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REVIEW ARTICLE

Levers to reconcile cured meat products with health concerns and culinary heritage

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ABSTRACT
The preservation of meat by methods such as salting, drying and/or smoking is ancestral and is linked to culinary heritage, through the geographical anchorage. These features and the associated know-how are the basis for the construction and recognition of quality signs that guarantee and certify certain commitments. Nevertheless, current scientific evidence shows that the consumption or particularly the over-consumption of certain meat products is conducive to the development of health problems. This raises the question of how to make these foods healthier without betraying their identity. This review addresses the possible levers.

HIGHLIGHTS

- Production of cured meats follows geographical or processing specifications.
- There is little room for manoeuvre in maintaining familiar tastes and flavours, but innovation exists.
- Different technological breakthroughs could limit salt intake for the consumer.

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Introduction

From the Neolithic period onwards, people settled down and began to domesticate livestock. This offered an opportunity to discover the possibility of preserving food, reducing sanitary risks and enhancing sensorial properties. Cooking, sometimes combined with other types of food processing, has also made it possible to make certain plants edible. Birlouez (2019) reports the case of bitter cassava which, without proper processing, is highly toxic due to the presence of cyanogenic glycosides which, when the cells are damaged, release hydrogen cyanide. For perishable food, such as meat and fish flesh, in addition to heat treatment, processes to reduce water activity have been in use for several thousand years. The preservation of meat, notably pig meat by salting, drying and smoking, is generally geographically anchored as a local tradition that has been carried on since antiquity. And there are a significant number of processed meat products. These features and the associated know-how are registered on a European platform (https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/geographical-indications-register/) However, these processes for preserving and storing meat products are singled out for criticism. Indeed, from a nutritional point of view, excessive dietary salt intake is associated with severe medical conditions such as cardiovascular disease (Wang et al. 2020). Moreover, often used nitrite and nitrate salts are considered hazardous to health, so much so that the IARC concluded that: 'Processed meat was classified as carcinogenic to humans (Group 1), based on sufficient evidence in humans that the consumption of processed meat causes colorectal cancer' (IARC 2018). Cured meats are an integral part of our diet, as they are appreciated and strongly associated with a cultural and culinary heritage. The current challenge is to reconcile tradition, cultural and culinary heritage with health concerns. In this sense, this review seeks to explore what the levers of innovation might be.

Regulatory levers

In the agri-food sector, the development and promotion of the quality of food can be achieved through the construction and recognition of quality signs that guarantee and certify certain commitments. European

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regulations on quality signs refer to 'quality terms'. These terms can be applied to products with a characteristic or a production/processing property that applies to areas with specific characteristics. Therefore, EU quality policies have been implemented to protect the names of specific products so as to promote their unique characteristics, linked to their geographical origin as well as traditional know-how. Moreover, European regulation (EU) No. 1151/2012 refers to the quality term 'mountain product' and allows member states to have additional national quality terms. In this respect, the French regulations provide for the terms 'mountain', 'farm' and 'high environmental value'. For the moment, certification of the latter has been mainly developed in the wine sector. So, the main labels or quality schemes in Europe are Organic, Protected Designation of Origin (PDO), Protected Geographical Indication (PGI), and Traditional Speciality Guaranteed (TSG). According to the type of label, the specifications focus on the method of production, the geographical origin, the farming method or even the recipe (TSG). The geographical indications system protects the names of products that originate from specific regions and have specific qualities or enjoy a reputation linked to the area of production. The differences between PDO and PGI are linked primarily to how much of the product's raw materials must come from the area, or how much of the production process has to take place within the specific region (see https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/geographical-indications-register/).

Protected Designation of Origin - PDO refers to a typical product in which all stages of production, manufacture and processing take place in the defined geographical area, and whose typicality is based on the terroir (interactions between the geographical, physical and biological environment and human factors).

Protected Geographical Indication - PGI refers to a typical product of which at least one stage in the production, manufacture and processing takes place in the defined geographical area, giving it a recognisable quality, reputation or other characteristic. Traditional Speciality Guaranteed - TSG refers to a traditional product, based on a traditional composition, manufacturing or processing method.

