close to sexual maturity
Volailles du Val de Sèvres	PGI	France	Val-de-Sèvres poultry (fowl; chicken; turkey)	Pure, crossbred and slow-growing rustic breeds	Male/female	Close to sexual maturity
Volailles du Velay	PGI	France	Velay poultry (fowl; chicken; guinea hen; turkey; capon)	Slow-growing, rustic breeds	Male/female	Close to sexual maturity
Us Zagorski puran	PGI	Croatia	Turkey (*Meleagris gallopavo domesticus*)	Croatian turkeys	Male/female	Maximum 6–8 months

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics)			
			Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Pork (*n* = 18)						
Carne de Bísaro Transmontano/Carne de Porco Transmontano	PDO	Portugal	Pork from pig (*Sus scrofa domesticus*)	Bísara breed	Male/female	Minimum 45 days (12 kg)
Carne de Porco Alentejano	PDO	Portugal	Pork from pig (*Sus scrofa mediterraneus*)	Alentejano breed	Male/female	Minimum 12–20 months (90 kg)
Cerdo de Teruel	PGI	Spain	Pork from pig (*Sus scrofa domesticus*)	Landrace or Large White or crossbred as dam line and Duroc as sire line breed	Male/female	Minimum 14–15 months (86 kg)
Cinta Senese	PDO	Italy	Pork from pig (*Sus scrofa domesticus*)	Cinta Senese breed	Male/female	Maximum 12 months
Kintoa	PDO	France	Pork from pig (*Sus scrofa domesticus*)	Basque black piebald breed	Male/female	Minimum 12–24 months (100 kg)
Meso crne slavonske svinje	PDO	Croatia	Pork from pig (*Sus scrofa domesticus*)	Black Slavonian (Fajferica) breed	Male/female	Piglets age maximum 120–150 days (20–30 kg); pigs maximum 450–730 days (100–170 kg)
Meso turopoljske svinje	PDO	Croatia	Pork from pig (*Sus scrofa domesticus*)	Turopolje breed	Male/female	Minimum 12 months
Porc d'Auvergne	PGI	France	Pork from pig (*Sus scrofa domesticus*)	Not specified	Male/female	Maximum 26 weeks (75 kg)
Porc de Franche-Comté	PGI	France	Pork from pig (*Sus scrofa domesticus*)	Not specified	Neutered male/female	Minimum 26 weeks (minimum 75 kg)
Porc de la Sarthe	PGI	France	Pork from pig (*Sus scrofa domesticus*)	Sarthe farm pork breed	Male/female	Minimum 26 weeks
Porc de Normandie	PGI	France	Pork from pig (*Sus scrofa domesticus*)	Bayeux breed	Male/female	Minimum 26 weeks
Porc de Vendée	PGI	France	Pork from pig (*Sus scrofa domesticus*)	Large White breed	Male/female	Minimum 26 weeks
Porc du Limousin	PGI	France	Pork from pig (*Sus scrofa domesticus*)	Cul-Noir de Saint-Yrieix la Perche breed	Male/female	Minimum 26 weeks
Porc du Sud-Ouest	PGI	France	Pork from pig (*Sus scrofa domesticus*)	Not specified	Male/female	120 kg
Porc noir de Bigorre	PGI	France	Pork from pig (*Sus scrofa domesticus*)	Pure-bred Gascon breed	Male/female	Minimum 12–24 months (100 kg)
Schwäbisch-Hällisches Qualitätsschweinefleisch	PGI	Germany	Pork from pig (*Sus scrofa domesticus*)	Preta breed	Male/female	Live male pigs 90 cm tall (275–330 kg), live females 80 cm tall (222–275 kg)
Viande de porc, marque nationale grand-duché de Luxembourg	PGI	Luxembourg	Pork from pig (*Sus scrofa domesticus*)	Not specified	Male/female	Not specified
金华两头乌猪/Jinhua Liang Tou Wu Zhu	PGI	China	Pork from pig (*Sus scrofa domesticus*)	Jinhua breed	Male/female	Minimum 213–226 days
Goat (*n* = 11)						
Cabrito da Beira	PGI	Portugal	Goat (*Capra hircus*)	Charnequeira or Serrana breed	Male/female	Minimum 40–45 days (6 kg)

Table 2. Continued

Name	Type (PDO/PGI)	Country	Intrinsic factors (animal characteristics): Species/animal type	Breed	Sex	Age at slaughter (and/or carcass weight)
Cabrito da Gralheira	PGI	Portugal	Goat (*Capra hircus*)	Serrana breed	Male/female	Minimum 40–45 days (6 kg)
Cabrito das Terras Altas do Minho	PGI	Portugal	Goat (*Capra hircus*)	Bravia and Serrana breed and their crossbreeds	Male/female	Minimum 2–4 months
Cabrito de Barroso	PGI	Portugal	Goat (*Capra hircus*)	Bravia and Serrana breed and their crossbreeds	Male/female	Minimum 3 months
Cabrito de Extremadura	PGI	Spain	Goat (*Capra hircus*)	Cabra Serrana, Payoya breeds or crossbreeds	Male/female	Cabrito de Extremadura kids maximum 50 days (6 kg); Cabrito de Extremadura maximum 90 days (9 kg)
Cabrito do Alentejo	PGI	Portugal	Goat (*Capra hircus*)	Serpentine breed	Male/female	Minimum 30–120 days (3½-7½ kg)
Cabrito Transmontano	PDO	Portugal	Goat (*Capra hircus*)	Serrana breed	Male/female	Minimum 30–90 days
Cordero Manchego	PGI	Spain	Goat (*Capra hircus*)	Manchega breed	Non-castrated male/female	Minimum 60–90 days
Κατσικάκι Ελασσόνας/ Katsikaki Elassonas	PDO	Greece	Goat (*Capra hircus*)	Capra Prisca or cross-breeds of Capra prisca with skopelos breed	Male/female	Minimum 30–55 (5½-9 kg)
Κατσικάκι Λήμνου/ Katsikaki Limnou	PGI	Greece	Goat (*Capra hircus*)	Capra prisca breed	Male/female	Minimum 60–90 days (8 kg)
鄂托克阿尔巴斯山羊肉/Etuoke Aerbasi Shan Yang Rou	PGI	China	Goat (*Capra hircus*)	Arbas breed	Male/female	Not specified
Game (*n* = 2)						
Lapin Poron liha	PDO	Finland	Reindeer meat (*Rangiferus tarandus*)	Not specified	Male/female	Calves minimum 5–8 months; adults minimum 1 year or older
天祝白牦牛/Tianzhu Bai Mao Niu	PGI	China	Yak meat (*Bos grunniens*)	Tianzhu White Yak	Male/female	Not specified

Name	Extrinsic factors (environmental characteristics): Place of origin	Farming system	Feed/diet	Organoleptic quality characteristics: Colour	Texture	Aroma and flavour	Link to provenance/evidence of typicity
Beef (*n* = 56)							
Bayerisches Rindfleisch/ Rindfleisch aus Bayern	Bavarian territory (Freistaat Bayern)	Extensive (natural grazing)	Pasture and hill grazing	Bright red, small veins of white fat that cover muscle mass	Firm, tender	Juicy, fragrant	Particular natural geographical and climatic conditions of the origin differentiate it in respect to other meats produced in the rest of Germany, making it a more prized product
Bœuf charolais du Bourbonnais	Allier and adjacent cantons in Cher and Nièvre, Creuse and Saône et Loire	Semi-extensive (natural grazing and fodder)	Grass, coarse fodder, dried feed, cereals, cake, concentrated feeds, roots and tubers	Not specified	Tender, fondant consistency	Superior organoleptic characteristics, strong, peculiar flavour	Historical reputation, characteristic breed and rearing method on natural meadows (diet from high grasslands, volcanic and natural fertile lands and bocages)
Bœuf de Bazas	Gironde, Landes and Lot-et-Garonne, in the region of Aquitaine	Semi-extensive (natural grazing and fodder)	Vegetation plus cereal- or minced maize-based fodder (maize, corn, barley, triticale, oat, rye)	Bright red	Unique oily consistency	Fine hazelnut taste	Historical reputation (since 13th century, fame of Boeuf de Bazas maintained by the traditional parade of

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
			integrated with raw forages (grass, hay) and/or roots and tubers				Carnival Wednesday), characteristic breed and rearing method
Bœuf de Chalosse	Hills of southern Aquitaine between Gave de Pau and the Adour restricted to Landes and adjoining cantons	Semi-extensive (natural grazing and fodder)	Grassland and farm produced fodder and fattened with maize for 6–12 months (finishing period)	Not specified	Tender	Superior organoleptic and quality characteristics	Historical reputation (beginning of 19th century when working cows were later fattened), characteristic breed and superior product quality
Bœuf de Charolles	Loire, Niévre and Rhône regions	Extensive (natural grazing)	Grazing on natural vegetation (grass) abundantly available due to area climatic conditions	Bright red, well marbled with fine veins of fat	Lingering juicy, tender	Acidic taste, aromas and smells rich, intense, reminiscent of cereals, plants and animal fat	Historical reputation and rearing method
Boeuf de Vendée	Ille-et-Vilaine in region Brittany; Loire-Atlantique, Maine-et-Loire, Mayenne, Vendée and Sarthe, in region Pays de la Loire; Deux-Sèvres, in region Poitou-Charentes, and Orne, in region of Lower Normandy	Semi-extensive (natural grazing and fodder)	Feed plus raw grass, hay and energetic and protein complements	Orange	Juicy, tender consistency	Characteristic flavour	Historical reputation and tenderness of meat
Bœuf du Maine	Sarthe, Mayenne and adjacent cantons including Maine et Loire and Mortagne and Alençon in Orne	Semi-extensive (natural grazing and fodder)	Natural grazing in free pastures (at least 7 months a year) and pasture grass-based fodder in stalls (maximum 5 months)	Not specified	Very tender	Superior organoleptic characteristics, very flavourful	Historical reputation (dates to the end of the 18th century) and characteristic region for grassland (oceanic, humid and mild climate of the Paysde-la-Loire region)
Carn d'Andorra	Andorra mountain settled in eastern Pyrenees	Extensive (natural grazing)	Natural grazing in mountain pastures plus feed including cereals and pulses	Pink to red	Tender, juicy, succulent	Characteristic flavour	Historical reputation, characteristic breed and rearing method that includes high quality mountain pastures and a specific fattening process
Carnalentejana	Beja, Évora and Portalegre and subdistricts of Alcácer do Sal, Grandola, Santiago do Cacém and Sines in district of Setúbal	Extensive (natural grazing)	Mediterranean spontaneous pastures and harvest remains (hay and straw)	Red to dark red	Fine texture, very succulent	Full flavour	Historical reputation, characteristic breed and rearing method where the pastures give the meat its distinctive organoleptic characteristics

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
Carne Arouquesa	Aveiro, Viseu, Porto and Vila Real	Extensive (natural grazing)	Natural pastures, local vegetation of rocky terrain, spontaneous shrubs and harvest remains	Pale pink (veal) to dark red (beef)	Firm, slight moist	Characteristic flavour	Historical reputation, characteristic breed and rearing method with natural vegetation
Carne Barrosã	Districts of Viana do Castelo, Braga and Vila Real	Extensive (natural grazing)	Natural pastures on mountainous slopes (spring and summer) of vacant lands plus agricultural products produced on the farm	Pink (veal) to dark red (beef)	Fine textured, succulent, tender	Superior organoleptic characteristics	Historical reputation and characteristic breed
Carne Cachena da Peneda	Arcos de Valdevez and Ponte da Barca in Viana do Castello district	Extensive (natural grazing)	Natural Atlantic vegetation	Pale pink to light red	Moist, very succulent, tender	Characteristic flavour	Historical reputation (dates to the start of the 20th century) and characteristic breed
Carne da Charneca	Santarém, Setúbal, Évora and Portalegre	Extensive (natural grazing)	Natural pastures (almost exclusively), harvest remains in periods of scarcity	Dark pink to dark red	Tender, succulent	Characteristic flavour and taste	Historical reputation and characteristic breed
Carne de Ávila	Huelva, Jaen, Sevilla, Teruel, Toledo, Caceres, Badajoz, La Rioja, Madrid and areas of the Autonomous Community of Castilla y León	Extensive (natural grazing)	Mother's milk (veal) and natural feed from the valleys, mountain areas and *dehesa* rangelands (wooded pasturelands)	Bright pink (veal), pale-medium to medium-cherry red (beef). White fat (veal) to cream fat (beef)	Firm consistency, fine moist grain	Rich and pleasant flavour	Historical reputation (dates to prehistoric times with bovine exploitation in this zone), characteristic breed and rearing method in the specific geographical environment (*dehesa*) characterized by the presence of holm oaks
Carne de Bovino Cruzado dos Lameiros do Barroso	Montalegre, Boticas and Chaves in district of Vila Real	Extensive (natural grazing)	Natural permanent pastures (lameiros) with grasses such as fescue, molar grass, woolly grass, spikenard, froggrass, brome, white clover, etc.	Pink (veal) to dark red (beef)	Tender, juicy	Flavourful	Historical reputation and rearing method in mountainous regions with marshes and forested areas
Carne de Bravo do Ribatejo	All municipalities in districts of Beja, Évora, Portalegre, Santarém and selected (7) municipalities in district of Setúbal, selected (4) municipalities in district of Lisbon, municipality of Idanha-a-Nova in district of Castelo Branco, and	Extensive (natural grazing)	Natural grazing on wild grasses, herbs, straw, and hay as well as supplementary feed from farm products	Dark to bright, cherry red	Smooth in texture (fat marbling), tender, firm consistency	Unique, intense and well-balanced flavour (linked to diet)	Historical reputation, rearing method (soil and climate conditions) and characteristic breed (native breed originating in marshlands of Tagus and Mondego rivers)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
	parish of Arazede in municipality of Montemor-o-Velho in district of Coimbra						
Carne de Cantabria	Autonomous Community of Cantabria	Semi-extensive (natural grazing or fodder)	Natural pastures in mountainous areas (spring and summer) or lowland pasture/fresh fodder (autumn) or silage forage (winter)	Light pink to pink (veal), light red to red (beef)	Firm	Characteristic flavour	Historical reputation (activity of grazing dates to 9th century) and grazing method
Carne de la Sierra de Guadarrama	Autonomous Community of Madrid	Extensive (natural grazing)	Natural pastures in the mountainous areas (spring, summer and autumn) or lower altitude pastures (winter) and fodder	Light red or pink meat, white well distributed fat	Tender	Characteristic flavour and taste	Historical reputation and characteristic breed
Carne de Salamanca	Province of Salamanca	Extensive (natural grazing)	Grasslands and stubble fields of the *dehesa* (wooded pasturelands), supplemented by hay and straw when natural resources are scarce	Bright pink to purplish-red	Juicy, tender, fine muscle fibres	Characteristic flavour and taste (linked to diet)	Historical reputation and rearing method in the specific geographical environment (*dehesa*) characterized by the presence of holm oaks
Carne de Vacuno del País Vasco/Euskal Okela	Basque provinces including Gipuzkoa, Bizkaia and Alava provinces	Extensive (natural grazing)	Free range pasturing plus nurtured with natural fodder like fresh grass and dried grass, straw and hay	Pink to red (Txahala), red to dark red (Zaharra and Idia)	Firm consistency, succulent, tender	Characteristic flavour	Historical reputation (existence of autochthonous Pirenaica breed in production area since Neolithic times) and characteristic breed
Carne dos Açores	Islands of the Azores: Santa Maria, São Miguel, Terceira, São Jorge, Graziosa, Pico, Faial, Flores and Corvo	Extensive (natural grazing)	Natural vegetation (pasturelands) including which varies across islands	Pink	Succulent, tender	Characteristic flavour	Historical reputation (16th century historians noted high quality beef produced in Azores) and rearing method with Atlantic climate of islands
Carne Marinhoa	Many of the counties belonging to the districts of Aveiro and Coimbra	Extensive (natural grazing)	Natural pastures	Pale pink to dark red	Firm, slightly moist, succulent	Characteristic flavour	Historical reputation, characteristic breed (dates to end of 19th century) and traditional rearing method based on natural pastures
Carne Maronesa	Municipal areas of Cabeceiras de Basto, Mondim de Basto, Ribeira de Pena, Vila pouca de Aguiar, Vila Real,	Semi-extensive or intensive (natural grazing or straw)	Mediterranean spontaneous pastures (in mountainous region) plus cereal grains	Dark pink to dark red, ivory coloured fat	Succulent, tender	Delicate and unique taste	Historical reputation (dates to middle of 19th century), characteristic breed and rearing method

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
	Amarante, Boticas, Chaves, Montalegre, Murça and Valpaços, in the districts of Vila Real and Braga						
Carne Mertolenga	Districts of Beja, Évora, Portalegre, Santarém and Setúbal	Extensive (natural grazing)	Mediterranean spontaneous pastures and/or straw and hay from the harvests	Dark pink to dark red	Succulent, not too fatty	Full of flavour, organoleptic characteristics due to feeding and rearing	Historical reputation, characteristic breed (always populated area around Mertola) and rearing method
Carne Mirandesa	Subdistricts of Bragança, Macedo de Cavaleiros, Mirando do Douro, Mogadouro, Vimioso and Vinhais	Extensive (natural grazing)	Natural grasslands (marshes) with spontaneous vegetation (more grasses in relation to leguminous plants)	Pink, evenly distributed lines of fat	Fine texture, moist, succulent	Succulent flavour (due to diet from rich vegetation)	Historical reputation (dates to Middle Ages), characteristic breed and local vegetation (edaphological-climatic conditions)
Carne Ramo Grande	Azores archipelago, made up of 9 islands: Santa Maria, São Miguel, Terceira, Graciosa, São Jorge, Pico, Faial, Flores and Corvo	Semi-extensive (natural grazing and fodder)	Pasture (natural or improved) by direct grazing and intercrops of grasses and legumes	Bright red	Firm consistency	Typical aroma and flavour	Historical reputation, specific climatic conditions and rearing method
Charolais de Bourgogne	Selected municipalities in departments of Ain, Cher, Côte d'Or, Loire, Nièvre, Rhône, Saône-et-Loire and Yonne	Semi-extensive (natural grazing and fodder)	Natural grazing in pastures (at least 6 months a year) and coarse fodder (solely from geographical area) in stalls	Bright red, finely marbled	Juicy, tender	Characteristic flavour	Historical reputation, rearing method and environment (quality of soils, grass abundance, favourable climate and hydrography, pedogeological diversity)
Fin Gras/Fin Gras du Mézenc	Selected (28) towns of Mont Mézenc straddles Ardèche and Haute-Loire	Extensive (natural grazing)	Mixture of aromatic plants, grasses, flowers and herbs such as lotus, clover, violet, bistort and yarrow	Pink to red, finely marbled	Juicy, tender	Characteristic taste and flavour	Historical reputation, rearing method and diet (aromatic plants, grasses, flowers and herbs)
Génisse Fleur d'Aubrac	Selected (313) municipal areas subdivided into departments of Aveyron, Cantal, Haute Loire and Lozère, in Midi-Pyrénées, Auvergne and Languedoc-Roussillon regions	Extensive (natural grazing)	Grazing plus feeding local resources	Brilliant red, some light streaks	Juicy, fine	Characteristic flavour	Historical reputation (farming in Aubrac mountain pastures), characteristic breed and rearing conditions
Irish Grass Fed Beef	Island of Ireland comprising of Ireland and Northern Ireland	Extensive (natural grazing)	Natural grass pastures (90% of intake) plus non-grass forage (straw;	Cherry-red, dark red	Juicy, succulent, tender	Distinct grass flavour (due to fatty acids) and	Rearing method and meat quality attributes

Table 2. Continued

Name	Extrinsic factors (environmental characteristics): Place of origin	Farming system	Feed/diet	Organoleptic quality characteristics: Colour	Texture	Aroma and flavour	Link to provenance/evidence of typicity
			fodder beet; maize; other grains) and concentrated feedstuff (not exceed 10%)			cooked qualities i.e., complex 'nutty' undertones	
Magyar szürkemarha hús	Areas of 19 counties of Hungary suitable for extensive keeping (meadows, reed banks and marshland) taken out of cultivation	Extensive (natural grazing)	Natural grass pastures (meadows, reed banks, marshland) plus feeding local resources (haylage or silage)	Red and dark scarlet (high myoglobin)	Dry-fibrous (more connective tissue)	Sour taste (like game meat)	Historical reputation (centuries-old practice) and rearing conditions (traditional, extreme-extensive, cattle walk 20–30 km per day)
Maine-Anjou	Municipal areas in departments of Ille-et-Vilaine in region Brittany, Loire-Atlantique, Maine-et-Loire, Mayenne, Vendée and Sarthe, in region Pays de la Loire, Deux-Sèvres, in region Poitou-Charentes, and Orne, in region of Lower Normandy	Semi-extensive (natural grazing and fodder)	Feed plus raw grass, hay and energetic and protein complements	Bold red tending to orange, finely marbled	Very juicy, tender	Characteristic flavour	Historical reputation, characteristic breed (typical from French mountainous Massif Armoricain) and tenderness of meat
Meso istarskog goveda - boškarina/Meso istrskega goveda - boškarina	Istrian Peninsula of Kvarner Islands, of Karst Plateau, Čičarija/Ćićarija/Cicceria, Podgrad/Materija Valleys/ Podgrajsko podolje and southern slopes of Brkini/ Brkini Hills	Semi-extensive (natural grazing and fodder)	Voluminous feed (pasture, straw) from local resources and tree leaves (from woods)	Light rosy to dark red, moderately marbled	Soft, juicy	Aromatic with pleasant fragrance, characteristic beefy taste	Historical reputation, rearing method and diet (tree leaves)
Orkney beef	Islands of Orkney (off North Coast of Scotland)	Extensive (natural grazing)	Natural grass and herbage	Deep red	Distinctive texture	Characteristic flavour from breed and diet	Historical reputation, characteristic breed and rearing conditions (topography, geology and climate of Orkney Islands influences dietary feed)
Rosée des Pyrénées Catalanes	Territories of Catalan Pyrenees in Spain and France	Extensive (natural grazing)	Mother's milk and mountain pasture grass	Pink to light red with white to cream colour fat	Tender	Rich in iron, low in fat	Historical reputation, rearing method and diet (mountain pasture grass)
Scotch Beef	Scotland mainland from border with England including islands off west coast, Orkney and Shetland Isles	Extensive (natural grazing)	Natural pastures (including hay and silage supplement)	Not specified	Tender, succulent	Characteristic and distinctive flavour	Historical reputation (dates to 19th century), rearing method (traditional way) and region feeding regime

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
Taureau de Camargue	Departments of Bouches-du-Rhône in region Provence-Alpes-Azur and departments of Gard and Hérault in region Languedoc-Roussillon	Extensive (natural grazing)	Forage-based diet of herbs and pasture in marshy land and cereals of hay by-products (from geographical origin)	Bright red, scarce fat (like game meat)	Tender	Tasteful and aromatic with gamey flavour	Historical reputation, rearing method (open air) and characteristic breed (bred for bull fighting and existed for centuries in Camargue region)
Ternera Asturiana	Autonomous Community of the Principality of Asturias	Extensive (natural grazing)	Mother's milk, mountain pasture (gramineous and leguminous plants) and fodder from natural pastures (winter)	Pink to red	Tender, compact consistency	Characteristic flavour and aroma	Historical reputation, rearing method and characteristic breed (Asturiana in area dates to immemorial times)
Ternera de Aliste	Selected municipalities in districts of Aliste, Sayago and Sanabria in province of Zamora	Semi-extensive (natural grazing and fodder)	Mother's milk and grazing at the pastures and fodder (when stabled until slaughter)	Pale pink (dairy), brighter pink (grazing), pearly-white fat	Firm, slightly moist consistency, tender, juicy	Subtle aroma and delicate taste	Historical reputation and rearing method
Ternera de Extremadura	Districts (22) of Autonomous Community of Extremadura	Extensive (natural grazing)	Natural pastures and fodder (straw, hay, cereals, legumes and fibres concentrates) and autochthon herbs from pastures	Bright red (Ternera); light red and purple (Añojo); cherry red (Novillo)	Compact consistency, fine structure	Characteristic flavour	Historical reputation (ancient traditions), rearing method (open air in all seasons of the year) and diet from Extremadura pastures (*dehesa*)
Ternera de los Pirineos Catalanes/Vedella dels Pirineus Catalans/Vedell des Pyrénées Catalanes	Selected comarches of Catalan Pyrenees in Spain and France, and selected municipalities of Pyrenees Orientales in France, and department of Aude in Pyrenees Massif in France	Extensive or semi-extensive (natural grazing and/or fodder)	Natural pasture grass and/or fodder (cereals and legumes)	Pink to bright red, white creamy fat	Tender	Characteristic flavour	Historical reputation
Ternera de Navarra/ Nafarroako Aratxea	North-western zones of Pirineos, Cuenca de Pamplona, Tierra Estrella, Navarra Media, Ribera Alta and selected (19) districts in Ribera Baja region, in Autonomous Community of Navarra	Extensive or semi-extensive (natural grazing and/or fodder)	Natural pastures and fresh fodder (summer) or dried forage (winter) or supplemented with cereals, legumes and authorized concentrates	Deep pink, light red or red, marbling low	Tender, succulent	Strong taste (high content of proteins and iron), aroma and taste of fat is weak	Historical reputation (originate in ancient times in production area), rearing method (open air in summer) and characteristic breed (adapted to extreme conditions)
Ternera Gallega	Provinces of Lugo and Orense and municipalities in provinces of La Coruna and Pontevedra	Extensive or semi-extensive (natural grazing and/or fodder)	Natural resources and/or supplementary feed like corn, potatoes, turnips and fresh/dried fodder and authorized concentrates	Light pink. pearly white fat (Ternera), pink to light red, cream fat (Añojo)	Compact consistency, slightly humid, tender, succulent	Strong and good taste	Historical reputation (bovine production dates to Celtic era) and characteristic breed
Vaca de Extremadura	Autonomous Community of Extremadura	Extensive (natural grazing)	Grazing fodder making up minimum 30% of feed	Cherry red to purple red, finely marbled		Aroma of animal fat, deep and	Historical reputation, rearing method in specific

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
			(grass, cereals, legumes) and other farm resources such as *dehesa* (wooded pasturelands) and *dehesa*-style landscape with 60% from local resources		Firm consistency, slightly moist, fine texture	long-lasting meaty flavour of beef	geographical environment (*dehesa*) characterized by presence of holm oaks and diet and characteristic breed (adapted to extreme conditions)
Vaca Gallega – Buey Gallego	Entire territory of Galicia	Semi-extensive (natural grazing and fodder)	Natural pasture grass and supplementary feed	Light pink to bright pink, red to cherry red (cow), red to purple-red (steers)	Firm consistency, tender	Characteristic flavour and aromatic smell	Historical reputation and characteristic breed
Vadehavsstude	Region of Wadden Sea (*Vadehavn*) in south-west of Denmark, including islands of Rømø, Mandø and Fanø and, on mainland, territory on northern border	Semi-extensive (natural grazing and fodder)	Grazing on salt meadows for minimum 4½ months per year and feed include grass and maize silage (winter)	Pink to red	Juicy, tender	Intense flavour, pronounced aroma, salty taste (due to diet)	Historical reputation (dates to Iron Age, ancient tradition of raising cattle), rearing method and diet (on salt meadows)
Veau d'Aveyron et du Ségala	Cantons (75) subdivided into departments of Aveyron, Tarn, Lot, Tarn-et-Garonne in Midi-Pyrenees region, and in Cantal department in Auvergne region	Intensive (milk and cereals)	Mother's milk and complementary cereal-based integration	Pink	Tender	Strong taste, delicate flavour	Historical reputation (ancient tradition of raising veal and cultivation of cereals), rearing method, characteristic breed and feed
Veau du Limousin	Departments of Haute-Vienne, Creuse, Corrèze, Indre, Charente, Vienne, Dordogne, Lot, Cantal and Puy de Dôme	Intensive (milk and feed)	Mother's milk and/or supplemented by adjuvants (sugar, fresh eggs) and/or suckler feed	White-rosy (due to iron deficiency in soil)	Tender	Slight aftertaste of hazelnut (due to noble fats of mother's milk)	Historical reputation (dates to late 19th century) and characteristic breed for the production of suckling calves
Viande de Blanc-Bleu Belge/ Belgisch Witblauw Vlees	Belgium	Semi-extensive (natural grazing and fodder)	Grass and feed (e.g., flax meal, corn)	Pink to red	Buttery soft texture, tender	Intense flavour, rich taste	Historical reputation and characteristic breed (local)
Vitela de Lafões	Municipal areas of Oliveira de Frades, Vouzela, São Pedro do Sul, Sever do Vouga, Viseu and Castro Daire, in Viseu district	Intensive (milk and feed)	Mother's milk and/or supplemented by hay, seasonal vegetation or corn flour concentrates	Light pink, evenly distributed fat	Regular consistency, slightly moist, succulent	Flavour from natural vegetation (cattle feed on)	Historical reputation (dates to 19th century), characteristic breed and local vegetation (edaphological-climatic conditions)
Vitellone Bianco dell'Appennino Centrale	The Marches, Abruzzo and Molise regions, provinces of Bologna, Ravenna,	Semi-extensive (natural grazing and fodder)	Natural pastures and/or forage from natural or artificial grassland and	Vivid red	Succulent, nourishing, fine grained	Characteristic aroma and flavour (due to	Historical reputation (dates to pre-Roman period), rearing

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
	Forlì-Cesena and Rimini in Emilia Romagna region; Benevento and Avellino, areas of Caserta in Campania region; Frosinone, Rieti, Viterbo, parts of provinces of Rome and Latina, in Lazio region; Grosseto, Siena, Arezzo, Florence, Pistoia, Prato, Livorno and Pisa in Tuscany region		herbaceous crops typical of the geographical area and/or simple or composed concentrated feed and mineral supplements			diet on pastures with specific aromatic components and pigments)	method and characteristic breed
Vitelloni Piemontesi della Coscia	Provinces of Alessandria, Asti, Cuneo, Turin and municipalities in provinces of Biella, Novara and Vercelli, in Piedmont region and some municipalities in provinces of Imperia and Savona in Liguria region	Semi-extensive (natural grazing and fodder)	Fodder making up minimum 70% of feed (natural or artificial meadows and herbaceous crops) or Simple/compound cereal-based feed with minerals and vitamins	Pink to bright red	Tender and succulent	Characteristic flavour, high protein content, low fat content	Historical reputation (dates to early 20th century), rearing method and characteristic breed with unique morphological characteristics (muscular mass)
Vlees van het rood ras van West-Vlaanderen	Belgian province of West Flanders	Extensive (natural grazing)	Grass and grassland products	Dark red, slightly marbled	Fine-grained	Intense and pronounced flavour of meat	Historical reputation, rearing method and characteristic breed
Weideochse vom Limpurger Rind	Limpurg mountains, Welzheimer forest, Ostalb-Foreland, Hohenlohekreis, Schwäbisch Hall district	Extensive (natural grazing)	Natural grazing in meadow with hay in winter as well as any addition of soy and its products or corn silage is prohibited	Pink to red	Excellently tender and juicy	Characteristic flavour and tasty meat	Historical reputation, breed and rearing method
Welsh Beef	Wales	Extensive (natural grazing)	Natural grazing on grass pastures	Red with yellowish white fat	Tender, succulent	Full flavoured	Historical reputation (cattle industry from Celts, Romans and Normans) and rearing method (traditional)
West Country Beef	West Country region of England	Extensive (natural grazing)	Natural grazing (minimum 6 months) on grass/forages (at least 70% of diet)	Pink to dark red with white to yellow fat	Tender, succulent	Rich flavour	Historical reputation, rearing method and diet (produces meat with higher *n*-3 fatty acids and vitamin E concentrations)
Sheep ($n = 54$)							
Abbacchio Romano	Entire territory of the Lazio region	Semi-extensive (natural grazing and fodder)	Mother's milk, natural pastures, meadows, grasses, dried fodder and concentrates	Light pink with solid white fat	Firm consistency, fine	Delicate flavour	Historical reputation (dates to 4th century), rearing method and diet

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
Agneau de l'Aveyron	Aveyron and adjacent cantons	Intensive (milk and cereals)	Mother's milk and complement of hay and straw, cereal-based feed	Rose-pink	Tender	Tasteful	Historical reputation, characteristic breed and rearing method (traditional)
Agneau de Lozère	259 municipalities in Cantal and Haute-Loire in region of Auvergne, Ardèche in region of Rhone-Alps and Lozère in Languedoc-Roussillon	Semi-extensive (natural grazing and fodder)	Mother's milk, natural vegetation and complement of cereal-based feed	White-rosy	White fat with solid consistency and malleable	Characteristic flavour	Historical reputation and characteristic breed (adapted to hardy environmental conditions)
Agneau de Pauillac	Department of Gironde in the Aquitaine region	Intensive (milk and cereals)	Mother's milk and complement of cereals and nitrogenous substances	Light red	White fat with firm consistency	Characteristic flavour and taste that recalls milk	Historical reputation (dates to 18th century), characteristic breed and rearing method (traditional)
Agneau de Sisteron	Provence-Alpes-Azur and Drôme in the Rhone-Alps region	Semi-extensive (natural grazing and fodder)	Mother's milk, grass and/or forages and complement of cereals	Slightly rosy	Tender, white/rosy fat with firm consistency	Peculiar flavour and taste (sweetness)	Historical reputation, Mediterranean climate, characteristic breed and rearing method (traditional)
Agneau des Pyrénées	Pyrénées Atlantiques	Semi-extensive (natural grazing and fodder)	Mother's milk (ewes feed on plants of meadows from spring to autumn and receive fodder in winter)	White or slightly pink	Succulent, tender, low-grain texture	Delicate flavour	Historical reputation and rearing method (traditional, diet of only milk and young slaughter age)
Agneau du Bourbonnais	Department of Allier and adjacent cantons in Creuse, Saône et Loire, Cher and Nièvre	Semi-extensive (natural grazing and fodder)	Mother's milk, grass meadows and/or forages and complement of cereal-based feed	Light red	Fibrous consistency	Characteristic taste tending to sweet tones	Historical reputation (dates to 18th century), characteristic breed and rearing method (traditional)
Agneau du Limousin	Departments of Limousin region and neighbours, Puy-de-Dôme, Allier and Cantal in Auvergne region; Cher and Indre; Charente and Vienne; Dordogne in Aquitaine region and Lot in Midi-Pyrénées region	Semi-extensive (natural grazing and fodder)	Mother's milk, grass and/or forages and complement of cereal-based feed	Light, slightly rosy	Fibrous consistency	Peculiar flavour, delicate aroma	Historical reputation (dates to 17th century), rearing method (traditional) and environment (oceanic climate favour the development of pastures to raise animals in open air)
Agneau du Périgord	Departments of Dordogne and Lot-et-Garonne in Aquitaine region, La Corrèze in Limousin region and Lot in Midi-Pyrénées region	Semi-extensive (natural grazing and fodder)	Mother's milk and fodder based on cereals (barley, wheat and maize) together with a nitrogenous complement	White to pale rose	Juicy, tender	White fat has sweet flavour, melts in mouth	Historical reputation (dates to 19th century) and characteristic breeds (resistant and ideal for pasture in dry lands with poor resources like the Périgord)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics): Place of origin	Farming system	Feed/diet	Organoleptic quality characteristics: Colour	Texture	Aroma and flavour	Link to provenance/evidence of typicity
Agneau du Poitou-Charentes	Poitou-Charentes region including Charente, Charente-Maritime, Deux-Sèvres and Vienne	Extensive (natural grazing)	Mother's milk for first 60 days plus seasonal grass range pastures	Pale rose/pink	Consistent, fine grain	Characteristics flavour	Historical reputation (dates to the Middle Ages in the 18th century) and characteristic breed (rounded and plump conformation due to specific pedo-climatic conditions)
Agneau du Quercy	Lot and adjoining cantons (excluding Cantal) plus comprising natural region of Quercy	Semi-extensive (natural grazing and fodder)	Mother's milk for first 70 days plus seasonal grass range pastures	Pale rose	Tender	Soft taste, velvety, superior organoleptic characteristics	Historical reputation (French ancient traditional lamb farming and national quality brand) and characteristic breed
Agnello del Centro Italia	Abruzzo, Lazio, The Marches, Tuscany and Umbria including Bologna, Rimini, Forlì-Cesena and Ravenna, parts of Modena, Reggio Emilia and Parma in Emilia-Romagna region	Semi-extensive (natural grazing and fodder)	Mother's milk, fodder of wild meadow plants, sown pasture, pulses and/or grasses from local area; reared free-range at least 8 months per year.	Pink with firm, creamy-white fat	Juicy, tender, extremely low intramuscular fat	Intense flavour	Historical reputation (mid-1900s) with conventions and publicity campaigns for meat quality, rearing method and characteristic diet
Agnello di Sardegna	Sardinia region	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, integrated fodder and fresh/dried cereals for spring lambs	Pale pink	Tender, succulent, easily digestible	Intense flavour and smell	Historical reputation (dates to Nuragic period 3000 B.C.), characteristic breed and typical Sardinian climate
Αρνάκι Ελασσόνας/ Arnaki Elassonas	Elassona province	Extensive (natural grazing)	Mother's milk, grazing on natural vegetation (including aromatic plants)	White to light pink	Juicy, tender	Pleasant smell and taste due to ewes grazing on aromatic plants	Historical reputation, characteristic breed and rearing method (traditional)
Αρνάκι Λήμνου/ Arnaki Limnou	Islands of Limnos and Agios Efstratios	Extensive (natural grazing)	Mother's milk, grazing on natural vegetation (including aromatic plants)	White to light pink	Tender, succulent	Characteristic, pleasant aroma and flavour	Historical reputation, characteristic breed, rearing method (traditional)
Barèges-Gavarnie	Different municipal areas of the department of Hautes-Pyrénées in the midi-pyrenees region	Extensive or semi-extensive (natural grazing and/or fodder)	Pastures in summer and spring plus hay and second cutting of grass in winter	Bright, brilliant red	Tender	Characteristic flavour	Historical reputation linked to accurate farming techniques used plus specific rules for animal handling, transport and slaughtering, and characteristic breed
Borrego da Beira	Districts of Castelo Branco and Guarda and small area in district of Santarém	Extensive (natural grazing)	Mother's milk, in mountains fed hay, branches from chestnut and oak trees (winter);	Light pink	Tender, succulent	Characteristic taste, unique milky aroma	Historical reputation (oldest ancient breed for *Ovis Aries* Studery) and environmental conditions

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
			high altitude pastures (summer)				
Borrego de Montemor-o-Novo	Municipal areas of Montemoro-Novo, Évora, Arraiolos and Mora in Évora district	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk for 60 days, grass in fields, supplemented with hay (winter) and fed with harvest remains (cereals)	Light pink	Tender with little fat	Delicate, succulent flavour	Historical reputation, oldest ancient breed with distinguishing morphological characteristics and rearing method
Borrego do Baixo Alentejo	Selected municipal areas (21) in Beja, Évora and Setubal districts	Intensive (milk and cereals)	Mother's milk plus straw and cereals	Light pink	Tender, succulent, compact consistency	Characteristic flavour	Historical reputation (dates to times of Roman occupation) and rearing method (traditional)
Borrego do Nordeste Alentejano	Portalegre district	Extensive (natural grazing)	Mother's milk, harvest remains, graze in fields, eat leaves and acorns of oak and other trees	Not specified	Very tender, succulent	Characteristic mild flavour	Historical reputation (oldest breed of Iberian Peninsula in Alentejo region), rearing and diet
Borrego Serra da Estrela	Selected municipal areas (14) in Coimbra, Guarda and Viseu districts	Extensive or semi-extensive (mother's milk, natural grazing and/or fodder)	Mother's milk, local vegetations, high low altitude pastures (summer), low altitude pastures (winter)	Pale to light pink	Tender	Delicate taste with even distribution of fat	Historical reputation (sheep linked to existence of wild Muflone that lived there before 4th ice age) and characteristic breed
Borrego Terrincho	Vila Real, Bragança, Viseu and Guarda districts	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, uncultivated mountain pastures, harvest remains (cereals)	Pale pink	Tender	Pleasant milky after taste	Historical reputation (dates to Middle Ages), characteristic breed plus and rearing method (traditional)
Comeragh Mountain Lamb	Comeragh mountains	Extensive (natural grazing)	Wild grasses such as sheep fescue, moorgrass, deergrass and common cotton grass plus heather, wildflowers	Pink to red	Tender, delicate	Profound flavour, nearly sweet, hint of liquorice or fennel	Historical reputation, rearing method, characteristic breed and free-range diet on wild grasses and flowers
Connemara Hill Lamb/Uain Sléibhe Chonamara	Corrib Lake and Inishmaan, Inisheer and Inishmore Islands	Extensive (natural grazing)	Vegetations including mountain herbs, heath and other plants	Pink	Hard consistency	Characteristics flavour	Historical reputation (dates to 19th century), characteristic breed and free-range diet on mountain herbs, heath and other plants
Cordeiro Bragançano	Municipal areas of Vinhais, Bragança, Macedo de Cavaleiros, Vimioso, Mirandela, Chaves and Valpaços, in Bragança district	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, pasture lands (spring), harvest remains (cereals) and grass of marshlands	Not specified	Tender	Flavoursome	Historical reputation (inked with oldest sheep breeds Galega Bragançana and European Mouflon), characteristic breed plus rearing method

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
Cordeiro de Barroso/ Anho de Barroso/ Cordeiro de leite de Barroso	Municipal areas of Boticas, Chaves, Mondim de Basto, Montalegre, Murça, Ribeira da Pena, Valpaços and Vila Pouca de Aguiar, in the Vila Real district	Extensive or semi-extensive (mother's milk with natural grazing and/or fodder)	Mothers' milk for 1 month, then feed on hay, willow branches, rye and dried fruit and/or pastures	Pink to light red	Tender, succulent, delicate consistency	Characteristics flavour (due to diet), excellent aroma	Historical reputation (lambs rearing of region) and characteristic breed
Cordeiro Mirandês/ Canhono Mirandês	Miranda do Douro, Mogadouro and Vimioso in Bragança district	Extensive or semi-extensive (natural grazing and fodder)	Mother's milk, natural grazing on aromatic plants (summer) and concentrated feed (winter)	Pink	Juicy, soft, consistent with non-exudative fat	Delicate, juicy taste, smells like game meat	Historical reputation, characteristic breed and rearing method (traditional)
Cordero de Extremadura	Extremadura	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, pasturelands, natural resources (wooded scrublands) and straw, grain, fodder, by-products and concentrates	Pale to bright pink	Juicy, tender, succulent	Excellent and pleasant mouthfeel	Historical reputation, rearing method (traditional extensive and semi-extensive method) and environmental conditions
Cordero Manchego	Albacete, Ciudad Real, Cuenca and Toledo districts including districts of Mancha, Manchuela, Centro and Almansa de Albacete; Mancha, Agro of Calatrava and Agro di Montiel of Ciudad Real, Manchuela, Low Mancha and High Mancha of Cuenca and Mancha of Toledo in Autonomous Community of Castilla-La Mancha	Extensive or semi-extensive (natural grazing and/or fodder)	Mothers' milk for 30 days, natural resources of the pastures, using fields, fodder, fallow land, stubble and bushes supplemented *ad libitum* with white straw and authorised concentrates	Pale pink	Tender, succulent	Pleasant characteristics flavour	Historical reputation (ancient origins) and temperate Mediterranean climate
Cordero de Navarra/ Nafarroako Arkumea	Autonomous Community of Navarra	Extensive or semi-extensive (natural grazing and/or fodder)	Mothers' milk for 45 days, pastures (summer), grass or dry oats and natural fodder like cereals and legumes (winter)	Mother-of-pearl light to pale pink	Soft consistency, tender, juicy	Characteristics flavour and taste	Historical reputation (lamb consumption since medieval times), characteristic breed and environmental conditions
Cordero Segureño	Provinces of Albacete, Almería, Granada, Jaén and Murcia, falling within Eastern Betic Mountains	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, products rich in fibre, spontaneous vegetation native to area, stubble fields of	Pale pink to pink	Juicy, tender	Characteristics flavour	Historical reputation and rearing method (traditional)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
			cereal and legume crops and occasionally, irrigated pastureland				
Dalmatinska janjetina	Lika-Senj region including Novalja and coastal slopes of Velebit mountain range; Zadar region including Benkovac, Biograd, Nin, Obrovac, Pag, Zadar and selected municipalities (28) and territory of Šibenik-Knin County	Semi-extensive	Karst pastures full of wild herbs (sage, heather, immortelle, thyme, yarrow), and endemic species	Light pink to pink	Juicy, tender	Pronounced smell, distinctive flavour	Specific climatic conditions and local feeding material gives the meat its flavour
Diepholzer Moorschnucke	Diepholzer region	Extensive (natural grazing)	Moorland grassland including heather, cotton grass, bent, sweet flag, various herbs, pine, birch, other wooden plants	Brilliant red colour	Tender, solid consistency	Characteristic gamey flavour	Historical reputation (Moorschnucke naming of peat sheep), characteristics rearing conditions and diet (grazing lands rich in peat)
Gower Salt Marsh Lamb	Gower Peninsula, South Wales	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk plus pastures of salt marsh vegetations, natural fodder	Pink to red	Tender and juicy	Sweet, delicate flavour with fresh, aromatic notes of slightly salted grass	Historical reputation (grazing of salt marshes since Middle Ages), rearing method with characteristic diet (salt marshes)
Hånnlamb	Gotland including Gotska Sandön	Semi-extensive (natural grazing and fodder)	Natural vegetation with herbs (thyme) and grasses plus hay/silage and concentrates as supplementary feed	Dark red	Fine grain, juicy	Pronounced taste, gamey flavour	Historical reputation of breed plus rearing method with characteristic climate and diet
Isle of Man Manx Loaghtan Lamb	Isle of Man in Irish Sea, off the West Coast of England	Extensive or semi-extensive (natural grazing and/or grains)	Natural pastures of gorse and bracken scrub and heather moorland, plus local grains in winter	Dark red	Tender	Distinctive gamey flavour	Historical reputation (sheep farming on the island dates to Middle Ages), characteristic breed and rearing method (traditional)
Íslenskt lambakjöt	Island of Iceland in the North Atlantic Ocean	Extensive (natural grazing)	Pastures (enriched by volcanic soil) filled with native grasses, herbs and berries	Dark red	Tender	Gamey flavour, pleasant taste, sweeter	Historical reputation, characteristic breed and diet
Jagnięcina podhalańska	Municipalities in districts of Cieszyn and Zywiec in Silesian voivodeship, Malopolskie voivodeship, entire districts of Nowy	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, natural grazing on aromatic plants with hay, silage and local fodder in winter	Pink	Soft, elastic structure	Delicate, juicy taste, gamey flavour	Historical reputation (dates to 14th century with the arrival of the Wallachian tribes) and rearing method (traditional)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics): Place of origin	Farming system	Feed/diet	Organoleptic quality characteristics: Colour	Texture	Aroma and flavour	Link to provenance/evidence of typicity
	Targ and Tatra along with Sucha Beskidzka, Limanowa and Nowy Sacz						
Keleméri bárányhús	Within administrative boundaries of the village of Kelemér	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, wild pastures and hay (grass, herbal and wild plants like scentless mayweed and yarrow), feed and fodder (barley, oats)	Bright red	Tender	Spicy aroma and flavour	Historical reputation and specific climatic ecological conditions with pastures that contain medicinal plants which give the meat its spicy aroma and flavour
Lakeland Herdwick	Cumbria	Semi-extensive (natural grazing and fodder)	Mountain flora, herbage of the fells including grasses, heather and plants (bilberry, finished on locally sourced grass, hay or silage	Light to dark pink	Succulent, tender	Gamey flavour	Historical reputation and rearing method (traditional)
Lechazo de Castilla y León	Autonomous Community of Castilla y León	Extensive (natural grazing)	Mother's milk (ewes graze on natural pastures and stubble fields)	White mother-of-pearl to pale pink	Very succulent, tender	Characteristics flavour	Historical reputation (dates to era of the Celtic invasion), characteristic breed and rearing method (traditional)
Lička janjetina	Gospić and municipalities of Donji Lapac, Karlobag, Lovinac, Perušić, Plitvička jezera, Udbina, Vrhovine, Senj, Brinje and Otočac in Lika-Segna region and Gračac	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, indigenous pastures (summer) and cereals, meadow hay (winter)	Bright to intense red	Tender, solid consistency	Aroma of mutton	Historical reputation (of aromatic lamb) and rearing method (traditional)
Lofotlam	Municipalities of Røst, Værøy, Moskenes, Flakstad, Vestvågøy, Vågan, Hadsel, Lødingen and islands in Raftsundet and Ingelsfjorden	Extensive or semi-extensive (natural grazing and/or fodder)	Mother's milk, natural grazing on special flora (including herbs, pasture grass) naturally salted by sea salt carried by wind and storms, seaweed	Pale to pink	Tender	Distinct aroma	Characteristic breed and qualities due to feeding on coastal grazing material (salty pastures, seaweed) and lambs' muscle activity on mountains
Lüneburger Heidschnucke	Lüneburger Heide, moor of Landkreis of Lüneburg, in federal state of Lower Saxony	Extensive (natural grazing)	Grasses, heather, cotton grass	Red	Delicate, tender	Intense, gamey flavour	Historical reputation (dates to 18th century), characteristic breed and rearing method (traditional)
Orkney Lamb	Orkney Islands off the North Coast of Scotland	Extensive (natural grazing)	Grassland with natural pastures, rich in grasses and an abundant amount of seaweed	Pink to red	Tender, succulent	Full of flavour	Historical reputation (ancient origin), rearing method (traditional) and region-specific feeding regime (including seaweed)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics): Place of origin	Farming system	Feed/diet	Organoleptic quality characteristics: Colour	Texture	Aroma and flavour	Link to provenance/evidence of typicity
Paška janjetina	Island of Pag	Extensive (natural grazing)	Mother's milk, meadows, wild herbs (rosemary, sage)	Pale pink	Tender, juicy	Mellow taste, distinct flavour from wild herbs (rosemary, sage)	Historical reputation, rearing method (traditional) and diet
Prés-salés de la baie de Somme	Salt marshes of Pas-de-Calais and Somme regions	Extensive or semi-extensive (natural grazing and/or fodder)	Halophytic pasture of salt marshes (especially alkali grass), finished on forage and concentrates	Pink with creamy-white fat	Juicy, tender	Distinct flavour from sea grass, tastes like iodine, sea flora and hazelnuts	Historical reputation, rearing method (traditional) and characteristic diet (salt marshes)
Prés-salés du Mont-Saint-Michel	Municipalities of Manche including Montsenelle, Baupte, Auvers and Méautis	Extensive or semi-extensive (natural grazing and/or fodder)	Halophytic pastures of salt marshes, finished on forage and concentrates	Pink to dark pink with marbled appearance	Juicy, tender	Intense, lasting flavours in mouth with no taste of wool grease	Historical reputation, rearing method (traditional) and characteristic diet (salt marshes)
Scotch Lamb	Scotland mainland from border with England including islands off West Coast, Orkney and Shetland Isles	Extensive (natural grazing)	Grass feeding with natural grazing as traditional feeding on pastures	Pink to red	Tender, succulent	Full of flavour	Historical reputation (origin dates to 19th century) and region feeding regime
Shetland Lamb	Shetland Isles including islands North Atlantic off to North Coast of Scotland	Extensive (natural grazing)	Grass feeding with natural grazing as traditional feeding on pastures	Red	Tender	Characteristic flavour	Historical reputation (due to ancient origin) and region feeding regime (rich pastures)
Ternasco de Aragón	Districts of Zaragoza, Huesca and Teruel in Autonomous Community of Aragón	Semi-extensive (natural grazing and fodder)	Mother's milk, grassland, natural pastures (including, wild rosemary, thyme), high-quality concentrated fodder	Pale pink	Tender, juicy, fine consistency	Delicate, characteristic flavour	Historical reputation (due to ancient origin), characteristic breed and rearing method (traditional)
Vadehavslam	Entire region of Wadden Sea in south-west Denmark, including islands of Rømø, Mandø and Fanø, on the continent, part of territory at northern limit of Wadden Sea	Extensive or semi-extensive (natural grazing and/or fodder)	Plants and grasses in salt meadows (summer); grasses, corn, fodder silage and hay integrated with barley (winter)	Not specified	Not specified	Tasty meat, typically salty	Historical reputation (since Iron Age), rearing method (traditional) and characteristic diet (salt meadows)
Welsh Lamb	Wales, including island of Anglesey	Extensive (natural grazing)	Grass pastures	Light pink to red	Tender, succulent	Sweet succulent flavour	Historical reputation (dates to 14th century) and rearing method (traditional)
West Country Lamb	West Country region	Extensive (natural grazing)	Grassland	Pink to dark red	Juicy, tender	Rich flavour	Historical reputation and rearing method (traditional)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
Poultry (*n* = 48)							
Canard à foie gras du Sud-Ouest (Chalosse, Gascogne, Gers, Landes, Périgord, Quercy)	Regions of Aquitaine, Midi-Pyrenees, Limousin and department of Aude in Languedoc-Roussillon region	Semi-extensive	Cereal grains or their derived products and of legume seeds plus open-air free range	Rosey	Soft, spreadable	Delicate, aromatic, not bitter taste	Historical reputation (dates to 17th century), breeding and transforming methods
Capão de Freamunde	Municipality of Paços de Ferreira and part of municipalities of Lousada and Paredes	Semi-extensive	Corn and variety of grasses plus weeds including *Holcus mollis*, *Lolium multiflorum* and *Plantago lanceolata L.*	Intense	Tender, slightly pasty, highly juicy	Characteristic flavour	Historical reputation (dates to 19th century), characteristic breed and rearing method (traditional)
Capón de Vilalba	Province of Lugo, Autonomous Community of Galicia, including municipalities of Muras, Xermade, Vilalba, Abadín, A Pastoriza, Guitiriz, Begonte, Cospeito and Castro de Rei	Semi extensive	100% natural cereal-based diet plus insects and larvae	Yellow carcass	Tender, succulent, juicy	Characteristic flavour and juiciness	Historical reputation and rearing method
Chapon du Périgord	Charente, Charente-Maritime, Corrèze, Dordogne, Gironde, Haute-Vienne, Lot, Lot-et-Garonne	Semi-extensive	Feed mostly made of cereals-based grains plus vitamins and supplements	Yellow carcass for naked neck, white for non-naked capon	Firm	Characteristic flavour	Historical reputation and rearing method (traditional)
Dinde de Bresse	Departments of Ain, Saône-et-Loire and Jura in regions Rhone-Alps, Burgundy and Franche-Comte	Semi-extensive	Grassy meadows and fodder (cereals from production area, maize, buckwheat, corn, oat, hybrid of corn and rye, milk and its by-products)	White	Fleshy	Characteristic flavour	Characteristic Bresse climatic conditions and breeding
Gall del Penedès	Penedès, Catalonia	Semi-extensive	Green grass, herbs and supplemented only with little grain and grape seed	Dark red	Fibrous	Intense, rich flavour of dried fruit, metallic taste	Historical reputation, characteristic (robust, hardy) breed, rearing method and diet that includes grape seeds
Oie d'Anjou	Many departments in regions Pays de la Loire, Centre and Poitou-Charentes	Semi-extensive	Grazing on natural vegetations plus feed with cereal grains and local fodder	Yellow	Elastic, rather fat	Characteristic flavour free from quills or pokes	Historical reputation (since 15th century) plus characteristic breed with fattening level