Organic Agriculture refers to products produced according to environmentally friendly practices, respecting biodiversity, natural resources and animal welfare, corresponding to an agroecological approach. Therefore, the link to defined geographical area, tradition or processing is more extensive. As a result, the present article will focus on the first three labels defined above.

In previous work, 3 types of dry-cured ham (Prosciutto di Parma PDO, Jambon de Bayonne PGI and Jamón Serrano TSG) were compared in order to highlight the parameters that distinguish them (M Raulet, personal communication, https://hal.science/hal-02986866v1). First of all, a property they share is image quality. Indeed, official signs guarantee the credibility and reliability of certified products, and thus ensure their recognition by consumers. Table 1 summarises the points of convergence and differentiation between the 3 dry-cured hams studied. The PDO dry-cured ham has the main constraints, while for TSG one less mandatory specification is required.

PDO and PGI are considered to be geographic indications which are largely protected for reasons of the connection between place and product; human factors, know-how and traditional methods; and cultural heritage. The role of culture, traditions or history in the definitions is promoted, but there is little research that specifically discusses how these narratives of culture and history are displayed on these labels (Castelló, 2020). Tables 2 and 3 show the range of delicatessen products in Europe with different quality schemes. In the European Union, dry-cured hams are labelled as PDO, PGI or TSG depending on the specific region and particular regulations. Italy has extensive food and agriculture resources, as well as the highest number of PDO and PGI labelled products in Europe (Velcovska and Sadilek 2014). Meat products account for about 16% of Italian PDOs/PGIs; this product category also includes dry-cured hams, which represent 7% of Italian PDOs. In this context, Parma, San Daniele and Toscano hams are the three most important

Table 1. Comparison of specifications for 3 dry-cured hams (prociutto di Parma AOP; Jambon de bayone PGI ; jamon Serrano TSG).

Step	Criteria	PDO	PGI	TSG
Animal	Genetic and breed	Mandatory filled	Non filled	Non filled
	Gender	Mandatory filled	Mandatory filled	Non filled
	Origin	Mandatory filled	Mandatory filled	Non filled
Rearing	Feed	Mandatory filled	Mandatory filled	Non filled
	Type of feeding	Mandatory filled	Non filled	Non filled
Slaughter	Animal Transportation	Mandatory filled	Non filled	Mandatory filled
	Slaughter	Non filled	Mandatory filled	Mandatory filled
	Carcass properties	Mandatory filled	Mandatory filled	Non filled
Processing	Geographical area	Mandatory filled	Mandatory filled	Non filled
	Fresh meat properties	Mandatory filled	Mandatory filled	Mandatory filled
	Additives	Mandatory filled	Mandatory filled	Mandatory filled
	Processing characteristics	Mandatory filled	Mandatory filled	Mandatory filled
Packaging	Characteristics of the final product	Mandatory filled	Mandatory filled	Mandatory filled

Legend
- (green) Criterion mandatory filled
- (grey) Criterion non filled

Table 2. List of Protected Geographical Indication (PGI) meat products (cooked, salted, smoked) registered on the EU platform.