Table 2. Continued

Name	Extrinsic factors (environmental characteristics): Place of origin	Farming system	Feed/diet	Organoleptic quality characteristics: Colour	Texture	Aroma and flavour	Link to provenance/evidence of typicity
Pintade de l'Ardèche	Massif cantons of Ardèche (Vivarais mountains) in central-eastern area of Massif Central	Semi-extensive	Cereals plus vegetables, minerals and vitamins	Dark red	Firm, less fatty	Intense flavour and taste	Historical reputation and free-range rearing method)
Pintadeau de la Drôme	Selected municipalities (256) in Drôme department in Rhone Alpes region	Extensive	Vegetable and mineral food, rich in vitamins	Dark red	Compact, fibrous consistency	Rich and piquant taste	Historical reputation (dates to end of 19th century), characteristic breed and feeding
Pollo y Capón del Prat	District lands of Castelldefelds, Cornelia de Llobregat, El Prat de Llobregat, Gavá, Sant Boi de Llobregat, Sant Climent de Llobregat, Sant Feliu de Llobregat, Viladecans and Santa Coloma de Cervellón	Semi-extensive	Free from fats, based on authorized food like cereals, soya, sunflowers, flour of lucernes or trefoil, milk by-products and beetroot molasses	Yellow and red	Refine	Fine sweet with less fat	Historical reputation (dates to 1752 and 1772) and characteristic breed
Poularde du Périgord	Charente, Charente-Maritime, Corrèze, Dordogne, Gironde, Haute-Vienne, Lot, Lot-et-Garonne	Semi-extensive	Grazing on natural vegetation, grass plus feed	Yellow carcass for naked neck	Firm	Characteristic flavour	Historical reputation and characteristic breed
Poulet de l'Ardèche/ Chapon de l'Ardèche	Ardèche mountain massif, Vivarais mountains, in central-eastern area of Massif Central	Semi-extensive	Vegetables, minerals and vitamins plus cereal (80% of diet)	Dark red	Firm, less fatty	Intense flavour	Characteristic breed and rearing method (traditional with low stocking densities)
Poulet des Cévennes/ Chapon des Cévennes	Ardéche, Villeneuve de Berg, Gard, Hérault and Lozére	Semi extensive	Plants, grass, natural cereal-based feed with no flour or animal fat supplemented with vegetable proteins (soybean, rape seed, sunflower seed), minerals and vitamins	Not specified	Juicy, succulent	Characteristic taste	Historical reputation (enjoyed from 1900 onwards) and characteristics climatic conditions of Cévennes nature
Poulet du Bourbonnais	Numerous municipalities in the Allier department	Semi extensive	Cereals (70%) from the geographical area, supplemented by 9–11% dairy products and 1–3% brewer's yeast	Pale and white	Fine, delicate	Marbled taste due to milk powder, distinctive flavour	Historical reputation (dates to end of 19th century), characteristic breed and rearing method (traditional)
Poulet du Périgord	Entire territory of Dordogne department and part of Charente, Corrèze, Gironde, Haute-Vienne, Lot, Lot-et-Garonne	Semi-extensive	Feed mostly made of cereals-based grains	Yellow or white skin	Firm muscle masses, fine bone structure	Characteristic flavour	Historical reputation and rearing method (traditional)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics): Place of origin	Farming system	Feed/diet	Organoleptic quality characteristics: Colour	Texture	Aroma and flavour	Link to provenance/evidence of typicity
Volaille de Bresse/ Poulet de Bresse/ Poularde de Bresse/Chapon de Bresse	Municipal areas (275) of Ain and Saône-et-Loire departments, part of Jura, in regions of Rhone-Alps, Burgundy and Franche-Comte	Semi-extensive	Natural grass, maize, cereals, dairy products	White flesh	Tender	Characteristic flavour	Historical reputation (dates to 12th November 1591), breeding practises and characteristics of production area
Volailles d'Alsace	Region of Alsace (including Bas-Rhin and Haut-Rhin departments)	Semi-extensive	Grass, vegetables, minerals, vitamins, with 75–80% of cereals; capon nurtured with milk	White or yellow skin	Firm flesh, tender	Tasteful flavour, gamey taste (fowl)	Historical reputation (dates to first years of 19th century), high content of proteins and low fats for meats
Volailles d'Ancenis	Loire-Atlantique department and western part of Maine-et-Loire department in Pays-de-la-Loire region	Semi-extensive	Grass, mix of cereals consisting of 75% cereals with oily seeds like soya, sunflower and rape, the rest contains proteins like beans	Pink	Firm flesh	Superior organoleptic characteristics with soft taste, peculiar taste due to cereals	Historical reputation (dates to 9th century), rearing method (traditional, century old tradition) and characteristics climatic conditions
Volailles d'Auvergne	Auvergne and surroundings	Semi-extensive	Feed includes corn, barley, oat and maize, fully free from fats or animal meals	Dark flesh (guinea hens)	Firm (guinea hens), tender (capons)	Unique flavour	Historical reputation (historic tradition of aviculture in production area) and characteristic feed
Volailles de Bourgogne	Burgundy region	Semi-extensive	Open air pasture grazing plus diet includes cereals (70–75%) completed with vegetable, soya and bean proteins	Fine skin	Tender	Superior organoleptic characteristics	Historical reputation (ancient origins in last century) plus breeding and diet characteristics
Volailles de Bretagne	Region of Brittany, some neighbouring cantons in Lower-Normandy and Paysde-la-Loire regions	Semi-extensive	Cereal-based diet plus open-air grazing	Varies per breed	Firm flesh	Superior organoleptic characteristics	Historical reputation (tradition of French aviculture), characteristic breed and rearing method (traditional in open air)
Volailles de Challans	Cantons of Vendée, Loire-Atlantique, Maine-et-Loire and Deux-Sèvres in regions Pays-de-la-Loire and Poitou-Charentes	Semi-extensive	Cereal-based diet plus open-air grazing	Varies per breed	Compact consistency	Superior organoleptic characteristics	Historical reputation (breeding dates to beginning of 19th century) plus climatic characteristics of region
Volailles de Cholet	Cholet region in municipal areas of St. Georges-sur-Loire, Chalonnes, Thouarce e Vihiers, Clisson et Vallet, Mauléon and Montagne-sur-Sèvre	Semi-extensive	Cereal-based diet plus open-air grazing	Varies per breed	Firm flesh	Superior organoleptic characteristics	Historical reputation (dates to end of 18th century) plus breeding method in open air and diet gives meat distinct taste

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
Volailles de Gascogne	Departments of Haute Pyrenees, Gers and Landes in region of Midi-Pyrenees, Atlantic Pyrenees, Lot-et-Garonne and its neighbouring areas in Aquitaine	Semi-extensive	Feed with 80% cereals (40–50% maize) plus early access to meadows	White	Firm	Characteristic flavour, extremely tasteful	Historical reputation (ancient origin) and characteristics rearing method in open air (tradition of poultry breeding in Gascogne)
Volailles de Houdan	Departments of Eure in Haute-Normandie, Eure-et-Loir in Centre and Yvelines regions, in Île-de-France area	Semi-extensive	Cereal-based feed and vegetable proteins	White flesh	Fondant consistency	Flavour like pigeon or partridge	Historical reputation (ancient breed) and characteristic breed
Volailles de Janzé	Departments of Ile-et-Vilaine and its neighbouring cantons in departments of Morbidhan, Côtes d'Armor, Manche, Mayenne, Maine et Loire and Atlantic Loire	Semi-extensive	Cereal-based feed and vegetable proteins	White except for guinea hen which is darker	Soft, tender	Taste of game (guinea hen)	Historical reputation (dates to 19th century) and rearing method (traditional)
Volailles de la Champagne	Departments of Marne, Aisne, Ardennes and some neighbouring regions	Semi-extensive	Vegetables, minerals and cereals plus open-air grazing	Not specified	Tender	Superior organoleptic characteristics	Historical reputation (famed since 1959) plus maize cultivation in the region
Volailles de la Drôme	Departments of Drôme and neighbouring cantons of Hautes-Alpes, Ardèche, Drôme and Isère	Semi-extensive	Cereal-based feed plus open-air grazing	Not specified	Firm flesh	Superior organoleptic characteristics	Historical reputation (existence of farms in region dates to 19th century) and rearing method (century-old tradition)
Volailles de l'Ain	Entire department of Ain and its neighbouring cantons in region of Rhône-Alpes	Semi-extensive	Open-air grazing on herbs, worms and insects in natural area, fed with 75% cereals	White	Fine	Tasteful	Historical reputation (ancient origins, linked to local production), characteristic breed and rearing method (traditional)
Volailles de Licques	Departments of Calais, Boulogne sur Mere, Montreuil sur Mere, Saint Omer and neighbouring cantons	Semi-extensive	Cereals and their by-products plus open-air grazing on grassy areas	Not specified	Firm flesh, compact	Excellent taste, flavourful	Historical reputation (fame dates to 18th century) plus crossbreeds, diet and special breeding method
Volailles de l'Orléanais	Departments of Loiret, Eure-et-Loire and Loir-et-Cher and their neighbouring cantons Loiret, Orne, Sarthe and Yonne	Semi-extensive	Cereals plus open-air grazing on grassy areas	Fine skin	Firm, compact	Flavourful	Historical reputation (linked to the existence of farms of winged animals in region) plus specific breeding method

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
Volailles de Loué	Departments of Sarthe and Mayenne; Orne, Indre-et-Loire, Loir-et-Cher and Eure-et-Loir and in neighbouring cantons; Maine-et-Loire within Segré commune and in cantons to north of River Loire, within Centre and Pays-de-la-Loire regions	Semi-extensive	Cereal-based feed plus open-air or roaming freely in local fields	Fine skin	Tender	Tasteful	Historical reputation (linked to existence of farms in region) plus characteristic breed of layer and breeding method
Volailles de Normandie	Departments of Seine-Maritime, Eure, Calvados, Manche and Orne and neighbouring cantons	Semi-extensive	Cereal-based feed plus open-air grazing	Darker	Compact	Tasteful	Historical reputation (farming dates to 19th century), characteristic breed and climatic characteristics of Normandy region
Volailles de Vendée	Department of Vendée and neighbouring cantons of Charente-Maritime, Loire-Atlantique, Maine-et-Loire and Deux-Sèvres, in Pays-de-la-Loire and Poitou-Charentes regions	Semi-extensive	Cereal-based feed plus open-air grazing	White to yellow	Tender	Very good, organoleptic features, tasteful, gamey flavour	Historical reputation (farming dates to start of 19th century), characteristic breed and rearing method (traditional) in line with climatic characteristics of Vendée area
Volailles des Landes	Department of Landes and neighbouring cantons of Gironde and Lot-et-Garonne in Aquitaine region	Semi-extensive	Cereal-based feed with minimum 50% maize plus open-air grazing	Not specified	Firm flesh	Superior organoleptic characteristics	Historical reputation (farming dates to 18th century), characteristic breed and rearing method (traditional) in line with climatic characteristics of Landes region
Volailles du Béarn	Department of Pyrénées-Atlantiques and neighbouring cantons of Gers, Landes and Hautes-Pyrénées in Aquitaine and Midi-Pyrenees regions	Semi-extensive	Maize (50%) and vegetables and minerals plus open-air rearing	Dark	Soft, velvety consistency	Tasteful	Historical reputation (dates to 18th century) and rearing method (traditional)
Volailles du Berry	Centre region and some neighbouring areas in regions of Poitou-Charentes, Burgundy, Limousin and Auvergne	Semi-extensive	Vegetables, minerals and vitamins, with minimum of 75% cereals plus open-air grazing	Not specified	Firm, compact	Tasteful	Historical reputation (dates to ancient origins) and characteristic breed
Volailles du Charolais	Departments of Saône-et-Loire and some cantons in Loire, Allier, Côte-d'Or and Rhône, in Burgundy,	Semi-extensive	Vegetables, minerals and vitamins, with minimum of 75% cereals plus	Light yellow	Firm	Higher organoleptic characteristics	Historical reputation (linked to aviculture tradition of region), characteristic breed and diet (grass and herbs)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
	Auvergne and Rhone-Alps regions		open-air grazing on green pastures/grass			due to herbs in diet	
Volailles du Forez	Cantons (27) of Puy de Dôme, cantons (16) of Haute-Loire, cantons (4) of Saôneet-Loire, located in Burgundy, Auvergne and Rhone-Alps regions	Semi-extensive	Vegetables, minerals and vitamins, with a minimum of 75% cereals plus open-air grazing	Not specified	Firm, fattier	Higher organoleptic characteristics, refined taste	Historical reputation (dates to 19th century when first poultry breeding developed), characteristic breed and specific climatic conditions
Volailles du Gatinais	Municipal areas (256) located in departments of Essonne and Seine-et-Marne in region Paris-Isle-of-France; in department of Loiret in region Centre and in department of Yonne in Burgundy region	Semi-extensive	Cereal-based diet plus open-air grazing on grass	Not specified	Compact	Tasteful	Historical reputation (existence dates to immemorial times, breed relaunched in 1950s) and characteristic breed
Volailles du Gers	Gers and neighbouring areas of departments of Haute-Garonne, Landes, Lot-et-Garonne, Pyrénées-Atlantiques, Hautes-Pyrénées and Tarn-et-Garonne, in Aquitaine and Midi-Pyrenees regions	Semi-extensive	Vegetables, minerals and vitamins, with minimum of 80% cereals plus open-air grazing	Dark (guinea hen)	Firm, tender (turkey)	High flavour, tasteful, game taste (guinea hen)	Historical reputation (linked to traditional farming of poultry), characteristic breed and rearing method (traditional in open air)
Volailles du Languedoc	Departments of Gard, Hérault, Lozère in Languedoc-Roussillon region, and several areas of Midi-Pyrenees, Provence-Alpes-Azur and Rhone-Alps regions	Semi-extensive	Vegetable and cereal-based diet plus open-air grazing (brushwood and grassy areas)	Fine	Firm	Flavourful	Historical reputation (dates to ancient origin), characteristic breed and rearing method (traditional in open air)
Volailles du Lauragais	Departments of Haute-Garonne, Aude, Tarn and some neighbouring municipal areas, in Midi-Pyrenees and Languedoc-Roussillon regions	Semi-extensive	Cereal-based feed in open-air plus grazing in grassy areas	Not specified	Firm	Characteristic flavour, tasteful	Historical reputation (dates to 15th and 16th century), characteristic breed and rearing method (traditional in open air)
Volailles du Maine	Area of Maine river and its confluents, municipal areas in departments of Sarthe, Mayenne, Orne, Eure-et-Loir, Loir-et-Cher, Maine-et-Loire, Indre-et-	Semi-extensive	Vegetables and minerals with almost 75% of cereals plus open-air grazing in grassy areas	Fine skin	Tender, compact	Characteristic flavour fat	Historical reputation (since the Middle Age) and rearing method (traditional in open air) with buckwheat/cereals cultivation in the area for feed

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
	Loire, in Pays-de-la-Loire, Lower-Normandy and Centre regions						
Volailles du plateau de Langres	Municipal areas in departments of Haute-Marne and Côte-d'Or, in Burgundy and Champagne-Ardenne regions	Semi-extensive	Vegetables and minerals, with almost 75% of cereals plus open-air grazing	Fine skin	Tender, compact flesh	Superior organoleptic characteristics	Historical reputation (as indicated by numerous bibliographic mentions) and rearing method (traditional in open air) with cereals cultivation in the area for feed
Volailles du Val de Sèvres	Department of Deux-Sèvres, in Poitou-Charentes region	Semi-extensive	Cereal-based feed plus open-air grazing	Not specified	Tender, compact flesh	Superior organoleptic characteristics	Historical reputation (numerous archive documents describe the existence of many poultry farms in region) and rearing method (traditional in open air) with cereals cultivation in the area for feed
Volailles du Velay	Department of Haute-Loire and neighbouring areas of Viverols and Arlanc in Auvergne region	Semi-extensive	Vegetables, minerals, vitamins, with minimum 75% of cereals plus open-air grazing	Not specified	Tender, compact flesh	Superior organoleptic characteristics	Historical reputation (long existence of poultry farms in region) and rearing method (traditional in open air) with geoclimatic conditions
Us Zagorski puran	Krapina and Zagorje, Varaždin and part of Zagreb region	Semi-extensive	Grazing on green grasses plus feed supplemented with grain	Pale yellow to light yellow	Tender, juicy	Delicate and pleasant taste	Historical reputation and characteristic breed
Pork (n = 18)							
Carne de Bísaro Transmontano/ Carne de Porco Transmontano	Bragança and Vila Real	Extensive (natural grazing)	Grazing on local vegetation (mostly chestnuts)	Light red and pinkish fat	Tender, succulent	Exceptional flavour	Historical reputation (dates to geographical studies of Tras-os-Montes, since 1932), characteristic breed and diet, grazing on chestnuts
Carne de Porco Alentejano	Beja, Évora, Portalegre, and parts of Setúbal, Santarém, Faro and Castelo Branco districts	Extensive (natural feeding)	Mother's milk for 45 days, natural vegetation such as oak tree, *Quercus suber*, *Quercus rotundifolia*, undergrowth and acorns	Pale to dark pink	Fine	Flavoursome	Historical reputation (beginning of 19th century), characteristic breed and natural vegetation-based diet (acorns)
Cerdo de Teruel	Province of Teruel including Zaragoza, Guadalajara, Cuenca, Valencia, Castellón and Tarragona	Semi-extensive (natural grazing and fodder)	Essentially cereal-based with at least 50% must come from defined geographical area	Pinkish-red	Succulent, tender	Mild-tasting	Historical reputation, characteristic breed and rearing method (traditional)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics): Place of origin	Extrinsic factors (environmental characteristics): Farming system	Extrinsic factors (environmental characteristics): Feed/diet	Organoleptic quality characteristics: Colour	Organoleptic quality characteristics: Texture	Organoleptic quality characteristics: Aroma and flavour	Link to provenance/evidence of typicity
Cinta Senese	Tuscany region	Extensive or semi-extensive (natural grazing and/or fodder)	Wood pasture and/or open ground sown with fodder and cereals	Bright red	Tender, succulent	Characteristic fresh aroma	Historical reputation (dates to Government fresco by Ambrogio Lorenzetti in 1340), high levels of marbling in meat PUFA, characteristic breed and rearing method (traditional)
Kintoa	Municipalities included in departments of Landes and Pyrénées-Atlantiques	Semi-extensive (natural grazing and fodder)	Grass and grassland products plus cereal based feed	Bright red, pink fat	Soft, tender	Intense persistent taste	Historical reputation, characteristic breed and rearing method (traditional)
Meso crne slavonske svinje	Zagreb, Croatia	Semi-extensive or intensive (natural grazing or feed)	Cereals (maize, barley, wheat, triticale) and legumes (soybeans, field peas, lupines, beans) plus supplement of coarse fodder (fresh green alfalfa, clover/grass mixtures, pumpkins, nettles, alfalfa hay)	Dark red	Hard	Characteristic flavour	Historical reputation, characteristic breed and rearing method (traditional)
Meso turopoljske svinje	Zagreb, Sisak-Moslavina, Varaždin, Vukovar-Syrmia, Osijek-Baranja, Slavonski Brod-Posavina, Požega-Slavonia, Virovitica-Podravina, Bjelovar-Bilogora, Koprivnica-Križevci, Međimurje, Krapina-Zagorje, Karlovac, and the city of Zagreb	Semi-extensive or intensive (natural grazing or feed)	Mother's milk, feed with 18% crude protein for suckling and compound feed made of cereals (maize, barley, wheat, triticale) and vitamin-mineral supplement for fattening period	Dark red	Compact muscle, juicy consistency	Characteristic rich flavour and aroma derived from fat	Historical reputation, characteristic breed and rearing method (traditional)
Porc d'Auvergne	Cantons and municipalities of Allier along with selected areas of Puy de Dôme, Haute Loire, Cantal, Nièvre, Saône et Loire, Loire, loire, Ardehe, Lozere, Aveyron, Lot, Correze, Creuse, Cher and Indre	Semi-extensive or intensive (natural grazing or feed)	Feed contains minimum 75% cereals and cereal-based products, must contain < 1.7% linoleic acid	Red	Tender, succulent, juicy	Pleasant taste with strong smell	Historical reputation and specificity of geographical conditions
Porc de Franche-Comté	All departments of Franche-Comté region	Semi-extensive or intensive (natural grazing or feed)	Diet consists of 15–35% milk whey plus cereals and their by-products	Uniform rose neither too dark nor too pale	Firm	Characteristic flavour	Historical reputation (origin 19th century), characteristic breeding and fresh milk whey-based feeding system

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
Porc de la Sarthe	Department of Sarthe and some municipal areas of the departments of Maine-et-Loire and Mayenne in region Pays-de-la-Loire, departments of Eure-et-Loir, Indre-et-Loire, and Loir-et-Cher in Centre region	Semi-extensive or intensive (natural grazing or feed)	After birth nurtured with vegetables, minerals, vitamins and milk-dairy products plus cereal based feeding during fattening	Pink to red	Tender	Tasteful	Historical reputation (origin dates to Middle Ages) and characteristic breed and open-air rearing method (traditional)
Porc de Normandie	Departments of Eure and Seine-Maritime in Haute-Normandie; Calvados, Orne and Manche in Basse-Normandie	Semi-extensive or intensive (natural grazing or feed)	After birth nurtured with vegetables, minerals, vitamins and milk-dairy products plus cereal based feeding during fattening	Pink to red	Tender	Tasteful, excellent flavour	Historical reputation (origin dates to Middle Ages) and characteristic breed and open-air rearing method (traditional)
Porc de Vendée	Municipal areas of department of Vendée, in region of Pays-de-la-Loire, and some areas of Poitou-Charentes region	Semi-extensive or intensive (natural grazing or feed)	Fodder includes corn, barley and other cereals, in addition to mineral salts and linseeds	Pink	Firm	Characteristic flavour	Historical reputation (origin dates to 19th and 20th centuries) and characteristic breed
Porc du Limousin	Limousin region comprising Haute-Vienne, Creuse and Corrèze, and Charente Limousine district	Semi-extensive or intensive (natural grazing or feed)	Cereals, with a limited amount of maize and of vegetable proteins	Pink to bright pink	Tender	Tasteful	Historical reputation (origin dates to 19th century), characteristic breed and rearing method (traditional)
Porc du Sud-Ouest	Aquitaine, Midi-Pyrénées and Poitou-Charentes	Intensive (cereals)	Dent corn (produced on farm or neighbouring cereal farms)	Pink to red	Juicy, tender	Intense taste	Historical reputation and rearing method (traditional)
Porc noir de Bigorre	Departments of Haut-Garonne, Gers and Pyrénées-Atlantiques, Haut-Pyrénées	Extensive or semi-extensive (natural grazing and/or fodder)	Grass and grassland products plus cereal based feed	Bright red with white fat	Slightly fibrous, soft, tender consistency	Characteristics flavour, juicy and tasteful	Historical reputation, characteristic breed and rearing method (traditional)
Schwäbisch-Hällisches Qualitätsschweinefleisch	Schwäbisch-Hällisches Qualitätsschweinefleisch in Hohenlohe area, in federal state Baden-Württemberg	Extensive or semi-extensive (natural grazing and/or fodder)	Natural pastures plus cereal feed, vitamins and supplementary fodder from production area	Dark red	Tender, succulent	Strong aroma and flavour	Historical reputation (dates to middle of 20th century), characteristic breed and rearing method (traditional)
Viande de porc, marque nationale grand-duché de Luxembourg	Grand duchy of Luxembourg	Intensive (cereals)	Cereals based feed plus fattening rations contain 60% cereal, maximum 1.5% polyunsaturated fatty acids and no fish meal	Red	Succulent, absence of pale, soft, exudative) meat	Tasteful	Historical reputation, characteristic breed and rearing method (traditional)

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
金华两头乌猪/ Jinhua Liang Tou Wu Zhu	Wucheng district, Jindong district, Lanxi city, Dongyang city, Yiwu city, Yongkang city, Pujiang county, Wuyi county and Pan'an county; region covers Hutian village, Huzhai town, Pan'an County in east, Yekengkou village, Sangang county, Wuyi county in south, Huanggangwu village, Shuiding town, Lanxi city in west, and Zhoujia village, Tanxi town, Pujiang county in north	Semi-extensive (natural grazing and fodder)	Feeding wild herbs, weeds and crops of barley, black bean and carrot and feed	Fresh red	Tender	Characteristic flavour	Historical reputation and characteristic rearing method (traditional)
Goat (n = 11)							
Cabrito da Beira	Districts of Guarda, Viseu and Castelo Branco	Extensive (natural grazing)	Mother's milk, wild grasses and shrubs in natural pastures	Pink	Succulent, tender	Characteristic taste	Historical reputation (dates to Neozoic period) and characteristic breed
Cabrito da Gralheira	Arouca, Vale de Cambra, São Pedro do Sul, Oliveira de Frades, Vila Nova de Paiva and Castro Daire, in Aveiro and Viseu districts	Extensive (natural grazing)	Grassland with natural pastures on wild grass and shrubs	Pink	Tender	Characteristic flavour	Historical reputation and characteristic breed
Cabrito das Terras Altas do Minho	Viana do Castelo and part of the Braga, Villa Real and Porto districts	Semi-extensive (natural grazing and fodder)	Natural pastures, hay, straw and concentrated nutrients	Red	Succulent	Characteristic flavour	Historical reputation and characteristic breed
Cabrito de Barroso	Boticas, Chaves, Montalegre and Vila Pouca de Aguiar	Extensive (natural grazing)	Natural pastures and products	Reddish	Tender, succulent	Characteristic pleasant flavour	Historical reputation (ancient goat rearing), characteristic breed and feeding
Cabrito de Extremadura	Verata, Retinta, Florida, Malagueña, Murciano-Granadina, Blanca Andaluza, Cabra de las Mesetas	Semi-extensive (natural grazing and fodder)	Grazing on natural resources of woodland and *dehesa* (wooded pasturelands), supplemented with straw, grain, fodder, by-products, concentrates (cereals, legumes, oilseeds, protein crops)	Pale pink to pink	Tender, succulent	Characteristic flavour, excellent taste	Historical reputation, characteristic breed and rearing method
Cabrito do Alentejo	Districts of Portalegre, Évora and Beja, and part of the municipalities of	Extensive (natural grazing)	Mother's milk, natural grazing on tree, shrub	Light pink to red	Tender, juicy	Pleasant aroma	Historical reputation and rearing method

Table 2. Continued

Name	Extrinsic factors (environmental characteristics): Place of origin	Farming system	Feed/diet	Organoleptic quality characteristics: Colour	Texture	Aroma and flavour	Link to provenance/evidence of typicity
	Grândola, Álcacer Do Sal and neighbouring areas		and herbaceous resources				
Cabrito Transmontano	Mirandela, Macedo de Cavaleiros, Alfandega da Fé, Carrazeda de Ansiães, Vila Flor, Torre de Moncorvo, Freixo de Espada à Cinta, Mogadouro, Valpaços and Murça	Extensive (natural grazing)	Natural vegetation in uncultivated fields, leaves from the poplar, beech, elm, olive trees	Pink to reddish	Tender, succulent	Excellent flavour and taste	Historical reputation (dates to Neozoic) period, characteristic breed and rearing method (traditional)
Cordero Manchego	Albacete, Ciudad Real, Cuenca and Toledo including districts of Mancha, Manchuela, Centro, Almansa de Albacete; Mancha, Agro of Calatrava, Agro di Montiel of Ciudad Real; Manchuela, Low Mancha, High Mancha of Cuenca; Mancha of Toledo in Autonomous Community of Castilla-La Mancha	Extensive (natural grazing)	Mother's milk for minimum 30 days, pastures grazing on natural resources using fields, fodder, fallow land, stubble, bushes	Pink	Tender, succulent	Pleasant characteristic flavour	Historical reputation (ancient origin) and temperate Mediterranean climate of areas
Κατσικάκι Ελασσόνας/ Katsikaki Elassonas	Elassona province	Extensive (natural grazing)	Mother's milk, grazing on natural vegetation of mountain pastures	White to pale pink	Juicy, tender	Characteristic aroma, pleasant smell and taste	Historical reputation and characteristic breed
Κατσικάκι Λήμνου/ Katsikaki Limnou	Islands of Limnos and Agios Efstratios	Extensive (natural grazing)	Mother's milk, vegetations of island and cereals and legumes based feed	pale pink to red	Tender, succulent	Characteristic aroma and flavour	Characteristics geographical conditions and rearing method
鄂托克阿尔巴斯山羊肉/Etuoke Aerbasi Shan Yang Rou	Arbas, Sumitu, Mukainao, Wulan, Mengxi and Qipanjing of Otog Banner in Ordos, inner Mongolia	Extensive (natural grazing)	Grazing in natural pollution-free pasture with aromatic and medicinal plants (onion leek with strong fragrance)	Light red	Tender, juicy, palatable	Characteristic and fragrant taste	Characteristic breed and specific rearing method
Game (n = 2)							
Lapin Poron liha	Lapland excluding cities of Kemi, Tornio and municipality of Keminmaa, municipalities of Hyrynsalmi, Kuivaniemi,	Extensive (natural grazing)	Natural pastures of vascular plants (rich in protein, vitamins, minerals, trace elements) in summer,	Dark red	Tender, thin muscle fibres	Characteristic gamey taste	Historical reputation (dates to 17th century), breeding (traditional) and diet

Table 2. Continued

Name	Extrinsic factors (environmental characteristics)			Organoleptic quality characteristics			Link to provenance/evidence of typicity
	Place of origin	Farming system	Feed/diet	Colour	Texture	Aroma and flavour	
	Kuusamo, Pudasjärvi, Suomussalmi, Taivalkoski and Yli-Ii and North River Kiiminkijoki and Puolanka-Hyrynsalmi		mushrooms during autumn and winter				
天祝白牦牛/ Tianzhu Bai Mao Niu	Tianzhu Tibetan Autonomous County, including towns of Songshan, Xidatan, Huazang Temple, Shimen, Zhuaxixiulong, Dachaigou, Tiantang, Tanshanling, Haxi, Qilian, Danma, Maozang, Dahonggou, Dongdatan, Duoshi, Saishisi, Anyuan, Sailalong and Dongping	Semi-extensive (natural grazing and fodder)	Wild pastures and feed	Bright red	Tender	Rich of wild taste	Specific climatic ecological conditions (adapted to plateau hypoxia, cold climate, consume roughage)

environmental factors and collective production knowledge of humans linked to a culture developed over years of experience whereas this interaction reveals originality resulting in reputation and confers typicity. This means there is no terroir without typicity, in which typicity is a distinct characteristic attributed to a product that makes it distinguishable from other similar products, which leads to appreciation from consumers who are familiar with the product. Therefore, protected and geographically unique products, guarantee a strong link of product with its terroir and enhances the typicity of the product.

To determine quality characteristics that influence meat provenance, more insight into the terroir and typicity of meat is required. It is therefore essential to determine what characteristics influence meat typicity from a certain region. However, it is becoming increasingly difficult to identify the geographical origin of meat. The livestock fattening is becoming progressively independent from site-specific production factors, and terroir-dependent traditional farm production systems are showing a decline of the use of traditional methods and genotypes, making it more difficult to distinguish one from another.[23] Yet, there are still some factors that can provide an indication of a product's origin and typicity. In this regard, Champredonde[20] identified multiple elements that give beef its typicity including the local production conditions, cattle breeds, knowledge of local operators along with interactions of the earlier-mentioned factors. A combination of these elements is what also constitutes provenance, so it can be said that among other things, the typicity of a food product especially meat is a result of its provenance.

Farm production system

The farm production system or the social dimension of provenance is closely linked to the spatial dimension for food. Globally, various production systems are used for rearing and fattening livestock to produce good quality, safe and healthy animal origin food for populations around the world. The most common methods employed in developed countries are: conventional feeding which uses combinations of extensive grazing of animals and intensive fattening with concentrates that mainly consist of different raw materials such as cereals, legumes, and so forth, feed additives as well as growth implants; and natural or organic feeding systems that is mainly based on extensive grazing with no or minimal other feed supplements for rearing of animals.[24,25] Livestock that forages extensively for their feed might ingest flora and fauna that are associated with specific local ecology or type of soil characteristic for that specific region, which can give an indication of origin.[20] Generally, this does not apply to concentrate-based diets, or diets based on the combination of extensive farming and concentrate supplements. The ingredients of the concentrate feed could originate from the same area where the animals are raised, but it is just as likely that they are sourced from an entirely different area or even continent. Tracing back feed supplements such as proteins or soybean meals can reflect the signature of two or more different areas. For some animals such as sheep and possibly cattle, this is less of a problem, since they are usually reared extensively and are therefore expected to ingest plants of which the origin can be traced.[23]

The feed of an animal and the way in which it is reared across all meat breeds, have been found to have a direct influence on the sensory and nutritional quality of meat.[26,27] Various studies across many animal species have shown that quantifiable components such as stable isotopes, trace elements, fatty acids, volatile organic compounds (VOCs) (e.g., terpenes and phenolics), carotenoids, and vitamin E are directly influenced by an animal's diet and can, therefore, provide information about its dietary background.[9] Among these, dietary influence on the animal carcass has a vital role in influencing the carcass fat level along with fatty acid composition[28] which also influences the organoleptic quality of the meat as indicated by the consumers.[29] This effect of diet and farming system on meat quality is a major factor in determining meat provenance.

Nowadays, farming systems and meat provenance are integral to the broader conversation about sustainable and ethical food production. Consumers are becoming more conscious of their choices, and there is a growing movement towards supporting practices that prioritize environmental sustainability, animal welfare, and transparency in the food supply chain. Various farming systems are practiced globally for the rearing of meat animals that mainly include conventional (intensive) farming, organic farming and grass-fed or pasture-raised (extensive) farming methods. The conventional farming method is often characterized by large-scale monoculture, the use of synthetic fertilizers and pesticides, and intensive farming practices. Contrary to this, organic farming focuses on sustainable and environmentally friendly practices and avoids synthetic chemicals, genetically modified organisms (GMOs), and emphasizes crop rotation and natural fertilizers whereas, grass-fed and pasture-raises livestock are raised on pasture rather than in confined spaces as this practice is believed to be more humane and can result in meat with different nutritional profiles.

Considering meat provenance information and data for PDO and PGI fresh meat products shown in Table 2, the farming systems are predominantly extensive and/or semi-extensive with animals fed plant materials from the natural environment. During winter, the specifications allow the feeding of animals with supplementary feed from the origin, harvest lands and other reputable sources. The beef products are mainly subjected to grassland feeding, natural grazing in mountain or woodland pastures with specific plants or vegetations plus complementary feed including cereals and pulses as well as in some cases animal fattening using specific feed is also practiced. For sheep, extensive and/or semi-intensive with outdoor feeding on the natural vegetation (which can include wild herbs and flowers, shrubs, seaweed, salt marshes, etc.) are mostly deployed for the rearing of animals, while 35 of the 54 sheep product types are suckling lamb with a diet of predominantly mother's milk. Open air, semi-extensive systems are mainly used for the rearing of poultry birds that are subjected to this category for meat provenance. Grassland feeding systems along with extensive and/or semi-extensive farming is practiced for goat rearing to obtain meat for provenance, while extensive (natural grazing) or semi-extensive farming is mainly practised for game. For pork, natural grazing (free-range) systems on specific vegetation/plants, extensive and/or semi-intensive farming system is mainly used for producing meat to fulfil the PDO and PGI requirements.

The pork meat quality is predominantly shaped by several factors, including the animal's genotype, the rearing system in which the pig is raised, and the conditions it experiences both before and after slaughter. Notably, a study revealed that pork from the Black Iberian pig breed, also known in Portugal as Alentejano (see *Carne de Porco Alentejano* in Table 2), when fed either low or high oleic acid diets reared either individually in pens or with access to outdoors conditions exhibited distinct characteristics reflecting the combined effects of rearing system and oleic acid supplementation on carcass composition, nutritional value mainly fatty acid profile, and authenticity.[30] Similarly, another study[31] investigated the impact of genotype and rearing system (high-oleic concentrate feed *versus* acorn and grass) on the composition of dry-cured Iberian ham, including fatty acid profiles, odour, and volatile compound characteristics. The study revealed that genotype had limited effects on most variables, with some exceptions related to specific odorants (methanethiol and octanal). In contrast, the rearing system exerted significant influence on numerous variables, underscoring the potential of different rearing systems in establishing a clear connection to the provenance of meat products.[31]

Product traceability and authenticity

In the present day, the global food supply chain has transformed into a complex network, driven by the imperative to meet the needs of an expanding global population. Within this intricate landscape, food traceability has gained paramount significance in safeguarding consumers health and upholding the safety and quality of food products. As per Codex Alimentarius (*Food import and export inspection and certification systems,* World Health Organization – Food and Agriculture Organization of the United Nations, 2007), traceability involves the ability to follow food movement through specified stage(s) of production, processing as well as distribution chain. In other words, food traceability mainly covers all aspects of the food using the *farm to fork* approach with the major focus on tracing the origin of the product at different levels in the supply chain. In this context, to ensure comprehensive data acquisition during the entire rearing and production process for animals, a highly effective approach is to implement a specific identifier attached to each animal at birth. This practice guarantees seamless traceability throughout the animal's entire life, encompassing crucial stages such as feeding, age at slaughter, transportation, distribution, and lifespan of the animal at sale. By adopting this method, it is possible to establish a robust system that promotes transparency, accountability and safeguards supply chain integrity and consumer confidence.[32]

Indeed, the implementation of a specific identifier for animals from birth is crucial to track and record all pertinent information throughout the entire food and production chain. While initially traceability was primarily mandated for PDO products to distinguish prestigious items from regular ones, its importance expanded significantly after the bovine spongiform encephalopathy crisis in the 1980s and 1990s. Since then, traceability has emerged as a vital tool to ensure not only product authenticity and differentiation but also to guarantee food safety and consumer protection. By enabling monitoring of an animal's journey from its earliest stages to its destination, traceability empowers authorities, supply chain actors, and consumers to promptly address any potential issues, contamination, or fraudulent activities that may arise later in the supply chain. As a result, traceability has become a fundamental aspect of modern-day food production and distribution, fostering greater accountability and confidence in the global food distribution system.[15]

Food traceability is also important to help guarantee a product's authenticity. Food authenticity is defined by Codex Alimentarious (*Discussion paper on food integrity and food authenticity,* World Health Organization – Food and Agriculture Organization of the United Nations, 2018) as 'the quality of a food to be genuine and undisputed to its nature, and claims, and to meet expected properties'. In other words, authenticity guarantees a match between the intrinsic and extrinsic product characteristics and the claims that are made regarding the product, ensuring a general product quality. While an effective traceability system significantly enhances the ability to track and monitor the journey of a product, it does not guarantee complete immunity against fraud or counterfeiting. Current traceability systems, although valuable and essential in supply chain management, are not efficacious in preventing all fraudulent activities. However, it is important to acknowledge that these systems play a vital role in mitigating fraud and enhancing the assurance of a product's provenance. By providing valuable data points and documentation at various stages of production and distribution, traceability systems create a transparent and accountable environment, making it more difficult for dishonest actors to pass off counterfeit or inferior products as authentic ones. In essence, while traceability alone may not eliminate all fraud, it acts as a powerful deterrent and can significantly reduce the occurrence of fraudulent practices.[33]

Product traceability does not necessarily have a major influence on meat quality characteristics. Storage might change some characteristics, but still, traceability is a very important factor for determining food provenance. Maintaining integrity of the supply chain for consumers throughout the production process about specific provenance claims concerning the origin or production system of animal meat being made requires the supply chain to manage information in a transparent way via consistent systems and protocols.[34] Food traceability stands as an essential instrument for verifying the origin and diet of animals, ensuring the delivery of premium-quality meat products to consumers.[35] An example of this is the verification of claims regarding the authenticity of a product, stating that grass-fed beef is actually grass-fed, or that chicken with a corn diet has in fact ingested corn. As mentioned by Wallace and Manning[34] transparency enables a proper transfer of information from the primary producer through every stage until the final consumer, making verification of quality claims made by retailers easier. This relies upon and is highly dependent on the effectiveness of management of all factors involved in the production chain, and includes management systems, certifications, and the use of technology to keep track of all the processes involved in the rearing of animals till consumption. It is also important to note that although traceability assists in deterring meat fraud, it cannot prevent it as a control measure since there are various opportunities and motivations along the supply chain where fraud can occur, regardless of the traceability system in place. This also implies that in addition to the current traceability systems the food supply chains require ongoing advancements in technology, such as Blockchain Technology (BCT) and DNA or molecular testing that can hold promise for further bolstering the security and integrity of traceability systems, paving the way towards even greater fraud prevention and product authenticity verification.