Country	PGI Meat products (cooked, salted, smoked, etc.)
Austria	Tiroler Speck
	Gailtaler Speck
Belgium	Jambon d'Ardenne
	Potjesvlees uit de Westhoek
	Saucisson d'Ardenne / Collier d'Ardenne / Pipe d'Ardenne
Bulgaria	Gornooryahovski sudzhuk
Croatia	Krčki pršut
	Baranjski kulen
	Slavonski kulen / Slavonski kulin
	Dalmatinski pršut
	Drniški pršut
	Međimursko meso 'z tiblice
	Dalmatinska pečenica
	Dalmatinska pancetta
	Samoborska češnjovka / Samoborska češnofka
Cyprus	Pafitiko Loukaniko
	Hiromeri Pitsilias
	Lountza Pitsilias
	Loukaniko Pitsilias
Finland	Aito saunapalvikinkku / Äkta basturökt skinka
France	Boudin blanc de Rethel
	Jambon sec des Ardennes / Noix de Jambon sec des Ardennes
	Jambon de Bayonne
	Canard à foie gras du Sud-Ouest
	Jambon de l'Ardèche
	Saucisson de l'Ardèche
	Saucisse de Morteau/ Jésus de Morteau
	Saucisse de Montbéliard
	Rillettes de Tours
	Pâté de Campagne Breton
	Jambon de Vendée
	Jambon de Lacaune
	Saucisson sec d'Auvergne/ Saucisse sèche d'Auvergne
	Jambon d'Auvergne
	Saucisson de Lacaune/ Saucisse de Lacaune
Germany	Schwarzwälder Schinken
	Ammerländer Schinken/ Ammerländer Knochenschinken
	Ammerländer Dielenrauchschinken/ Ammerländer Katenschinken
	Greußener Salami
	Nürnberger Bratwürste / Nürnberger
	Thüringer Leberwurst
	Thüringer Rostbratwurst
	Thüringer Rotwurst
	Holsteiner Katenschinken / Holsteiner Schinken / Holsteiner Katenrauchschinken / Holsteiner Knochenschinken
	Rostbratwürste
	Rindfleischwurst
	Göttinger Feldkieker
	Göttinger Stracke
	Halberstädter Würstchen
	Eichsfelder Feldgieker / Eichsfelder Feldkieker
	Flönz
	Oecher Puttes/ Aachener Puttes
	Aachener Weihnachts-Leberwurst/ Oecher Weihnachtsleberwurst
	Spreewälder Gurkensülze
Hungary	Budapesti téliszalámi
	Gyulai kolbász / Gyulai
	Pároskolbász
	Csabai kolbász / Csabai
	Vastagkolbász
Ireland	Timoleague Brown Pudding
	Sneem Black Pudding

(*continued*)

Table 2. Continued.

Country	PGI Meat products (cooked, salted, smoked, etc.)
Italy	Mortadella Bologna Speck Alto Adige / Südtiroler Markenspeck / Südtiroler Speck Prosciutto di Norcia Cotechino Modena Zampone Modena Bresaola della Valtellina Salame d'oca di Mortara Salame Cremona Lardo di Colonnata Salame S. Angelo Ciauscolo Prosciutto di Sauris Porchetta di Ariccia Prosciutto Amatriciano Coppa di Parma Salame Felino Salama da sugo Finocchiona Salame Piemonte Pitina Mortadella di Prato Lucanica di Picerno
Poland	Kiełbasa lisiecka Kiełbasa piaszczańska Krupnioki śląskie Kiełbasa biała parzona wielkopolska
Portugal	Presunto de Barroso Chouriço Mouro de Portalegre Cacholeira Branca de Portalegre Painho de Portalegre Lombo Enguitado de Portalegre Lombo Branco de Portalegre Linguiça de Portalegre Morcela de Assar de Portalegre Morcela de Cozer de Portalegre Farinheira de Portalegre Chouriço de Portalegre Salpicão de Vinhais Chouriça de Carne de Vinhais/ Linguiça de Vinhais Morcela de Estremoz e Borba Chouriço grosso de Estremoz e Borba Linguíça do Baixo Alentejo / Chouriço de carne do Baixo Alentejo Paio de Beja Sangueira de Barroso-Montalegre Alheira de Barroso-Montalegre Salpicão de Barroso-Montalegre Chouriça de Carne de Barroso-Montalegre Chouriço de Abóbora de Barroso-Montalegre Paia de Toucinho de Estremoz e Borba Farinheira de Estremoz e Borba Chouriço de Carne de Estremoz e Borba Paia de Lombo de Estremoz e Borba Presunto de Campo Maior e Elvas/ Paleta de Campo Maior e Elvas Presunto de Santana da Serra / Paleta de Santana da Serra Presunto de Vinhais / Presunto Bísaro de Vinhais Chouriço Azedo de Vinhais / Azedo de Vinhais / Chouriço de Pão de Vinhais Butelo de Vinhais / Bucho de Vinhais/ Chouriço de Ossos de Vinhais Alheira de Vinhais Maranho da Sertã Alheira de Mirandela Presunto de Melgaço Chouriça de carne de Melgaço Salpicão de Melgaço Chouriça de sangue de Melgaço Chouriça Doce de Vinhais
Romania	Salam de Sibiu Cârnaţi de Pleşcoi

(*continued*)

Table 2. Continued.