A requirement for a successful meat traceability system is an adequate understanding of the composition of meat and the way in which this influences its authenticity. Sufficient information is necessary to differentiate between different meat components and the ways they are dependent on the animal's origin and production system.[9] Databases and models of geographical origins and production systems need to be set up to compare test samples with, and it is important that these must be standardized for the authenticity comparison. In this context, Nicoloso *et al.*[21] described the key fundamentals of a good traceability system that include: unique product (or batch) identification throughout its entire history; gathering information of the product and its movements; and the establishment of an integrated information management system. Thus, so far, no single system that identifies the product throughout the entire supply chain with full specificity, including all three points, is available. However, a few promising developments exist. The radiofrequency identification (RFID) systems can enable the tracking of individual animals[36] whereas a geographic information system (GIS) and/or BCT system can be very useful to track a product while maintaining proper transparency and data collection throughout the entire chain that will help to mitigate the fraud prevalence and mitigate the risk of fraud vulnerability for the supply chain integrity.[34]

In recent years, RFID systems in combination with other technologies has been used to build a traceability system to track and monitor individual animals. The RFID system contains three parts including the tag that contains specific information and is attached to the animal, a reader to receive information with, and a database to store the information received from the animal in.[36] Although, the tag can either be attached to the animal's ear or can be implanted there is still a risk of the tags being lost during the animal's life or during slaughtering making the traceability uncertain. Overall, managing the animal's tag during the production process and even at slaughtering level is controllable, traceability becomes even more difficult after the animal is slaughtered and the meat is further processed into different cuts and meat products.[36]

The GIS can be used to store, index and archive data based on the geographic coordinates of the product's elements, and when combined with stable isotope analysis, a food isotope map can be generated that can help to better manage the food traceability requirement of the product.[34] Isotope tests can be performed, and when the data is compared to an isotope map, a product's provenance and authenticity can be demonstrated. Although such maps already exist for products such as beer, cheese, and olive oil,[37–39] databases and maps for meat products are currently not widely developed. However, the development of these maps can be an effective tool for the authentication and verification of meat provenance for the traceability of meat and meat products for consumers. Additionally, BCT systems can be used to provide a cryptographically secure record of 'blocks' of the data concerning the origin, process steps, environmental variations, microbial records, and so forth, linked to the product across whole supply chains[40] and could possibly also be used to keep track of information from an RFID system. The use of BCT to create traceability systems and establish provenance in the food supply chain seems promising and can be used to trace the authenticity of the products. However, its success completely relies on the stakeholders in the supply chain. To assure provenance, in the case of both GIS and BCT systems, it is of great importance that all stakeholders provide accurate and transparent data concerning the tracing of the meat product otherwise the system will not work effectively. There is always a need for proper collaboration for the data that is difficult to manage but still, this technology has the potential to track the provenance of the meat.[41]

It is evident that various technologies exist to ensure the traceability of meat and thereby provide a direct link to the origin of meat and meat-based products. Yet, there are still many challenges that exist as the traceability of a product cannot directly guarantee its authenticity. To ensure meat provenance (and its authenticity), other approaches are still required. Meat tracing in relation to provenance can be done by using analytical methods to obtain data of animal meat, carcass and cuts along with processed meat products to quantify the relevant meat compounds and the organoleptic quality characteristics that can be used as markers to correlate meat quality and authenticity for the meat-based systems. In essence, the combination of analytical testing for product authentication and robust traceability systems plays a critical role in the proactive monitoring of fraud and effectively curbing its potential escalation. On the one hand, these analytical approaches confirm and protect product provenance (by verifying the true identity), while on the other hand, they provide a way to better understand the effects that external factors may have on the product and how it can influence intrinsic meat quality and validate associated claims for the meat and its products. Before one can decide which techniques to use, it is important to first obtain product knowledge and identify the characteristics along with specific compounds that are unique to the product. Therefore, it is crucial to develop and validate various meat provenance markers that can later be used for meat authentication considering meat provenance. Although there is a lot of published literature that covers meat fraud, authenticity and food fraud vulnerability, limited information exists regarding the use of analytical markers for meat provenance that need to be developed for future use.

MEAT PROVENANCE MARKERS AND THEIR RELATION TO MEAT QUALITY

The meat quality indicators and provenance play pivotal roles in the meat industry, especially as consumer awareness continues to rise. These factors impact consumer choices, food safety, and the overall management of the supply chain. Examining meat quality involves a thorough consideration of both intrinsic factors, such as animal characteristics, and extrinsic factors, including environmental influences (Table 1). Organoleptic quality attributes, such as colour, texture, aroma, and flavour, are deemed essential, particularly for products with PDO or PGI status (Table 2). In terms of meat composition, intrinsic factors like breed, species, sex, and age at slaughter contribute substantially. Meanwhile, extrinsic factors like place of origin, feed, and farming systems are crucial environmental elements influencing the provenance of meat animals. Tracing the authenticity of meat involves scrutinizing quantifiable compound differences at various levels. This includes meat composition factors like protein, fatty acids, and amino acid composition, as well as considerations for animal sex and age at slaughter. For provenance determination, trace elements such as selenium (Se), rubidium (Rb), iron (Fe), stable isotopes (δ^{13}C, δ^{2}H, δ^{18}O, δ^{15}N, δ^{87}Sr), and plant biomarkers (i.e., antioxidants, terpenes, metabolites) are of interest. These compounds provide valuable insights into the place of origin, feed variations, and farming systems associated with meat animals. Additionally, pH levels, colour values (L^*, a^*, b^*), tenderness, sensory attributes, and volatile compounds play crucial roles in assessing meat provenance, particularly in the context of organoleptic quality attributes. Nowadays, a comprehensive understanding of both meat quality indicators and provenance is essential for ensuring the integrity, safety, and quality of meat products in the dynamic landscape of the modern meat industry.

Composition and organoleptic characteristics of meat in relation to intrinsic factors

Meat composition refers to the various components that are engaged in constituents of meat including proteins, fats, carbohydrates, minerals, and water. Intrinsic factors related to meat composition often considered crucial in determining the quality of fresh meat include the animal's age at slaughter, muscle type and location, growth hormones, health and stress, post-mortem changes, water content as well as connective tissue and collagen content in the carcass of the meat animals.[20] Moreover, animal breed is one of the major factors contributing to the typicity of meat associated with a certain territory or origin, as showcased in Table 2. Hence, the genetics of an animal constitute an important factor of variation for organoleptic quality characteristics in different animal breeds and species and plays an important role in distinguishing speciality products when addressing the meat fraud scenario.[42]

The genetic makeup of the animal influences its meat composition as some breeds are known for producing meat with specific attributes such as marbling, also called intramuscular fat (IMF), that enhances flavour and tenderness.[43] Thus, the work of Conanec *et al*.[44] concluded that the breeds known for their high lipid content exhibit distinctive beef flavour intensity, whereas double-muscled, fast-growing, and meat-centric breeds are often associated with the production of exceptionally tender meat. In addition, meat from rustic breeds showed lower tenderness and juiciness.[44] Animal breeds, Piemontese, Limousin and Friesian, showed a substantial impact on IMF and fatty acid profiles.[45] The Piemontese had the lowest levels of IMF and saturated fatty acids (SFAs), while the Friesian breed showed the highest levels of IMF, SFAs and monounsaturated fatty acids (MUFAs). In general, Limousin animals showed intermediate characteristics, while for cholesterol, non-significant differences were observed between breeds.[45] However, it should be noted that the IMF content of all animal species is very unequal according to breeds, the type of muscle considered and the age at slaughter of the animal,[42] which may contribute to explaining the differences found. Examining the organoleptic attributes of PDO and PGI fresh beef reveals a spectrum of meat colour, ranging from a light pink/red hue to a vibrant red, interspersed with fine veins of white IMF, largely influenced by animal age (Table 2). Additionally, the meat is identified as lingering juiciness, tenderness, a refined texture, with consistency ranging from firm to tender, indicative of its quality. Delving into the organoleptic quality, the aroma and flavour profile of beef encompass distinctive elements. Notably, the meat carries a characteristic flavour, evoking a true essence of beef, coupled with a pleasant aroma. The taste profile is marked by a tasteful and aromatic blend, influenced by the specific feeding regimen. Other attributes associated with beef are tasty, fragrant and salty, all of which are attributes intrinsically linked to the origin and eating habits/diet of the animals. Furthermore, the provenance of fresh beef from beef animals is intricately linked to a combination of factors such as historical, reputation and the breed of the animal with a significant influence on the distinctive attributes of the meat. Together, these elements contribute to the rich profile of flavours and textures that define fresh beef with PDO and PGI designations (Table 2).

Similarly, leaner lamb carcasses with less subcutaneous fat and marbling, showed lower tenderness than those breeds with more fat.[46] When considering the distinctive features associated with PDO and PGI certifications as detailed in Table 2 for lamb meat, intrinsic factors play a pivotal role. These encompass the specific lamb species, carefully designated based on the locality of production systems, involving both male and female animals. Additionally, the age at slaughter, typically specified within a range from days (30–180 days) to years (1–2 years), is a key determinant. Specific weight requirements further contribute to ensuring the production of high-quality meat. The organoleptic quality characteristics of the lamb meat under PDO and PGI specifications are meticulously defined. The colour spectrum ranges from light/bright pink to rosy/red/bright red, while specific textures, including fresh, tender, soft and elastic, succulent and tender, and juicy, contribute to the overall quality. The gamy meat features or specific characteristics, and the aroma of lean quality meat, along with distinctive aromas and flavours linked to the production system and diet, are key identifiers for lamb meat falling under the PDO/PGI classification. These characteristics collectively underline the stringent and detailed standards upheld by these certification systems for lamb products (Table 2).

For pork, several studies have found that local pig breeds are characterized by their higher IMF content, sometimes linked with a higher proportion of MUFA, and lower drip loss which could be linked to its higher juiciness and unique flavour Poklukar *et al.*[47] Exploring the key attributes associated with PDO and PGI designated pork, intrinsic factors, notably the species, are precisely delineated based on production locale, encompassing both male and female animals for the production of fresh meat (Table 2). Specific criteria include weight requirements corresponding to the age at slaughter is also specified for most of the pork animals. Intrinsic factors contribute significantly to the distinctive quality of the meat. Furthermore, the provenance of pig meat is deeply rooted in historical reputation and the use of specific breeds. These factors collectively contribute to the production of high-quality pork that aligns with the stringent requirements of PDO and PGI designations.

With regard to poultry (including fast and medium growing meat types and slow growing egg types), genotype played a significant role in influencing the lipid content and fatty acid composition of both breast and thigh meat.[48] Slow-growing birds exhibited the lowest lipid levels in meat, the lowest proportions of MUFAs, and the highest proportions of polyunsaturated fatty acids (PUFAs). Notably, the total *n*-3 PUFA content in the breast meat of slow-growing birds was twice that of fast-growing and fell in between that of medium-growing birds (8.07% *versus* 4.07% *versus* 5.14%) in terms of total fatty acids.[48] The organoleptic attributes of PDO and PGI fresh poultry meat revealed colour variation from white, light pink, yellow to dark red, which is mainly influenced by bird type, age and feeding method whereas, soft, spreadable, tender, juicy and succulent with firm flesh and muscles are the major textural characteristics of the poultry meat, indicative of its quality (Table 2). Delving into the organoleptic quality, the aroma and flavour profile of poultry encompass distinctive elements such as superior organoleptic characteristics, fine meat with excellent taste are some of the specific flavour requirements. As has been discussed for pork and beef, the quality of poultry is also closely related to historical and reputational factors.

As well as the breed, the sex and age of the animal at the time of slaughter also influence typicity, and can primarily affect protein, fat, vitamins, and mineral content of meat along with sensory properties. Female animals tend to be fatter given that their muscle development is lower when compared to male animals.[49] Thus, heifers had increased fat thickness, steers and heifers had higher marbling scores, higher sensory quality and low *n*-6:*n*-3 ratio, high levels of conjugated linoleic acid (CLA) and MUFAs and lower Warner–Bratzler shear force (WBSF)[50] as it has been also observed for female lambs.[51] However, research has shown that the sex effect is strongly dependent on the production system (feedlot *versus* pasture).[52] For chickens, some studies point out that the meat from male breasts had a significantly lower water-holding capacity (WHC) and significantly higher cooking loss than that of females.[53] A study on organic production of Ross chickens revealed that the meat from females showed higher protein, dry matter, fibre diameter and shear force and a significantly lower fat level than the male group.[54] Thus, where meat provenance is related to the sex of an animal, these compositional differences could assist in distinguishing provenance for different meat animals.

In this regard, age at slaughter showed a significant influence on the colour of meat from Eastern Anatolian red bulls slaughtered at different months. Thus, older animals (19, 25 and 27 months) presented higher values of L^*, a^* and hue compared to their younger counterparts (15 and 17 months).[55] The age of the animal at slaughter and muscle type affected dry matter, ether extract, ash and crude protein non-significantly, however, slaughter age influenced tenderness, juiciness, chewability and shear force significantly. Furthermore, tenderness, juiciness, flavour intensity and consumer acceptability were reported higher for bulls of 19 months whereas, the age increment resulted in lower scores for already reported traits.[55] Accordingly, a study on deer (*Dama dama* L.) reared in Poland[56] showed that carcasses of young deer (18–30 months) had lower IMF contents and lower levels of toughness, elasticity, cohesiveness, heat drip and higher pH values compared to older animals. For goats, the higher the age at slaughter the higher the pH values, thiobarbituric acid reactive substance (TBARS) and the lower the colour stability[57] and the tenderness.[58] However, very young goats have lower IMF[59] which negatively affects juiciness and flavour. For lamb meat, a lower tenderness with a darker colour as the age of slaughter increases (2 *versus* 5 months) has also been reported by Polidori *et al.*[60] The older animals showed also significant higher content of fat and protein, rumenic acid (a CLA), collagen content and both iron and manganese levels. Other studies however did not find significant differences for pH, cooking loss, or chemical composition but older lambs (40 *versus* 60 days) had meat with higher a^* value and higher SFA contents.[61] Finally, pork meat (Iberian × Duroc breed) also showed a progressive increase in a^* value due to a higher content of myoglobin and on extensively reared animals it also leads to less fat infiltration, greater losses during cooking and to greater toughness.[62] These results agree with those findings in Duroc × Landrace × Yorkshire which also reported higher drip and cooking losses and higher b^* values and a decrease in sensory quality. However, older animals showed higher *n*-3 PUFA percentage, crude protein along with essential amino acids (EAAs).[63] Similar results were found for chickens, and older animals (60, 90, 120, 150 and 180 days of age) often presented a higher pH, lower drip loss, higher shear force, darker, and redder breast meat.[64] However, chickens have shown to be very sensitive to age at slaughter. A recent study has shown that differences of 2 days (28, 30, 32 or 34 days) significantly affected protein, ash, WHC of thigh shear force while redness tended to increase and lightness tended to decrease with age.[65]

Age has also been shown to influence the metabolism and muscle composition of meat.[66] Proteomic analysis of water-soluble proteins in pigs of two different breeds, slaughtered at 6, 9 and 12 months of age, revealed that out of a total of 1125 protein spots scrutinized, 41 proteins displayed variations in abundance attributed to age. In addition, mass spectrometry identified a total of 63 proteins that underwent changes, classifying them as structural, metabolic, stress/defence and other proteins. In the case of chicken, it is observed that a higher age at slaughter is accompanied by an increase in meat proteins.[66] Despite these changes, the individual amino acid composition does not show variations attributed to sex and age at slaughter,[67] although it does show differences between breeds.

Composition and organoleptic characteristics of meat in relation to extrinsic factors

According to Fig. 2, extrinsic factors that affect meat quality are the place of origin, feed and farming system that, as previously stated, are very related.

The diet of an animal plays a crucial role in shaping the provenance and quality of meat as an intricate relationship between diet and meat characteristics exists as it is a multifaceted interplay that significantly influences flavour, texture, and the nutritional profile of meat. The composition of an animal's diet, whether it includes grass, grains, forage, or a combination of these, contributes distinct nuances to meat. For instance, animals raised on pasture may produce meat with more robust and complex flavours, often attributed to varied plants/vegetation species consumed during grazing. However, a diet rich in grains may impart a sweet and milder taste to the meat. The impact of diet extends beyond flavour. It also influences the composition of IMF, which contributes to the tenderness and juiciness of the meat. Among these factors, extensive farming has increased in popularity since it enhances the fatty acid composition of meat.[28] Certain feeding regimes may result in higher levels of ω-3 fatty acids or other desirable nutritional components in meat, adding to its overall health benefits.[68] *Irish Grass Fed Beef* (Table 2) is specified to have a distinct grass flavour due to fatty acids and cooked qualities, that is, complex 'nutty' undertones. Furthermore, the connection between animal diet and meat provenance goes beyond taste and nutritional aspects. The specific geographic location where animals graze or are raised, along with the unique environmental conditions and soil composition, contributes to the terroir, characteristic taste and flavour imparted by the environment which is particularly evident in meats with PDO or PGI status, where the link between the meat's qualities and its origin is emphasized as the role of fatty acids,[69] amino acids,[70] volatile compounds,[71] trace elements,[72] stable isotope ratios,[73] along with plants biomarkers such as antioxidants, terpenes and metabolites (Table 2).

The use of different feeding treatments to change meat fatty acid composition has been widely studied and the research keeps looking for more effective feeding strategies which optimize fatty acid composition and the oxidative stability of meat.[74] In this context, numerous studies have addressed the practice of raising animals on pasture because it significantly elevates their exposure to and intake of forages, thus influencing the fatty acid composition of meat. In a comprehensive study,[29] the fatty acid composition of pigs was examined across three distinct dietary regimens. The results revealed the highest ω-3 fatty acid concentration was observed in pigs on a grain-free diet, followed by the 50% grain-fed group, and the lowest in pigs exclusively fed 100% grain.[29] Similarly, Nogoy *et al.*[75] found that the ratio between *n*-6 and *n*-3 fatty acids is more favourable in grass-fed (low *n*-6:*n*-3 ratio) animals than the concentrate-fed (high *n*-6:*n*-3 ratio) livestock. Similar results can be observed in the fatty acid composition of grass-fed cattle and lambs, where the meat from these animals has been shown to contain higher proportions of linolenic acid (C18:3*n*-3), less linoleic acid (C18:2*n*-6), and higher proportion of PUFA than the concentrate-fed animals.[76] Besides this, the inclusion of a higher proportion of grass feeding in the diet increases the antioxidant capacity[77] and the carotenoid levels of the muscles. Moreover, pasture-fed animals show higher levels of carotenoids, retinoids and other volatile compounds such as 2,3-octanedione together with lower levels of skatole. For example, the natural grass diet of *West Country Beef* (Table 2) produces meat with higher *n*-3 fatty acids and vitamin E concentrations.

Not only the chemical composition, but also the isotopic ratio and mineral composition is affected by the diet because if C_3 plants, such as vegetables, fruits, and cereals δ^{13}C which values range between −30 and −23‰ are included in the diet, the value of δ^{13}C in meat would decrease, while if C_4 plants are included such as maize, sugarcane, sorghum, and millet with δ^{13}C ranging from −14 to −12‰, the meat δ^{13}C would increase.[78] This is the reason why the inclusion of acorns in the diet of Iberian pigs decreased the δ^{13}C (‰) as observed by Hernández-Jiménez *et al.*[79]

The place of origin also shows an influence on meat composition, with extensively reared cattle kept at higher altitudes showing higher PUFA values.[80] The geographical origin has been shown to influence the levels of mineral elements both essential and pollutants.[9] Therefore, Dehelean *et al.*[73] reported that meat samples from Romania were characterized by their levels of potassium (K), Rb and palladium (Pd), and the sodium/potassium (Na/K) ratio varied according to the country of meat production. However, the contents of some mineral elements can be altered by the inclusion of mineral supplements and also depend on the farming system, thus Fe contents were found to be higher in conventional pork than in organic pork.[36] Place of origin strongly affects the isotopic ratio of meat samples because the δ^2H and δ^{18}O values of precipitation decrease from low-latitude, low-elevation, and coastal regions to inland areas of high-latitude and mountainous regions.[81] However, climates with higher temperatures led to intensive processes of plant transpiration and evaporation and subsequently to increased ^{2}H and ^{18}O isotope fingerprints in meat samples as observed in Spain as compared to Romania and Hungary.[73]

Breeding conditions also influence meat quality characteristics and is mostly dependent on the way the farmer treats and manages the animals. The effects these factors have on meat quality are highly variable, making it difficult to establish general laws on the consequences of breeding conditions on meat quality.[42] The environmental conditions particularly temperature, humidity and rainfall are dependent on the farming conditions where the animals are kept. Temperature extremes mainly affect the storage of muscle glycogen and consecutively the ultimate pH of meat resulting in a pale colour and lower curing-cooking yield of chicken meat,[82] reduces growth and development resulting in fatter animals that can affect meat quality.[83] However, low temperature conditions in animal rearing produce leaner animals.[84] Not only farming practices but also pre-slaughter transportation affects meat quality. One study carried out on young goat kids[85] indicated that, regardless of its duration, transportation had a significant impact on various parameters indicating stress in live animals and the stress-induced effects affected fat cover in carcasses and colour parameters.

Focusing on the farming system, male livestock animals are frequently subjected to castration procedures even though this practice is not typically viewed favourably in terms of animal welfare.[42] The castration of animals can affect meat composition since it promotes lipid accretion that can lead towards the fattening of a carcass.[86] In this context, a study conducted on Piemontese cattle revealed that in comparison to intact males, castrated cattle exhibited lower water and hydroxyproline alongside higher protein and fat levels.[87] Similarly, in old male goats castration increased cholesterol and SFA levels in the *Longissimus dorsi* muscles[88] as was also reported for castrated pigs.[89] Likewise, another study carried out to determine the effect of immunocastration on carcass quality in pigs subjected to four treatments as entire males, females, surgically castrated males and vaccinated males, reported that surgically castrated and vaccinated males were fatter than others in the loin muscle area whereas, surgically castrated were fatter and entire males were leaner in ham area.[90] These results are in line with those reported for the Alentejano breed. This study also found that entire males presented lower antioxidant capacity and myoglobin contents and lighter colour than that of castrates.[89] When gilts and castrates were compared, no effects on pH, moisture, cooking loss, WHC, and WBSF were usually observed, while for IMF the results are controversial and sometimes a higher content was observed for gilts and in other cases the opposite was reported.[91,92]

Traditional farming systems, associated with native breeds, are growing in popularity around the world due to consumers' belief that they provide higher quality meat compared to meat from 'factory farmed' or intensively produced animals. Also, consumers positively value the better living conditions of the animals (welfare). In this regard, a study conducted to elucidate the effect of different keeping ways and feeding regimes on the fattening of native Złotnicka Spotted pigs, revealed compelling insights.[93] Notably, the acorn-fed pigs exhibited higher fat contents, which played a pivotal role in enhancing flavour and juiciness. Furthermore, they demonstrated a significantly higher MUFA content and lower atherogenic, thrombogenic, and peroxidability indices which underscore the profound influence of housing and feeding practices on the overall quality of native pig breeds. Moreover, the organoleptic qualities of PDO or PGI pork are characterized by specific visual attributes, including a colour spectrum ranging from light/bright red to pinkish-red marbled with IMF. The texture is defined by fine, succulent, tender, and slightly fatty characteristics. Notably, the aroma of quality meat and its distinctive flavour are integral to the overall profile. These sensory aspects are intricately linked to the production system and diet (Table 2).

Provenance markers

The earlier results show that the different intrinsic and extrinsic factors linked to meat provenance affect the chemical composition and organoleptic quality of meat, but as noted earlier, the composition and quality characteristics of meat can in turn be indicators of provenance or provenance markers.

Trace elements as meat provenance markers

The presence of trace elements in the meat could be a good indicator of the origin or of meat provenance. The mineral composition of meat changes with breed and age of animals, muscle type and feeding practices and geographical site of rearing.[92,94] Certain minerals and trace elements from soil that are characteristic of a certain area can be present in the meat if the animal consumed/ingested sufficient quantities of them through dietary ingestion of grass or feed resources.[95] This is mostly the case for Se, Rb and Fe, which can get deposited in organ meats and skeletal muscles.[23,96]

The Se concentrations have been found to be higher in American soil than European soil, which can be substantiated by findings by Franke *et al.*,[97] showing high Se concentrations in North American beef and Brazilian poultry. Scientific literature has recorded average Se concentrations (in mg kg^{-1} dry matter) in Swiss organic beef (0.15 mg kg^{-1}) and conventional beef (0.26 mg kg^{-1}) that are notably less than the levels observed in beef originating from North America (0.43 mg kg^{-1}).[98] Unfortunately, Se and other trace elements are also being fed to animals through feed supplements which is a common occurrence that sometimes makes it difficult to determine if the Se or other elements present in meat originated from the local feed resources from soil or from a supplement.

The Rb is often found in high quantities in plants and drinking water from granite and gneiss weathering soils, but the amount that accumulates in meat and organs is dependent on the species.[99] Similarly, a study was carried out in which cattle beef samples from Europe, the United States, South America, Australia and New Zealand were analysed to determine geographical origin. The results identified by canonical discriminant analysis of key elements (i.e., Sr, Fe, Rb and Se) provided maximal discrimination among beef samples considering geographical areas. The findings concluded that elemental analysis can be used to trace the origin of beef meat.[100]

As far as Fe content is concerned, it does not seem to be influenced by geographical origin. Thus, studies carried out with beef from Denmark, the United Kingdom, Australia and the United States showed no significant differences in Fe content, with values ranging from 16 to 24 mg kg^{-1} of wet tissue.[101] However, feeding does seem to be a conditioning factor for Fe content. Thus, research carried out by Purchas and Zou[102] showed that Angus crossbred heifers fed on grass in New Zealand showed higher Fe contents in wet tissue than Angus crossbred heifers fed on pasture in the United States. Similar results have been described in pork where the Fe contents found in conventional pork are higher than those found in organic pork from the same area in China.[36]

The measurement of other trace elements either alone or in combination has also shown potential in dietary background and geographical origin assignment.[9] Research on pork meat[103] showed that it was possible to identify pork by origin based on 29 macroelements and trace elements in samples from Korea, the United States and four European countries.

Heavy metals, often seen as pollutants, can also be characteristic to a certain geographical origin. Some heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn) may be from human action, but these metals are also found in the environment from natural sources (soil erosion and weathering of the earth's crust).[104] Contaminated feed, drinking water and agricultural soils play important roles in the transfer of these toxic metals to the animal body.[105] Thus, residual concentrations of Pb and Cd have been found in muscle and offal of chickens, cattle, goats and sheep raised in Tarkwa, Ghana[106] and in Benin City, Nigeria,[107] in cattle and sheep raised in Egypt[108] and in chicken meat raised in Karachi, Hyderabad and Thatta, Pakistan.[109] The presence of As and Pb has been described in veal and pork from Augusta Area, southern Italy.[104] While in some regions of China the presence of As, Cd, Hg, and Pb has been described in pig, beef, mutton, chicken, and duck meat.[110] However, tracing these might not be useful for determining animal origin based on fresh meat cuts as they end up in inner organs usually not eaten by the consumers.[111] Thus the highest levels of Pb and Cd appear to be found in the liver and kidney. The research carried out by Aljazzar *et al.*[105] on bovine meat showed that the kidney was the organ with the highest Cd residues, followed by the liver, rumen, colon, lung and tongue, with significantly higher values in all cases than those found in muscle. Since it is often difficult to distinguish natural soil trace elements from feed supplemented ones. Hence, a more pragmatic option might be to verify trace elements that are specific for local drinking water, litter, as well as in air,[23] which cannot be falsified or masked easily and thus can ensure food authenticity with special reference to meat and meat products. However, these methods are especially promising for origin verification of poultry because they are often not in contact with their local environment.

Stable isotopes as meat provenance markers

Stable isotopes are atoms of the same element with identical numbers of protons but varying numbers of neutrons. Isotope analysis entails the measurement of ratios between different isotopes of elements like carbon (C), nitrogen (N), hydrogen (H), and oxygen (O) in a sample. By scrutinizing the stable isotopic composition, researchers can gain valuable insights into the geographical origin and composition of various food types. When it comes to meat, it can provide information about the animal's diet because the composition of bio-elements in animal tissue directly depends on the diet composition consumed by the animal.

If the diet is characteristic of a specific area, analysing isotope ratios can link it to its geographical origin whereas, C isotopic composition can be related to production systems owing to different photosynthetic pathways of plants that are mainly consumed by animals. The C_3 plant tissues deplete carbon dioxide (CO_2) in relation to atmosphere to about 19% while C_4 plants depletes about 4%. Indeed, plants preferentially assimilate lighter and more abundant isotope ^{12}C and the $\delta^{13}C$ value for atmospheric CO_2 is 0% which means $\delta^{13}C$ values are negative compared to that of atmospheric CO_2. Then, C_3 plants show more negative values than C_4 plants which means that animals fed with C_3 plants show more negative values of $\delta^{13}C$.[79] Additionally, C_3 type plants (vascular and crop plants) are commonly found in temperate climate areas whereas C_4 plants (corn, sugar cane and sorghum) are mainly found in tropical areas that are usually not used in organic farming systems. Not only geographical provenance but also production system, pasture *versus* cereal based along with organic *versus* conventional systems, can be identified by using $^{13}C/^{12}C$ ratios.[9]

The different ^{15}N contents is a consequence of environmental parameters like climate and soil conditions as well as agricultural practices of different geographical areas.[112] The chemical fertilizer also depletes ^{15}N more relative to organic fertilizer,[113] which is a potential reason why $\delta^{15}N$ value of cattle from pasture-feeding regions are higher than fed on cereal based feeds.[114] However, the presence of leguminous plant, which uses N of air as N source, can result in a decrease of $\delta^{15}N$.[115] This fact has been related to the lower $\delta^{15}N$ values found in products from animals grazing on mountains as leguminous plants are more widespread in these poor fertilized soils.[116] However, Piasentier *et al.*[113] found that $\delta^{15}N$ values were not dependant on the animal feeding regime as reported in a study in which lambs were fed on a similar diet but in different countries, resulting in meat with different ^{15}N relative abundances. Furthermore, another study by Cormie and Schwarcz[117] demonstrated that climate and precipitation can influence feed composition that can affect the isotopic composition of meat. For deer consuming plants such as corn and sorghum, an inverse correlation between amount of precipitation and $^{15}N/^{14}N$ ratios were found in which decrease of local precipitation led to an increased $^{15}N/^{14}N$ ratio which agrees with the work of Heaton *et al.*[118] who found that water stress increases ^{15}N content in soil. This is due to fact that air N is transformed into inorganic and organic forms of N through a physical process and microorganisms activity present in soil which are also affected by factors such as soil depth and climate affecting $\delta^{15}N$ values of soils.[81]

Although not direct indicators of geographical origin, the ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ can serve as valuable indirect tools for discerning geographical provenance, especially when specific feedstuffs are traditionally associated with certain regions. This becomes even more potent when these ratios are analysed in conjunction with other isotopes like H and O. Besides isotopic ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$), isotopic ratios of sulphur ($^{34}S/^{32}S$) and strontium ($^{87}Sr/^{86}Sr$) can give an indication of the origin of feed and soils, while hydrogen ($^{2}H/^{1}H$) and oxygen ($^{18}O/^{16}O$) ratios are predominantly influenced by the drinking water[23] which in turn depends to geographical location decreasing from low-latitude and low-elevation coastal regions towards inland and high-latitude and rocky regions.[119] Furthermore, atmospheric conditions have also been reported to affect stable $^{18}O/^{16}O$ and $^{2}H/^{1}H$ ratios in groundwater and change when moving land inward from seashores which can give an indication of origin of meat animals for provenance.[100]

Multi-element stable isotope ratio analysis involving C, N, H and S serves as a valuable analytical tool for confirming the geographical origin of meat of various animals. In a comprehensive study, beef collected from nine different European and non-European countries were, after defatting, subjected to isotope ratio mass spectrometry to determine ratios of $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{2}H/^{1}H$, and $^{34}S/^{32}S$. The study unveiled notable variations in mean isotopic values among beef originating from different locations. Discriminant analysis identified four critical isotope ratios that were significant for discriminating geographical origin, accurately assigning 84.9% of meat samples to their respective countries of origin (with 82.2% success on cross-validation). Moreover, when additional information about feeding practices was considered, beef samples could be classified according to their geographical origin. Notably, all pasture-fed Irish beef samples were correctly classified along with cross-validation, underscoring the technique's potential in identifying the origin of meat animals for provenance.[120] Likewise, the study conducted by Boner and Förstel[121] demonstrated the possibility of distinguishing between German and Argentinian beef by examining O and H stable isotopic ratios, while ratios involving S and N proved valuable in distinguishing between various local geographic areas within three different farms in Colonia Bay.

These isotope ratios ($^{13}C/^{12}C$,$^{15}N/^{14}N$, $^{2}H/^{1}H$ and $^{34}S/^{32}S$) have also demonstrated the technique's potential in detecting clustering of beef samples based on specific environmental rearing conditions in a study carried out in 13 different locations spanning eight countries.[78] Moreover, isotope measurements revealed significant differences among coastal and inland regions alongside production sites at various latitudes, regions characterized by distinct geological compositions, and diverse farming systems linked to animals' dietary choices, whether primarily C_3 or C_4 based or a combination of both.[78]

Animal diet is one of the vital components linked to meat provenance particularly considering the origin region for South African lamb. Thus, a study carried out on defatted meat from the *Longissimus lumborum* muscle of Dorper lambs showed that the $\delta^{13}C$ and $\delta^{15}N$ values of lamb meat were mainly influenced by the origin of the meat, mainly reflecting dietary factors and environmental conditions.[122]

Significant variations have been observed in stable isotope ratios such as ^{18}O [isotope ratio mass spectrometry (IRMS)] and

Journal of The Science of Food and Agriculture published by John Wiley & Sons Ltd on behalf of Society of Chemical Industry.

^{1}H, ^{2}H and ^{13}C [nuclear magnetic resonance (NMR)] based on production site and dietary factors in meat samples collected from Charolais steers raised at diverse geographical locations in France, where they were fed on either maize silage indoors or on a grass-fed diet. Furthermore, discriminant factorial analysis effectively facilitated the identification of both the production site and the diet of the animals using these parameters.[123] The $\delta^{34}S$ of meat proteins tends to reflect the S values of plants on which meat animals especially cattle are fed, that are mainly influenced by the soil geology the plants grow on (e.g., the presence of sulphates or sulphides along underlying local bedrock type).[78] Whereas, additional influential factors encompass fertilization practices, including S amendments, and the known sea-spray effect due to sea proximity.[69,124] While if the local bedrocks are poor in ^{34}S, for instance, if they are characterized by high amounts of volcanic S or if they are rich in sulphides, a decrease in the isotopic ratio in meat tissues is observed.[124] Other factors reported to affect this parameter are microbial processes in soil.[69] However, some studies have found that $\delta^{34}S$ did not display geographical differences,[125] while others found a strong variation within countries due to the effect of the distance from the sea.[126] Finally, although less studied, the breed effect of meat animals has been reported to influence $\delta^{34}S$[127] showing that it could be a good marker for meat provenance.

To date, there has been no extensive research conducted on the climatic impact on the diet of extensively farmed livestock, but any future research on the topic of detection of precipitation from stable isotope ratios could be useful in determining the geographical origin of livestock for meat. Also, it is promising to explore the role of the isotopic ratio of $^{87}Sr/^{86}Sr$ for determining its role in meat provenance as its occurrence is highly dependent on soil type and specific geographical features that are typical of certain areas. It does not interfere with the environment, so it is not influenced by temperature or vegetation, which can make it easier to constrain results to certain areas for tracing origin for meat animals.[128] In fact, when this ratio was used to identify geographical origin, it was concluded that $^{87}Sr/^{86}Sr$ were site-specific. For example, when inland *versus* island is compared[129] or when the geological settings of the sample site are considered[130] reflecting lithological properties of each region. However, it remains a challenge to use this ratio to discriminate a broader geographical origin such as between countries.[126,131,132]

Plant biomarkers as meat provenance markers

Plant biomarkers for meat provenance are related to the identification of specific compounds derived from plants as they can provide valuable information about the geographical origin, feeding habits, and processing methods of animals contributing to transparency and authenticity in the meat supply chain. Biomarkers found in plants can be transferred to animals through their diet and can be retained in animal tissues and meat and can serve as indicators of an animals' dietary sources and environments. By analysing biomarkers in meat, one can gain insights into the animal's diet as to whether they were raised on pasture, in feedlots, or with specific supplementary feeds that can help to trace meat provenance.

According to Prache *et al.*[133] components such as carotenoids, phenols and terpenes can be classified as plant biomarkers. Besides this, there are also metabolic markers derived from the animal metabolism which include fatty acids and volatiles such as 2,3-octanedione and 3-methylindole (skatole). Likewise, Darwish *et al.*[108] conducted a study to determine the total carotenoids, β-carotene, and retinol concentrations in livers and muscles of ungulates including cattle, buffalo, sheep, goats and horses. The results showed that cattle and horses exhibited the highest levels of both total carotenoids and β-carotene whereas, sheep showed the highest accumulation of retinol. In contrast, the lowest levels of retinol were observed in buffalo. These findings demonstrate the compatibility of various plant metabolites for the differentiation of meat animals.

The grass feeding system increases the antioxidant content in muscles of meat animals whereas, antioxidants such as vitamin E have beneficial effects on extending shelf life of meat by preventing autoxidation of PUFA that can positively influence visual organoleptic quality characteristics.[29] Other plant compounds that are potential tracers of extensive feeding or geographical origin to trace authenticity includes terpenes (plant metabolites) and animal metabolites such as 2,3-octanedione and skatole.[15]

In this respect, 2,3-octanedione (skatole) and terpenes have been studied as biomarkers to track meat origin in calves reared with different feeding strategies. Pasture-fed animals showed several terpene-rich compounds in their composition and higher levels of 2,3-octanedione in their fat. Likewise, although all animals showed skatole in perirenal and subcutaneous fats, animals fed a concentrate-rich diet showed lower levels of this compound.[134] In poultry, the antioxidant activity of vitamin E, carotenoids and polyphenols from ingested plant extracts (rosemary and oregano) can be used as biomarkers. However, the amounts of these compounds are highly variable depending on factors such as the level of total fat and especially the PUFA content.[135]

The examination of carotenoids in meat animals holds significance considering the growing consumer interest in authenticating animal diets. For instance, carotenoids serve as valuable markers for tracing the origins of pasture-fed animals. In this regard, carotenoid content in sheep on a housed diet was shown to be significantly lower, ranging from 2% to 3%, compared to animals on a pasture diet. Lutein, zeaxanthin and β-carotene were the main plasma carotenoids found in grazing lambs. Furthermore, when lambs reached slaughter weight, those animals fed on grass had higher levels of plasma carotenoids than those fed in stalls. This distinction reliably differentiated the grass-fed lambs from all other feeding groups.[136] Various studies based on objective and subjective measurements reported that livestock fed on pastures had higher levels of carotenoid pigments such as xanthophyll or lutein in their fat deposits than those fed on concentrate diets.[137] Accordingly, Röhrle *et al.*[138] reported that the β-carotene in the subcutaneous adipose tissue in heifers fed with barley concentrate was lower than that from pasture and silage followed by pasture or silage followed by pasture with concentrate whereas, lutein in the subcutaneous adipose tissue differed between groups with 0.13, 0.10, 0.08 and 0.04 μg/g for pasture, silage followed by pasture, silage followed by pasture with concentrate and concentrate groups, respectively. Principal component analysis of carotenoids in adipose tissue, colour (L^*, a^*, b^*, chroma and hue) and reflectance were able to distinguish animals fed barley concentrate and pasture diets but not between different pasture-based groups.

The volatile biomarkers present in ruminant tissues also serve as effective discriminators between pasture-based and concentrate-based dietary systems. The research carried out by Sivadier *et al.*[139] aimed to track the persistence of volatile tracers originating from a pasture diet in perirenal and caudal subcutaneous fat of lambs. The results identified 39 tracers from the grass diet, including terpenes, 2,3-octanedione and toluene, which can distinguish four different diets in both tissues. The majority of the compounds exhibited 'short' persistence, for example, 2,3-octanedione and terpenes, while some displayed 'medium' or 'long' persistence and finally discriminant analysis tracer ratios from adipose tissues enabled correct differentiation of different diets indicating potential for meat provenance.[139] The oxidation of meat can result in off-flavours which tend to be stronger when the animal diet contains tannins and these compounds are more common in grass fed diets. The 2,3-octadione has been reported to be 25 times higher in grass-fed animals than concentrate-fed. Although 2,3-octadione does not necessarily give an off-flavour, it is often associated with causing perceived flavour differences between grass and concentrate-fed meat animals.[24]

Likewise, retinoid levels in the liver can be used as biomarkers. These levels have been used to establish traceability of feeding practices in Iberian pigs, to distinguish between the *montanera* system, characterized by free-range rearing and a diet centred on pasture and acorns, and the *cebo* system, known for its intensive approach with a concentrate-based diet.[140] Retinoid levels in the liver were able to classify the diet of Iberian pigs with 93% accuracy rates far superior to those offered by other methods such as the determination of perirenal fat.

The fatty acid composition can also be used as a plant biomarker. In fact, fat is an important indicator of diet, since the profile of fatty acids in muscles or tissues, particularly for monogastric animals, reflects fatty acids ingested by the animal through the diet.[141] The transition in feeding systems for meat animals, ranging from a diet based on grass to concentrate, exerts a significant impact on aspects such as growth, carcass characteristics, and meat quality, particularly the fatty acid profile. In this context, pasture-fed Timahdite lambs exhibited a superior percentage of PUFA, especially in terms of n-3 fatty acids compared to feeding systems comprising concentrate and hay. Additionally, they displayed a lower n-6:n-3 ratio, along with a higher percentage of conjugated linoleic.[142] A pasture-finishing diet can lead to greater deposition of n-3, CLA fatty acids, and a lower n-6:n-3 ratio in lean meat compared to the grain-finishing diet.[143] The incorporation of n-3 PUFA in the muscle is facilitated by a higher concentration of linolenic acid, often found in roughages which is a natural source of antioxidants that can lower the lipid oxidation rate, usually observed in grass-finished beef whereas, pasture-finished also alters the concentration of volatile compounds formed during cooking meat owing to the changes in the fatty acid profile.[144]

The pH and stress biomarkers as meat provenance markers

One of the main indications of breeding conditions and the way the animal was treated on the farm, during transportation as well as pre-slaughter conditions is the ultimate pH of meat; determined by the extent of the pH decline 24 h post-mortem that can influence meat quality attributes A high pH results in dark, firm, dry (DFD) meat, while a low pH results in pale, soft, exudative (PSE) meats because of the denaturation of proteins.

The stress which the animal experiences either on the farm, during transport or at slaughter has long been recognized as prominent factors influencing pH values.[145] Transportation also had a significant impact on various blood parameters indicating stress in live animals, such as glucose, cortisol, and creatine kinase.[85] The stress level that an animal experience is not directly linked to provenance, but some stress causes such as transport from farm to slaughterhouse or temperature extremes during rearing and transport could give an inexplicit indication of meat animal origin. For example, animals reared at remote locations might show more signs of stress due to the longer transportation times.[146] Besides this, some studies point out that stress biomarkers can hypothetically react differently depending on the breed or farm management system which are factors related with meat provenance. In this sense, recent studies[147] showed both factors had the highest impact on cortisol, lactate, and serum amyloid A which were identified as potential stress biomarkers in relation to ultimate pH. In fact, increased cortisol levels were observed in wilder or nervous 'temperament' breeds both for calves and sheep.[148]

The environmental conditions particularly temperature, humidity and rainfall are dependent on the farming conditions if the animals are kept indoors but can also be influenced by regional climatic conditions. In this context, some studies have shown that acute-heat stress conditions resulted in the decrease of the ultimate pH of chicken meat.[82] Similarly, another study[84] illustrated the effect of low temperatures of animal rearing conditions on the ultimate pH. Piglets raised in cold temperatures were found to exhibit a lower ultimate pH than those raised at thermoneutral temperatures; even when they were fed at will, their capacity of ingestion was too limited to cover their increasing needs. This effect, however, was found to be reversible if the pigs were placed in neutral temperatures in the finishing phase of their growth.

Furthermore, for poultry, exposure to continuous temperatures above 32 °C caused oxidative stress by elevating citrate synthase activity, the messenger RNA (mRNA) expression of M-CPT1, and phosphorylation level of AMPKα and reduced mRNA expression of avUCP whereas, heat exposure for 14 days increased the pH values. Overall, the study concluded that chronic heat stress impairs meat quality by causing mitochondria to malfunction, affecting energy-substance aerobic metabolism that can lead towards increased glycolysis. Pigs are also quite sensitive to high temperatures and when they suffer heat stress they tend to decrease their feed intake resulting in IMF[149] and an increase of the oxidative reactions altering the meat quality.[150] However, it has been found that for some traditional breeds like Iberian pigs heat exposure did not affect pH and stimulated the activity of antioxidant defences.[151]

Organoleptic quality characteristics as meat provenance markers

Organoleptic qualities refer to sensory attributes of a product that can be perceived by the human senses, such as appearance, texture, taste, smell and even sound. These qualities play a pivotal role in determining the overall sensory experience and consumer acceptance of various products, including meat. Considering meat and meat products, organoleptic qualities are crucial as they influence consumer preferences and can vary based on cultural and personal preferences. In the context of meat production and culinary arts, understanding and optimizing these qualities can lead to more enjoyable and satisfying meat products. It is difficult to assign certain organoleptic quality characteristics to certain animal species since these highly vary per breed and species and are also influenced by factors such as age and sex (Table 2).

Colour

The meat appearance on retail shelves is critical for consumer acceptance and particularly, the colour of lean tissue is an important quality indicator for consumers. The meat colour aspects considered as most important ones include paleness, redness and browning. The paleness or lightness of meat is related to the myoglobin concentration and light scattering properties whereas, redness and brownness are more related to the myoglobin concentration and the chemical state of the myoglobin, particularly oxymyoglobin.[152] It has been documented that meat from extensively farmed livestock is darker than meat from animals fed concentrates. Additionally, the animals finished on pasture had a value of L^* (lightness) about 5% lower than animals finished on concentrate.[24] This is due to a higher content of myoglobin in the muscle, an effect directly linked to the farming method, diet, as well as physical activity level of the animal. For example, the purple red colour of *Vaca de Extremadura* beef (Table 2) is because the meat has a higher concentration of myoglobin. This is due to a range of factors, including the farming system, which involves greater levels of physical activity in extreme conditions in the search for food in the *dehesa*-style landscape (wooded pasturelands). The combination of these factors has an impact on the desirable and distinguishing aspects of the meat.

Similarly, the beef from organic grazing systems also tends to have a more intense red colour (higher a^* value) than meat from concentrate-fed beef, but this pronounced effect is less visible with animal age.[80] Accordingly,[153] the growth rate had a greater impact on muscle and fat deposition in feedlot steers than pasture fed; feedlot animals had higher *Longissimus* muscle area and meat luminosity compared to pasture fed steers. For meat colour, steaks of feedlot high (F-H) steers reported higher L^* values than other steaks whereas, beef from F-H cattle showed higher b^* value (yellowness) than pasture high and low as well as older animals have higher concentrations of iron resulting in dark coloured meat compared to meat from young animals. Another study,[55] reported that slaughter age and muscle type affect quality attributes in eastern Anatolian red bull as older animals (19, 25 and 27 months) had higher L^*, a^* and hue values than younger animals (15 and 17 months). Likewise, Bureš and Bartoň[154] reported the effect of sex and slaughter age on Charolais × Simental breed and the results showed an animal sex and slaughter age interaction, therefore *Longissimus lumborum* colour was lighter in bulls slaughtered at 18 months compared to 14 months and darker in older heifers than young ones. Nevertheless, the study reported that without proper information about the production background of the animal, it might be difficult to determine the difference between colour influenced by farming method, age at slaughter, or intrinsic meat characteristics such as muscle fibres type along with fatty acid composition.

The pasture-fed animals that primarily ingest luscious green vegetation generally deposit more yellow pigments (higher b^*) into their fat, which has led to propose the analysis of these pigments to authenticate grass feeding of animals.[155] The slow-growing poultry species have more physical activity that can influence carcass colour resulting in meat and fat with more (dark) yellow colour.[156] In this regard, outdoor access increased a^* and b^* colour value of turkey thigh muscles. The slow-growing and the fast-growing turkey genotypes had higher L^* values for breast than medium-growing genotype whereas, the slow-growing genotype had lower a^* and pH values for breast meat. Additionally, breast meat of slow-growing genotype was more yellow (higher b^*) while the high-growing genotype had higher L^* and lower a^*.[157] The colour of bovine subcutaneous adipose tissue (carcass fat) depends on animal age, gender and breed especially for cattle. Diet is the most important extrinsic factor; however, its influence depends on feeding duration along with the type of feeding. The cattle reared under extensive grass-based production systems generally have more yellow carcass fat than intensively-reared, concentrate-fed counterparts which is mainly caused by carotenoids from green forage. The different nutritional strategies cause differences in fatty acid composition and it may be reflected by variations in fat colour which can aid authentication of dietary history and origin of meat. Yet this potential utility is complicated by the simultaneous rather than discrete use of forages and concentrates in real production systems.[158] The fat colour is a valuable tool for tracing feeding practices also for Iberian pigs where it has been proven useful in distinguishing between *montanera* and *cebo* systems.[140] Notably, L^* values for *montanera*-fed animals differed significantly from those fed on concentrates.