Country	PGI Meat products (cooked, salted, smoked, etc.)
Slovenia	Prleška tünka Zgornjesavinjski želodec Šebreljski želodec Kraški pršut Kraški zašink Kraška pancetta Prekmurska šunka Kranjska klobasa
Spain	Sobrasada de Mallorca Cecina de León Lacón Gallego Jamón de Trevélez Salchichón de Vic / Llonganissa de Vic Botillo del Bierzo Chorizo Riojano Chosco de Tineo Chorizo de Cantimpalos Jamón de Serón Morcilla de Burgos

https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/geographical-indications-register/.

Italian consortia for the production of PDO dry-cured hams. And Parma and San Daniele represent ~50% of the entire Italian production, reaching a total economic value of more than one billion €per year.

Tradition aka cultural heritage

For human beings, eating is a physiological need as defined in Maslow's hierarchy of needs (Maslow 1943). Access to food, dietary habits, and pleasure are major determinants of our consumption of food. Food has a biological function, but its organisation is a social fact that allows us to understand different societies. In the United States, food is thought of in nutritional terms, whereas this is much less the case in Europe, where the notions of pleasure and conviviality during shared meals predominate (de Saint Pol 2017a). For UNESCO, the foundations of cultural identity are based on cultural heritage and food, either in the social or private sphere. Culture and food are a source of identity and a cultural and natural heritage carried by traditional knowledge and practices[1].

History tells us about ancestral practices for the processing and storage of meat products. The first written references to the salting of pig meat appear during the Roman Empire, at the end of the second century BC. Food preservation is common in every culture because meat and flesh are highly perishable. In cold climates, meat is frozen on ice. In tropical climates, foods are dried in the sun. Fermentation is a valuable food preservation method and creates more palatable and nutritious foods. Microorganisms responsible for fermentation can produce vitamins as they ferment (salami, chorizo, chouriço, dry-cured sausages …) and are used to create foods from less desirable ingredients. And, of course, curing using salt helps to desiccate foods. Salting using raw salts from different sources (rock salt, sea salt, spiced salt, etc.) is a common and even culinary practice. Salts such as nitrites preserve the red colour of meat. Moreover, from a health perspective, nitrites inhibit the spores of *Clostridium botulinum* (Barat and Toldra 2011). In 2006, the European Commission gave the following definition of "traditional" related to foods [2]: "Traditional means proved usage in the community market for a time period showing transmission between generations; this time period should be the one generally ascribed as one human generation, at least 25 years" (EU, 2006). The Italian Ministry of Agricultural, Food and Forestry Policies gives a more restricted definition: 'Agrifood products whose methods of processing, storage and ripening are consolidated with time according to uniform and constant local use'.

Meat processing principles

Cooked and cured meat

For cured-cooked products, salting is carried out by adding more or less concentrated brine, which is a homogeneous mixture in water of functional ingredients such as sodium chloride, the most important ingredient quantitatively and qualitatively (Pegg and Honikel 2014). Sodium provides the salty taste; chloride ions allow the solubilisation of muscle proteins and favour their retention of the water constituting the muscle (water retention capacity), thus ensuring good technological performance during cooking and slicing. Substitute salts authorised by the Code of

Table 3. List of Protected Designation of Origin (PDO) meat products (cooked, salted, smoked) registered on the EU platform.

Country	PDO Meat products (cooked, salted, smoked, etc.)
Croatia/Slovenia	Istarski pršut / Istrski pršut
Finland	Lapin Poron kuivaliha Lapin Poron kylmäsavuliha
France	Lonzo de Corse / Lonzo de Corse – Lonzu Jambon sec de Corse / Jambon sec de Corse - Prisuttu Coppa de Corse / Coppa de Corse - Coppa di Corsica Jambon noir de Bigorre Jambon du Kintoa
Hungary	Szegedi szalámi / Szegedi téliszalámi
Italy	Prosciutto di San Daniele Prosciutto di Modena Prosciutto di Parma Prosciutto Veneto Berico-Euganeo Salame Brianza Salame di Varzi Pancetta di Calabria Salsiccia di Calabria Soppressata di Calabria Capocollo di Calabria Salamini italiani alla cacciatora Culatello di Zibello Valle d'Aosta Lard d'Arnad Prosciutto Toscano Valle d'Aosta Jambon de Bosses Prosciutto di Carpegna Pancetta Piacentina Coppa Piacentina Salame Piacentino Soprèssa