Texture characteristics

Meat texture refers to the physical feel, consistency, and mouthfeel of meat when it is cooked and consumed which is influenced by numerous factors, including the animal's breed, age, diet, muscle usage, and cooking method of meat. The different breeds possess distinct characteristics for meat texture and flavour owing to variations in genetics and feeding methods along with husbandry practices. Considering breeds for beef, Angus is known for its marbling that refers to IMF responsible for tender and juicy meat texture whereas, Hereford beef tends to have more moderate marbling level compared to Angus leading towards a slightly lean texture. Also, Wagyu beef which comes from highly valued Japanese breeds like Kobe, is well-known for its extremely high marbling level resulting in a buttery, melt-in-mouth texture whereas, Holstein cattle which are primarily raised for dairy products produce lean beef with tough or less tender meat texture owing to its low marbling level.

The texture of German Holstein and Simmental bulls randomly allocated to either indoor concentrate feeding or pasture feeding revealed that WBSF values of pasture-fed bulls were significantly higher (relates to tougher meat) compared to that of concentrate-fed bulls.[159] Similarly another study by Nuernberg *et al.*[160] reported that pasture-fed bulls meat was tougher than meat from concentrate-fed bulls. The concentrate feeding system enables the animals to grow at much faster rate and results in more tender meat than the grass feeding system.[161] Also, giving animals access to outdoor living areas increases their physical activity which can decrease the fattening of animals and increase meat toughness leading towards decreased tenderness of meat. Contrary to that, non-significant differences were reported by the dietary regime on meat juiciness despite the differences it causes in fat level as well as meat tenderness.[162]

Considering pork meat texture, Duroc pork is known for its rich flavour and good marbling level resulting in tender and juicy meat and Berkshire pork is highly marbled and tender whereas, Yorkshire pork breeds which are commonly used commercial pork breeds yield lean meat comparatively drier compared to other breeds. In this regard, Migdał *et al.*[163] reported that for different breeds (Polish Landrace, Polish Large White, Duruc, Pietrain and Pulawska) shear force values of loin and ham meat increased with the progression of animal age and texture parameters such as hardness and chewiness were significantly affected. Another study on different pig breeds (Duroc, Landrace and Yorkshire) indicated that marbling scores showed significant differences for breed and sex on meat quality characteristics. In addition, pork with lower ultimate pH showed lower cooking loss, higher lightness and shear force irrespective of animal breeds.[164]

Considering the texture of lamb meat, Suffolk lamb is known for its meatiness and lean texture, while Dorset lamb has good balance of meat and fat resulting in tender meat whereas, Navajo-Churro which is a heritage breed have a slightly gamier flavour with lean hard texture. Additionally, Sañudo *et al.*[165] reported that the tenderness of lamb meat is influenced by animal breed, and the same holds for the widespread animals of beef breeds.[166] In this context[167] the Najdi sheep breed had higher ultimate pH and lower cooking loss than Awassi and Harri breeds. Awassi and Harri sheep had higher myofibril fragmentation index, longer sarcomere length and lower hardness and chewiness than the Najdi sheep.

For the texture of poultry meat, chicken raised for meat (broilers) possess tender meat with a relatively mild-flavour owing to their fast growth rate in contrast to heritage chicken breeds like Rhode Island Red or Plymouth Rock which have a firm texture and strong flavour that is attributed to the longer growth period and physical activity of these chicken breeds.[168] In this context, characteristics like 'chewiness', 'hardness' and 'springiness' have been found to be different between jidori-niku and chunky broiler with chewiness and hardness reported to be highest in chunky broiler *Pectoralis major* and followed by jidori-niku *Biceps femoris*, while the springiness values were highest in jidori-niku *Biceps femoris* muscles.[169]

Aroma and flavour characteristics

Aroma and flavour play a crucial role in enhancing the overall sensory experience of food products especially meat dishes and processed meat products which is mainly influenced by meat type, cooking method, seasonings and accompanying ingredients, chemical reactions during cooking as well as storage conditions after cooking or processing. In this context, Vasta and Priolo[170] reported that volatile compounds are influenced by an animal's dietary pattern and the presence of certain compounds makes it possible to identify meat based on its diet or even geographical origin for provenance.

The VOCs affect both aroma and flavour, which means that the flavour of the meat is also influenced by the dietary patterns of an animal. The distinct proportions and amounts of individual VOCs varied significantly among different meat animal species, opening new research avenues for characterizing animal species, authenticating meat species, and identifying anomalies for food fraud detection or meat provenance.[171] Thus, turkey had the highest total concentration of VOCs, while chicken exhibited the lowest. Among mammalian meats, veal and beef exhibited a higher total concentration of VOCs compared to pork.

The volatile profiling not only elucidates aromatic qualities of animal meat but also holds promise as a method for distinguishing and authenticating it. Accordingly, to Yang *et al.*[172] the five most-consumed meats like duck, chicken, beef, mutton and pork can be easily distinguished based on volatile flavour compounds profiles. Among these flavour compounds, including 2-pentyl furan, 2-butyl furan, 2-hexyl furan, 1-octen-3-ol and 1-octen-3-one, there was a positive correlation with duck meat, while methyl esters emerged as the primary discriminant biomarkers for beef. The study's conclusion highlighted that the phenomenon of volatile profiling for authentication was attributed to variations in fatty acid patterns across different meat species.[172]

Tibetan pork is favoured for its unique aroma originating from chemical reactions during cooking owing to characteristic precursors like fatty acids, free amino acids, reducing sugars and thiamine that are mainly linked to the pig's specific rearing method.[173] The study compared semi-free range and commercial (indoor) rearing systems reported that the pork had characteristic higher ω-3 PUFA, aromatic (phenylalanine), and S-containing (methionine and cysteine) free amino acids, higher thiamine and lower reducing sugars whereas, boiled Tibetan pork displayed elevated levels of heptanal, 4-heptenal, and 4-pentylbenzaldehyde compounds in comparison to commercial pork. Additionally, multivariate analysis unveiled precursors combination along volatiles possessed the discriminative potential for characterizing Tibetan pork.[173] Similarly, the identification of the feeding system in Iberian pigs (*montanera*, *cebo* extensive and *cebo*) can be carried out by studying the composition of volatile compounds in the subcutaneous fat of the pig, being the volatile compounds involved 2,2,2,4,6,6-pentamethyl-heptane, *m*-xylene, 2,4-dimethyl-heptane, 6-methyl-tridecane, 1-methoxy-2-propanol, isopropyl alcohol, *o*-xylene, 3-ethyl-2,2-dimethyl-oxirane, 2,6-dimethyl-undecane, 3-methyl-3-pentanol and limonene compounds.[174]

Chicken meat is rich in unsaturated fatty acids so making it particularly prone to lipid oxidation and the generation of VOCs. In this regard, Mancinelli *et al.*[175] reported that genotype and cooking method strongly influenced VOCs like aldehydes, alkadienes, alkenes, furans, amides, alcohols, and other compounds. Furthermore, it was observed that the slow-growing genotype exhibited a greater extent of VOCs production and *n*-3 fatty acid loss, while the medium-growing genotype showed more significant reduction in *n*-6 fatty acids. In contrast, the fast-growing genotype displayed minimal losses in antioxidants and PUFAs, resulting in the least production of VOCs.[175] Thus, it could contribute to the reason why consumers tend to prefer free-range chickens raised in superior welfare conditions due to their unique taste and flavour, which often command higher market prices compared to chickens raised intensively in barns.

It is important to note that the compounds responsible for meat flavour are pH-dependent and pH-sensitive and are particularly influenced by high final pH values in the carcass. Thus, Priolo *et al.*[175] identified at least ten flavour components of meat from grass-fed animals that were pH-dependent. Likewise, high final pH values in lamb meat are often associated with the production of off-flavours.

Another extrinsic factor that has been found to occasionally influence the organoleptic quality is the type of habitat the animal is exposed to or the feeding system. For example, the raising of pigs on straw is often associated with a superior bacon flavour[176] whereas raising them on sawdust bedding with an outdoor area, instead of a conventional slatted floor, can produce juicier pork meat with higher yellowness and hue values which also depends on muscle type.[177] Although, these effects have not been extensively studied, they underscore the potential impact of environmental conditions.[177,178] There is much uncertainty about the actual effects of habitat on quality, but it could be especially important to take this into account for PDO and PGI products since it can give a specific typicity to products. Similarly, the processing can also be important for PDO and PGI products as it can add a special flavour to it, for example, from bacteria, smoke, or air, which do not only give a product its typicity but might also be specific to manufacturing practices in a certain geographical area.[23]

CONCLUSIONS

An immensely significant facet of meat authentication within the contemporary meat industry revolves around the concept of provenance which encompasses a multifaceted interplay of numerous factors, including geographical origin, farm production systems or rearing methods, traceability, and authenticity systems. These elements converge to bestow a distinct sense of originality, reputation, and unique characteristics upon the meat product. The geographical origin and farm production system are extrinsic factors responsible for giving a product its typicity and directly influence the intrinsic meat composition and organoleptic quality characteristics whereas, traceability and authenticity are crucial to manage information transparently in the supply chain to ensure the product is indeed what it is supposed to be. This means that by assessing relevant meat composition and organoleptic quality characteristics, an indication of a meat product's provenance can be obtained. The most suitable provenance markers that can provide a strong link to extensive farming systems are trace elements and stable isotopes as they directly reflect the dietary composition (often geographical origin specific) of an animal. Essentially, the natural diet provides an indication of origin as certain plants and/or elements from the soil are characteristic of certain geographical regions that can also help to determine the meat animal's provenance for authenticity. Other markers that can be used to indicate diet or origin are plant biomarkers, fatty acid composition, volatile flavour compounds, pH, and the organoleptic characteristics, but their link is less evident, as they can also be influenced by extrinsic factors unrelated to provenance. To be able to trace these markers to the extrinsic factors that determine provenance, it is essential to have a good traceability system in place for the integrity of the supply chain. Animal species and breed are also important markers for provenance, and to prevent fraud of protected products it is important to take this into account as some products are only produced from specific breeds or species and will lose their typicity if these requirements are not met considering meat animals as well as processed meat products.

ACKNOWLEDGEMENTS

This work was financially supported by the mEATquality project (https://meatquality.eu/) which is funded by the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 101000344. Any opinions, findings and conclusions or recommendations expressed in this material are that of the authors and the European Commission does not accept any liability in this regard.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

1 Verbeke W, Pérez-Cueto FJ, de Barcellos MD, Krystallis A and Grunert KG, European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Sci* **84**:284–292 (2010).
2 Loughnan S, Bratanova B and Puvia E, The meat paradox: how are we able to love animals and love eating animals. *Mind* **1**:15–18 (2012).
3 Damez J-L and Clerjon S, Quantifying and predicting meat and meat products quality attributes using electromagnetic waves: an overview. *Meat Sci* **95**:879–896 (2013).
4 Ballin NZ, Authentication of meat and meat products. *Meat Sci* **86**: 577–587 (2010).
5 Teixeira A and Rodrigues S, Meat quality, brands and consumer trends, in *More than Beef, Pork and Chicken – The Production, Processing, and Quality Traits of Other Sources of Meat for Human Diet*. Springer, Berlin, pp. 21–29 (2019).
6 Becker T, Benner E and Glitsch K, Consumer perception of fresh meat quality in Germany. *Br Food J* **102**:246–266 (2000).
7 Khan KS, Kunz R, Kleijnen J and Antes G, Five steps to conducting a systematic review. *J R Soc Med* **96**:118–121 (2003).
8 Morgan K, Marsden T and Murdoch J, *Worlds of Food: Place, Power, and Provenance in the Food Chain*. Oxford University Press, USA (2006).
9 Monahan FJ, Schmidt O and Moloney AP, Meat provenance: authentication of geographical origin and dietary background of meat. *Meat Sci* **144**:2–14 (2018).
10 Olson JC and Jacoby J, Cue utilization in the quality perception process ACR Special *Volumes* (1972).
11 Poveda-Arteaga A, Krell J, Gibis M, Heinz V, Terjung N and Tomasevic I, Intrinsic and extrinsic factors affecting the color of fresh beef meat—comprehensive review. *Appl Sci* **13**:4382 (2023).
12 Dashdorj D, Amna T and Hwang I, Influence of specific taste-active components on meat flavor as affected by intrinsic and extrinsic factors: an overview. *Eur Food Res Technol* **241**:157–171 (2015).
13 Vergara H and Gallego L, Effect of electrical stunning on meat quality of lamb. *Meat Sci* **56**:345–349 (2000).
14 Joo S, Kim G, Hwang Y and Ryu Y, Control of fresh meat quality through manipulation of muscle fiber characteristics. *Meat Sci* **95**: 828–836 (2013).
15 Hocquette J-F, Richardson RI, Prache S, Medale F, Duffy G and Scollan ND, The future trends for research on quality and safety of animal products. *Ital J Anim Sci* **4**:49–72 (2005).
16 Acebron LB and Dopico DC, The importance of intrinsic and extrinsic cues to expected and experienced quality: an empirical application for beef. *Food Qual Prefer* **11**:229–238 (2000).
17 Caroprese M, Ciliberti MG, Marino R, Napolitano F, Braghieri A, Sevi A *et al.*, Effect of information on geographical origin, duration of transport and welfare condition on consumer's acceptance of lamb meat. *Sci Rep* **10**:9754 (2020).
18 Bernués A, Olaizola A and Corcoran K, Extrinsic attributes of red meat as indicators of quality in Europe: an application for market segmentation. *Food Qual Prefer* **14**:265–276 (2003).
19 Soon JM and Liu X, Chinese consumers' risk mitigating strategies against food fraud. *Food Control* **115**:107298 (2020).
20 Champredonde M, The source and market development of a premium product–beef from the Argentine pampas. *Meat Sci* **79**:534–540 (2008).
21 Nicoloso L, Crepaldi P, Mazza R, Ajmone-Marsan P and Negrini R, Recent advance in DNA-based traceability and authentication of livestock meat PDO and PGI products. *Recent Pat Food Nutr Agric* **5**:9–18 (2013).
22 Casabianca F, Sylvander B, Noël Y, Béranger C, Coulon JB and Giraud GFG, *LTerroir et typicité: Un enjeu de terminologie pour les indications géographiques*. VIe Congrès International Sur Les Terroirs Viticoles, (2006).
23 Franke BM, Gremaud G, Hadorn R and Kreuzer M, Geographic origin of meat—elements of an analytical approach to its authentication. *Eur Food Res Technol* **221**:493–503 (2005).
24 Webb EC and Erasmus LJ, The effect of production system and management practices on the quality of meat products from ruminant livestock. *S Afr J Anim Sci* **43**:413–423 (2013).
25 Wileman B, Thomson D, Reinhardt C and Renter D, Analysis of modern technologies commonly used in beef cattle production: conventional beef production versus nonconventional production using meta-analysis. *J Anim Sci* **87**:3418–3426 (2009).
26 Scollan ND, Dannenberger D, Nuernberg K, Richardson I, MacKintosh S, Hocquette J-F *et al.*, Enhancing the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Sci* **97**:384–394 (2014).
27 Woods VB and Fearon AM, Dietary sources of unsaturated fatty acids for animals and their transfer into meat, milk and eggs: a review. *Livest Sci* **126**:1–20 (2009).
28 Webb EC and O'neill H, The animal fat paradox and meat quality. *Meat Sci* **80**:28–36 (2008).
29 Wood J, Enser M, Fisher A, Nute G, Sheard P, Richardson R *et al.*, Fat deposition, fatty acid composition and meat quality: a review. *Meat Sci* **78**:343–358 (2008).
30 Martins J, Neves J, Freitas A and Tirapicos J, Rearing system and oleic acid supplementation effect on carcass and lipid characteristics of two muscles from an obese pig breed. *Animal* **9**:1721–1730 (2015).

31 Del Pulgar JS, Carrapiso A, Reina R, Biasioli F and García C, Effect of IGF-II genotype and pig rearing system on the final characteristics of dry-cured Iberian hams. *Meat Sci* **95**:586–592 (2013).
32 Zhang X, Wu X, He H, Zhu L and Tang X, Studies on DNA technology for pork traceability based on SNPs markers. *J Agric Sci Technol* **13**: 85–91 (2011).
33 Olsen P and Borit M, The components of a food traceability system. *Trends Food Sci Technol* **77**:143–149 (2018).
34 Wallace CA and Manning L, Food provenance: assuring product integrity and identity. *CABI Rev* (2020).
35 Hui YH, *Handbook of Meat and Meat Processing*. CRC Press, Boca Raton (2012).
36 Zhao J, Li A, Jin X and Pan L, Technologies in individual animal identification and meat products traceability. *Biotechnol Biotechnol Equip* **34**:48–57 (2020).
37 Carter J, Yates H and Tinggi U, A global survey of the stable isotope and chemical compositions of bottled and canned beers as a guide to authenticity. *Sci Justice* **55**:18–26 (2015).
38 Chiocchini F, Portarena S, Ciolfi M, Brugnoli E and Lauteri M, Isoscapes of carbon and oxygen stable isotope compositions in tracing authenticity and geographical origin of Italian extra-virgin olive oils. *Food Chem* **202**:291–301 (2016).
39 Stevenson R, Desrochers S and Hélie J-F, Stable and radiogenic isotopes as indicators of agri-food provenance: insights from artisanal cheeses from Quebec, Canada. *Int Dairy J* **49**:37–45 (2015).
40 Pearson S, May D, Leontidis G, Swainson M, Brewer S, Bidaut L *et al*., Are distributed ledger technologies the panacea for food traceability? *Glob Food Sec* **20**:145–149 (2019).
41 Galvez JF, Mejuto JC and Simal-Gandara J, Future challenges on the use of blockchain for food traceability analysis. *TrAC Trends Anal Chem* **107**:222–232 (2018).
42 Lebret B, Prache S, Berri C, Lefèvre F, Bauchart D, Picard B *et al*., Qualités des viandes: influences des caractéristiques des animaux et de leurs conditions d'élevage. *INRAE Prod Anim* **28**:151–168 (2015).
43 Jeremiah L, The influence of subcutaneous fat thickness and marbling on beef: palatability and consumer acceptability. *Food Res Int* **29**: 513–520 (1996).
44 Conanec A, Campo M, Richardson I, Ertbjerg P, Failla S, Panea B *et al*., Has breed any effect on beef sensory quality? *Livest Sci* **250**:104548 (2021).
45 Brugiapaglia A, Lussiana C and Destefanis G, Fatty acid profile and cholesterol content of beef at retail of Piemontese, Limousin and Friesian breeds. *Meat Sci* **96**:568–573 (2014).
46 Sañudo C, Sierra I, Olleta J, Martin L, Campo M, Santolaria P *et al*., Influence of weaning on carcass quality, fatty acid composition and meat quality in intensive lamb production systems. *Anim Sci* **66**:175–187 (1998).
47 Poklukar K, Čandek-Potokar M, Batorek Lukač N, Tomažin U and Škrlep M, Lipid deposition and metabolism in local and modern pig breeds: A review. *Animals* **10**:424 (2020).
48 Sirri F, Castellini C, Bianchi M, Petracci M, Meluzzi A and Franchini A, Effect of fast-, medium-and slow-growing strains on meat quality of chickens reared under the organic farming method. *Animal* **5**: 312–319 (2011).
49 Chabault M, Baéza E, Gigaud V, Chartrin P, Chapuis H, Boulay M *et al*., Analysis of a slow-growing line reveals wide genetic variability of carcass and meat quality-related traits. *BMC Genet* **13**:1–8 (2012).
50 Mueller LF, Balieiro JCC, Ferrinho AM, TdS M, da Silva Corte RRP, de Amorim TR *et al*., Gender status effect on carcass and meat quality traits of feedlot Angus× Nellore cattle. *Anim Sci J* **90**:1078–1089 (2019).
51 Miguel E, Blazquez B and Ruiz de Huidobro F, Liveweight and sex effects on instrumental meat quality of Rubia de El molar autochthonous ovine breed. *Animals* **11**:1323 (2021).
52 Nassu R, Tullio R, Berndt A, Francisco V, Diesel T and Alencar M, Effect of the genetic group, production system and sex on the meat quality and sensory traits of beef from crossbred animals. *Tropl Anim Health Prod* **49**:1289–1294 (2017).
53 Hailemariam A, Esatu W, Abegaz S, Urge M, Assefa G and Dessie T, Effect of genotype and sex on breast meat quality characteristics of different chickens. *J Agric Food Res* **10**:100423 (2022).
54 Cygan-Szczegielniak D and Bogucka J, Growth performance, carcass characteristics and meat quality of organically reared broiler chickens depending on sex. *Animals* **11**:3274 (2021).
55 Kopuzlu S, Esenbuga N, Onenc A, Macit M, Yanar M, Yuksel S *et al*., Effects of slaughter age and muscle type on meat quality characteristics of eastern Anatolian red bulls. *Arch Anim Breed* **61**: 497–504 (2018).
56 Żochowska-Kujawska J, Kotowicz M, Sobczak M, Lachowicz K and Wójcik J, Age-related changes in the carcass composition and meat quality of fallow deer (Dama dama L.). *Meat Sci* **147**:37–43 (2019).
57 Abhijith A, Warner RD, Ha M, Dunshea FR, Leury BJ, Zhang M *et al*., Effect of slaughter age and post-mortem days on meat quality of longissimus and semimembranosus muscles of Boer goats. *Meat Sci* **175**:108466 (2021).
58 Saccà E, Corazzin M, Bovolenta S and Piasentier E, Meat quality traits and the expression of tenderness-related genes in the loins of young goats at different ages. *Animal* **13**:2419–2428 (2019).
59 Webb E, Casey N and Simela L, Goat meat quality. *Small Rumin Res* **60**: 153–166 (2005).
60 Polidori P, Pucciarelli S, Cammertoni N, Polzonetti V and Vincenzetti S, The effects of slaughter age on carcass and meat quality of Fabrianese lambs. *Small Rumin Res* **155**:12–15 (2017).
61 Budimir K, Trombetta MF, Francioni M, Toderi M and D'Ottavio P, Slaughter performance and carcass and meat quality of Bergamasca light lambs according to slaughter age. *Small Rumin Res* **164**:1–7 (2018).
62 Ortiz A, Tejerina D, García-Torres S, González E, Morcillo JF and Mayoral AI, Effect of animal age at slaughter on the muscle fibres of longissimus thoracis and meat quality of fresh loin from Iberian× Duroc crossbred pig under two production systems. *Animals* **11**: 2143 (2021).
63 Guo Z, Chen X, Chen D, Li M, Yin J, Yu B *et al*., Effects of slaughter age on carcass traits and meat quality of crossbred (Duroc × Landrace × Yorkshire) finishing pigs. *Anim Biotechnol* **33**: 339–345 (2022).
64 Li J, Yang C, Peng H, Yin H, Wang Y, Hu Y *et al*., Effects of slaughter age on muscle characteristics and meat quality traits of Da-Heng meat type birds. *Animals* **10**:69 (2019).
65 Park S-Y, Byeon D-S, Kim G-W and Kim H-Y, Carcass and retail meat cuts quality properties of broiler chicken meat based on the slaughter age. *J Ani Sci Technol* **63**:180–190 (2021).
66 Hollung K, Grove H, Færgestad EM, Sidhu MS and Berg P, Comparison of muscle proteome profiles in pure breeds of Norwegian Landrace and Duroc at three different ages. *Meat Science* **81**:487–492 (2009).
67 Prache S, Lebret B, Baéza E, Martin B, Gautron J, Feidt C *et al*., Quality and authentication of organic animal products in Europe. *Animal* **16**: 100405 (2022).
68 Ponnampalam EN, Mann NJ and Sinclair AJ, Effect of feeding systems on omega-3 fatty acids, conjugated linoleic acid and trans fatty acids in Australian beef cuts: potential impact on human health. *Asia Pac J Clin Nutr* **15**:21–29 (2006).
69 Mekki I, Camin F, Perini M, Smeti S, Hajji H, Mahouachi M *et al*., Differentiating the geographical origin of Tunisian indigenous lamb using stable isotope ratio and fatty acid content. *J Food Compos Anal* **53**: 40–48 (2016).
70 Dalle Zotte A, Gleeson E, Franco D, Cullere M and Lorenzo JM, Proximate composition, amino acid profile, and oxidative stability of slow-growing indigenous chickens compared with commercial broiler chickens. *Foods* **9**:546 (2020).
71 Wang F, Gao Y, Wang H, Xi B, He X, Yang X *et al*., Analysis of volatile compounds and flavor fingerprint in Jingyuan lamb of different ages using gas chromatography–ion mobility spectrometry (GC–IMS). *Meat Sci* **175**:108449 (2021).
72 Lizhuang H, Xiang Y, Huang Y, Hocquette J-F, Bryant RH, Wang X *et al*., Using mineral elements to authenticate the geographical origin of Yak Meat. *Kafkas Univ Vet Fak Derg* **25**:93–98 (2019).
73 Dehelean A, Feher I, Romulus P, Magdas DA, Covaciu F-D, Kasza AM *et al*., Influence of geographical origin on isotopic and elemental compositions of pork meat. *Foods* **12**:4271 (2023).
74 Wood J and Enser M, Manipulating the fatty acid composition of meat to improve nutritional value and meat quality, in *New Aspects of Meat Quality* Technology and Nutrition. Woodhead Publishing, Cambridge, pp. 501–535 (2017).
75 Nogoy KMC, Sun B, Shin S, Lee Y, Li XZ, Choi SH *et al*., Fatty acid composition of grain-and grass-fed beef and their nutritional value and health implication. *Food Sci Anim Res* **42**:18–33 (2022).
76 Descalzo AM, Insani E, Biolatto A, Sancho A, García P, Pensel N *et al*., Influence of pasture or grain-based diets supplemented with

vitamin E on antioxidant/oxidative balance of Argentine beef. *Meat Sci* **70**:35–44 (2005).
77 Revilla I, Plaza J and Palacios C, The effect of grazing level and ageing time on the physicochemical and sensory characteristics of beef meat in organic and conventional production. *Animals* **11**:635 (2021).
78 Bontempo L, Perini M, Pianezze S, Horacek M, Roßmann A, Kelly SD *et al*., Characterization of beef coming from different European countries through stable isotope (H, C, N, and S) ratio analysis. *Molecules* **28**:2856 (2023).
79 Hernández-Jiménez M, González-Martín MI, Martínez-Martín I, Revilla I and Vivar-Quintana AM, Carbon stable isotopes, fatty acids and the use of NIRS to differentiate IBERIAN pigs. *Meat Sci* **182**: 108619 (2021).
80 Razminowicz R, Kreuzer M, Lerch K and Scheeder M, Quality of beef from grass-based production systems compared with beef from intensive production systems In *Land Use Systems in Grassland Dominated Regions Proceedings of the 20th General Meeting of the European Grassland Federation, Luzern, Switzerland, 21–24 June 2004*, Ed. vdf Hochschulverlag AG an der ETH Zurich, pp. 1151–1153 (2004).
81 Camin F, Bontempo L, Perini M and Piasentier E, Stable isotope ratio analysis for assessing the authenticity of food of animal origin. *Compr Rev Food Sci Food Saf* **15**:868–877 (2016).
82 Debut M, Berri C, Baéza E, Sellier N, Arnould C, Guemene D *et al*., Variation of chicken technological meat quality in relation to genotype and preslaughter stress conditions. *Poult Sci* **82**:1829–1838 (2003).
83 Kumar M, Ratwan P, Dahiya S and Nehra AK, Climate change and heat stress: impact on production, reproduction and growth performance of poultry and its mitigation using genetic strategies. *J Therm Biol* **97**:102867 (2021).
84 Faure J, Lebret B, Bonhomme N, Ecolan P, Kouba M and Lefaucheur L, Metabolic adaptation of two pig muscles to cold rearing conditions. *J Anim Sci* **91**:1893–1906 (2013).
85 Alcalde M, Suárez M, Rodero E, Álvarez R, Sáez M and Martínez T, Effects of farm management practices and transport duration on stress response and meat quality traits of suckling goat kids. *Animal* **11**:1626–1635 (2017).
86 Prunier A and Bonneau M, Y a-t-il des alternatives à la castration chirurgicale des porcelets? *INRAE Prod Anim* **19**:347–356 (2006).
87 Destefanis G, Brugiapaglia A, Barge M and Lazzaroni C, Effect of castration on meat quality in Piemontese cattle. *Meat Sci* **64**:215–218 (2003).
88 Santos-Filho J, Morais S, Rondina D, Beserra F, Neiva J and Magalhaes E, Effect of cashew nut supplemented diet, castration, and time of storage on fatty acid composition and cholesterol content of goat meat. *Small Rumin Res* **57**:51–56 (2005).
89 Martins JM, Charneca R, Garrido N, Albuquerque A, Jerónimo E, Guerreiro O *et al*., Influence of sex on meat and fat quality from heavy Alentejano pigs finished outdoors on commercial and high fiber diets. *Animals* **13**:3099 (2023).
90 Gispert M, Oliver MÀ, Velarde A, Suarez P, Pérez J and i Furnols MF, Carcass and meat quality characteristics of immunocastrated male, surgically castrated male, entire male and female pigs. *Meat Sci* **85**: 664–670 (2010).
91 Magowan E, Moss B, Fearom A and Ball E, Effect of breed, finish weight and sex on pork meat and eating quality and fatty acid profile. *Agri-Food and Biosci Institute, UK* **28**:1–34 (2011).
92 Kim JA, Cho ES, Jeong YD, Choi YH, Kim YS, Woo Choi J *et al*., The effects of breed and gender on meat quality of Duroc, Pietrain, and their crossbred. *J Anim Sci Technol* **62**:409–419 (2020).
93 Szyndler-Nędza M, Świątkiewicz M, Migdał Ł and Migdał W, The quality and health-promoting value of meat from pigs of the native breed as the effect of extensive feeding with acorns. *Animals* **11**: 789 (2021).
94 Cabrera M, Ramos A, Saadoun A and Brito G, Selenium, copper, zinc, iron and manganese content of seven meat cuts from Hereford and Braford steers fed pasture in Uruguay. *Meat Sci* **84**:518–528 (2010).
95 Médale F, Lefèvre F and Corraze G, Qualité nutritionnelle et diététique des poissons: Constituants de la chair et facteurs de variations: Poissons. *Cahiers de Nutrition et de Diététique* **38**:37–44 (2003).
96 Mourot J and Lebret B, Modulation de la qualité de la viande de porc par l'alimentation. *INRAE Prod Anim* **22**:33–40 (2009).
97 Franke BM, Haldimann M, Reimann J, Baumer B, Gremaud G, Hadorn R *et al*., Indications for the applicability of element signature analysis for the determination of the geographic origin of dried beef and poultry meat. *Eur Food Res Technol* **225**:501–509 (2007).
98 Rayman MP, The importance of selenium to human health. *Lancet* **356**:233–241 (2000).
99 Shen W-H, The plant E2F–Rb pathway and epigenetic control. *Trends Plant Sci* **7**:505–511 (2002).
100 Heaton K, Kelly SD, Hoogewerff J and Woolfe M, Verifying the geographical origin of beef: the application of multi-element isotope and trace element analysis. *Food Chem* **107**:506–515 (2008).
101 Williamson C, Foster R, Stanner S and Buttriss J, Red meat in the diet. *Nutr Bull* **30**:323–355 (2005).
102 Purchas R and Zou M, Composition and quality differences between the longissimus and infraspinatus muscles for several groups of pasture-finished cattle. *Meat Sci* **80**:470–479 (2008).
103 Kim JS, Hwang IM, Lee GH, Park YM, Choi JY, Jamila N *et al*., Geographical origin authentication of pork using multi-element and multivariate data analyses. *Meat Sci* **123**:13–20 (2017).
104 Di Bella C, Traina A, Giosuè C, Carpintieri D, Lo Dico GM, Bellante A *et al*., Heavy metals and PAHs in meat, milk, and seafood from Augusta area (Southern Italy): contamination levels, dietary intake, and human exposure assessment. *Front Public Health* **8**: 273 (2020).
105 Aljazzar A, El-Ghareeb WR, Darwish WS, Abdel-Raheem SM and Ibrahim AM, Content of total aflatoxin, lead, and cadmium in the bovine meat and edible offal: study of their human dietary intake, health risk assessment, and molecular biomarkers. *Environ Sci Pollut Res* **28**:61225–61234 (2021).
106 Bortey-Sam N, Nakayama SM, Ikenaka Y, Akoto O, Baidoo E, Yohannes YB *et al*., Human health risks from metals and metalloid via consumption of food animals near gold mines in Tarkwa, Ghana: estimation of the daily intakes and target hazard quotients (THQs). *Ecotoxicol Environ Saf* **111**:160–167 (2015).
107 Ogbomida ET, Nakayama SM, Bortey-Sam N, Oroszlany B, Tongo I, Enuneku AA *et al*., Accumulation patterns and risk assessment of metals and metalloid in muscle and offal of free-range chickens, cattle and goat in Benin City, Nigeria. *Ecotoxicol Environ Saf* **151**:98–108 (2018).
108 Darwish WS, Ikenaka Y, Morshdy AE, Eldesoky KI, Nakayama S, Mizukawa H *et al*., β-Carotene and retinol contents in the meat of herbivorous ungulates with a special reference to their public health importance. *J Vet Med Sci* **78**:351–354 (2016).
109 Khan MZ, Perween S, Gabol K, Khan IS, Baig N, Kanwal R *et al*., Concentrations of heavy metals in liver, meat and blood of poultry chicken Gallus domesticus in three selected cities of Pakistan. *Can J Pure Appl Sci* **9**:3313–3324 (2015).
110 Han JL, Pan XD and Chen Q, Distribution and safety assessment of heavy metals in fresh meat from Zhejiang, China. *Sci Rep* **12**:3241 (2022).
111 Chessa G, Calaresu G, Ledda G, Testa M and Orrù A, Lead, zinc and cadmium in biological tissues of sheep bred in a polluted area, in *Trace Metals in the Environment*. Elsevier, London, pp. 479–483 (2000).
112 Rossman N, Zlotnik VA, Rowe C and Szilagyi J, Vadose zone lag time and potential 21st century climate change effects on spatially distributed groundwater recharge in the semi-arid Nebraska Sand Hills. *J Hydrol* **519**:656–669 (2014).
113 Piasentier E, Valusso R, Camin F and Versini G, Stable isotope ratio analysis for authentication of lamb meat. *Meat Sci* **64**:239–247 (2003).
114 Guo B, Wei Y, Pan J and Li Y, Stable C and N isotope ratio analysis for regional geographical traceability of cattle in China. *Food Chem* **118**: 915–920 (2010).
115 Yoneyama T, Ito O and Engelaar WM, Uptake, metabolism and distribution of nitrogen in crop plants traced by enriched and natural 15 N: Progress over the last 30 years. *Phytochem Rev* **2**:121–132 (2003).
116 Versini A, Zeller B, Derrien D, Mazoumbou J-C, Mareschal L, Saint-André L *et al*., The role of harvest residues to sustain tree growth and soil nitrogen stocks in a tropical Eucalyptus plantation. *Plant and Soil* **376**:245–260 (2014).
117 Cormie AB and Schwarcz HP, Effects of climate on deer bone δ15N and δ13C: lack of precipitation effects on δ15N for animals consuming low amounts of C4 plants. *Geochim Cosmochim Acta* **60**:4161–4166 (1996).
118 Heaton TH, Spiro B and Robertson SMC, Potential canopy influences on the isotopic composition of nitrogen and sulphur in atmospheric deposition. *Oecologia* **109**:600–607 (1997).

119 Bowen GJ, Ehleringer JR, Chesson LA, Stange E and Cerling TE, Stable isotope ratios of tap water in the contiguous United States. *Water Resour Res* **43**:W03419 (2007).
120 Osorio MT, Moloney AP, Schmidt O and Monahan FJ, Multielement isotope analysis of bovine muscle for determination of international geographical origin of meat. *J Agric Food Chem* **59**:3285–3294 (2011).
121 Boner M and Förstel H, Stable isotope variation as a tool to trace the authenticity of beef. *Anal Bioanal Chem* **378**:301–310 (2004).
122 Erasmus SW, *The Authentication of Regionally Unique South African Lamb, Ed*. Stellenbosch University, Stellenbosch (2017).
123 Renou J-P, Bielicki G, Deponge C, Gachon P, Micol D and Ritz P, Characterization of animal products according to geographic origin and feeding diet using nuclear magnetic resonance and isotope ratio mass spectrometry. Part II: Beef meat. *Food Chem* **86**:251–256 (2004).
124 Camin F, Bontempo L, Heinrich K, Horacek M, Kelly S, Schlicht C *et al*., Multi-element (H, C, N, S) stable isotope characteristics of lamb meat from different European regions. *Anal Bioanal Chem* **389**:309–320 (2007).
125 Nie J, Shao S, Xia W, Liu Z, Yu C, Li R *et al*., Stable isotopes verify geographical origin of yak meat from Qinghai-Tibet plateau. *Meat Sci* **165**:108113 (2020).
126 Rees G, Kelly SD, Cairns P, Ueckermann H, Hoelzl S, Rossmann A *et al*., Verifying the geographical origin of poultry: the application of stable isotope and trace element (SITE) analysis. *Food Control* **67**:144–154 (2016).
127 González-Martín MI, Escuredo O, Hernández-Jiménez M, Revilla I, Vivar-Quintana AM, Martínez-Martín I *et al*., Prediction of stable isotopes and fatty acids in subcutaneous fat of Iberian pigs by means of NIR: a comparison between benchtop and portable systems. *Talanta* **224**:121817 (2021).
128 Beard BL and Johnson CM, Strontium isotope composition of skeletal material can determine the birth place and geographic mobility of humans and animals. *J Forensic Sci* **45**:1049–1061 (2000).
129 Shin W-J, Ryu J-S, Kim R-H and Min J-S, First strontium isotope map of groundwater in South Korea: applications for identifying the geographical origin. *Geosci J* **25**:173–181 (2021).
130 Rummel S, Dekant C, Hölzl S, Kelly S, Baxter M, Marigheto N *et al*., Sr isotope measurements in beef—analytical challenge and first results. *Anal Bioanal Chem* **402**:2837–2848 (2012).
131 Franke BM, Koslitz S, Micaux F, Piantini U, Maury V, Pfammatter E *et al*., Tracing the geographic origin of poultry meat and dried beef with oxygen and strontium isotope ratios. *Eur Food Res Technol* **226**: 761–769 (2008).
132 Shin WJ, Choi SH, Ryu JS, Song BY, Song JH, Park S *et al*., Discrimination of the geographic origin of pork using multi-isotopes and statistical analysis. *Rapid Commun Mass Spectrom* **32**:1843–1850 (2018).
133 Prache S, Cornu A, Berdagué J-L and Priolo A, Traceability of animal feeding diet in the meat and milk of small ruminants. *Small Rumin Res* **59**:157–168 (2005).
134 Serrano E, Cornu A, Kondjoyan N, Agabriel J and Micol D, Traceability of grass feeding in beef: terpenes, 2, 3-octanedione and skatole accumulation in adipose tissue of young bulls. *Animal* **5**:641–649 (2011).
135 Bou R, Codony R, Tres A, Decker EA and Guardiola F, Dietary strategies to improve nutritional value, oxidative stability, and sensory properties of poultry products. *Crit Rev Food Sci Nutr* **49**:800–822 (2009).
136 Prache S, Priolo A and Grolier P, Persistence of carotenoid pigments in the blood of concentrate-finished grazing sheep: its significance for the traceability of grass-feeding. *J Anim Sci* **81**:360–367 (2003).
137 Priolo A, Micol D and Agabriel J, Effects of grass feeding systems on ruminant meat colour and flavour: A review. *Anim Res* **50**:185–200 (2001).
138 Röhrle F, Moloney A, Osorio M, Luciano G, Priolo A, Caplan P *et al*., Carotenoid, colour and reflectance measurements in bovine adipose tissue to discriminate between beef from different feeding systems. *Meat Sci* **88**:347–353 (2011).
139 Sivadier G, Ratel J and Engel E, Persistence of pasture feeding volatile biomarkers in lamb fats. *Food Chem* **118**:418–425 (2010).
140 Álvarez R, Vicario I, Meléndez-Martínez A and Alcalde M, Effect of different carotenoid-containing diets on the vitamin a levels and colour parameters in Iberian pigs' tissues: utility as biomarkers of traceability. *Meat Sci* **98**:187–192 (2014).
141 Montowska M and Pospiech E, Is authentication of regional and traditional food made of meat possible? *Crit Rev Food Sci Nutr* **52**:475–487 (2012).
142 Boughalmi A and Araba A, Effect of feeding management from grass to concentrate feed on growth, carcass characteristics, meat quality and fatty acid profile of Timahdite lamb breed. *Small Rumin Res* **144**: 158–163 (2016).
143 Patino H, Medeiros F, Pereira C, Swanson K and McManus C, Productive performance, meat quality and fatty acid profile of steers finished in confinement or supplemented at pasture. *Animal* **9**:966–972 (2015).
144 Lindqvist H, Nadeau E and Jensen SK, Alpha-tocopherol and β-carotene in legume–grass mixtures as influenced by wilting, ensiling and type of silage additive. *Grass Forage Sci* **67**:119–128 (2012).
145 Sokolova I, Mitochondrial adaptations to variable environments and their role in animals' stress tolerance. *Integr Comp Biol* **58**:519–531 (2018).
146 Schwartzkopf-Genswein K, Faucitano L, Dadgar S, Shand P, González L and Crowe T, Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: a review. *Meat Sci* **92**:227–243 (2012).
147 García-Torres S, Cabeza de Vaca M, Tejerina D, Romero-Fernández MP, Ortiz A, Franco D *et al*., Assessment of stress by serum biomarkers in calves and their relationship to ultimate pH as an indicator of meat quality. *Animals* **11**:2291 (2021).
148 Pajor F, Antonovics B, Bodnár Á, Egerszegi I, Bárdos L and Póti P, Comparison of temperament and certain meat production traits of Ratska breeds and colour varieties. *Magyar Állatorvosok Lapja* **139**: 287–294 (2017).
149 Ma X, Wang L, Shi Z, Chen W, Yang X, Hu Y *et al*., Mechanism of continuous high temperature affecting growth performance, meat quality, and muscle biochemical properties of finishing pigs. *Genes Nutr* **14**:1–15 (2019).
150 Montilla SIR, Johnson TP, Pearce SC, Gardan-Salmon D, Gabler NK, Ross JW *et al*., Heat stress causes oxidative stress but not inflammatory signaling in porcine skeletal muscle. *Temperature* **1**:42–50 (2014).
151 Pardo Z, Fernández-Fígares I, Lachica M, Lara L, Nieto R and Seiquer I, Impact of heat stress on meat quality and antioxidant markers in Iberian pigs. *Antioxidants* **10**:1911 (2021).
152 Purslow PP, Gagaoua M and Warner RD, Insights on meat quality from combining traditional studies and proteomics. *Meat Sci* **174**:108423 (2021).
153 Gómez JFM, Antonelo DS, Beline M, Pavan B, Bambil DB, Fantinato-Neto P *et al*., Feeding strategies impact animal growth and beef color and tenderness. *Meat Sci* **183**:108599 (2022).
154 Bureš D and Bartoň L, Growth performance, carcass traits and meat quality of bulls and heifers slaughtered at different ages. *Czeh J Anim Sci* **57**:34–43 (2012).
155 Prache S, Martin B, Noziere P, Engel E, Besle J-M, Ferlay A *et al*., Authentification de l'alimentation des ruminants à partir de la composition de leurs produits et tissus. *INRAE Prod Anim* **20**:295–308 (2007).
156 Fanatico A, Cavitt L, Pillai P, Emmert J and Owens C, Evaluation of slower-growing broiler genotypes grown with and without outdoor access: meat quality. *Poult Sci* **84**:1785–1790 (2005).
157 Sarica M, Ocak N, Turhan S, Kop C and Yamak U, Evaluation of meat quality from 3 Turkey genotypes reared with or without outdoor access. *Poult Sci* **90**:1313–1323 (2011).
158 Dunne P, Monahan F, O'mara F and Moloney A, Colour of bovine subcutaneous adipose tissue: a review of contributory factors, associations with carcass and meat quality and its potential utility in authentication of dietary history. *Meat Sci* **81**:28–45 (2009).
159 Dannenberger D, Nuernberg K, Nuernberg G and Ender K, Carcass- and meat quality of pasture vs concentrate fed German Simmental and German Holstein bulls. *Arch Anim Breed* **49**:315–328 (2006).
160 Nuernberg K, Dannenberger D, Nuernberg G, Ender K, Voigt J, Scollan ND *et al*., Effect of a grass-based and a concentrate feeding system on meat quality characteristics and fatty acid composition of longissimus muscle in different cattle breeds. *Livest Prod Sci* **94**: 137–147 (2005).
161 Resconi V, Campo M, Font i Furnols M, Montossi F and Sañudo C, Sensory quality of beef from different finishing diets. *Meat Sci* **86**:865–869 (2010).
162 Oury M-P, Picard B, Istasse L, Micol D and Dumont R, Mode de conduite en élevage et tendreté de la viande bovine. *INRAE Prod Anim* **20**:309–326 (2007).
163 Migdał W, Różycki M, Mucha A, Tyra M, Natonek-Wiśniewska M, Walczycka M *et al*., Meat texture profile and cutting strength

analyses of pork depending on breed and age. *Annal Anim Sci* **20**: 677–692 (2020).
164 Li Y, Cabling MM, Kang H, Kim T, Yeom S, Sohn Y *et al.*, Comparison and correlation analysis of different swine breeds meat quality. *Asian Australas J Anim Sci* **26**:905–910 (2013).
165 Sañudo C, Alfonso M, Sanchez A, Berge P, Dransfield E, Zygoyiannis D *et al.*, Meat texture of lambs from different European production systems. *Aust J Agr Res* **54**:551–560 (2003).
166 Chambaz A, Scheeder M, Kreuzer M and Dufey P-A, Meat quality of Angus, Simmental, Charolais and Limousin steers compared at the same intramuscular fat content. *Meat Sci* **63**:491–500 (2003).
167 Suliman G, Al-Owaimer A, El-Waziry A, Hussein E, Abuelfatah K and Swelum A, A comparative study of sheep breeds: fattening performance, carcass characteristics, meat chemical composition and quality attributes. *Front Vet Sci* **8**:647192 (2021).
168 Grashorn M and Serini C, Quality of chicken meat from conventional and organic production In *Proceedings of the XII European Poultry Conference*, Citeseer, pp 10–14 (2006).
169 Sasaki K, Motoyama M, Tagawa Y, Akama K, Hayashi T, Narita T *et al.*, Qualitative and quantitative comparisons of texture characteristics between broiler and jidori-niku, Japanese indigenous chicken meat, assessed by a trained panel. *J Poult Sci* **54**:87–96 (2017).
170 Vasta V and Priolo A, Ruminant fat volatiles as affected by diet. A review. *Meat Sci* **73**:218–228 (2006).
171 Ni Q, Khomenko I, Gallo L, Biasioli F and Bittante G, Rapid profiling of the volatilome of cooked meat by PTR-ToF-MS: Characterization of chicken, turkey, pork, veal and beef meat. *Foods* **9**:1776 (2020).
172 Yang Y, Li J, Xing J, Xing W, Tang C, Rao Z *et al.*, Untargeted profiling and differentiation of volatiles in varieties of meat using GC Orbitrap MS. *Foods* **11**:3997 (2022).
173 Zhao L, Erasmus S, Yang P, Huang F, Zhang C and van Ruth S, Establishing the relations of characteristic aroma precursors and volatile compounds for authenticating Tibetan pork. *Food Chem* **427**: 136717 (2023).
174 Narváez-Rivas M, Pablos F, Jurado JM and León-Camacho M, Authentication of fattening diet of Iberian pigs according to their volatile compounds profile from raw subcutaneous fat. *Anal Bioanal Chem* **399**:2115–2122 (2011).
175 Mancinelli AC, Silletti E, Mattioli S, Dal Bosco A, Sebastiani B, Menchetti L *et al.*, Fatty acid profile, oxidative status, and content of volatile organic compounds in raw and cooked meat of different chicken strains. *Poult Sci* **100**:1273–1282 (2021).
176 Maw S, Fowler V, Hamilton M and Petchey A, Effect of husbandry and housing of pigs on the organoleptic properties of bacon. *Livest Prod Sci* **68**:119–130 (2001).
177 Lebret B, Prunier A, Bonhomme N, Foury A, Mormède P and Dourmad J-Y, Physiological traits and meat quality of pigs as affected by genotype and housing system. *Meat Sci* **88**:14–22 (2011).
178 Averós X, Brossard L, Dourmad J-Y, de Greef KH, Edge HL, Edwards SA *et al.*, A meta-analysis of the combined effect of housing and environmental enrichment characteristics on the behaviour and performance of pigs. *Appl Anim Behav Sci.* **127**:73–85 (2010).

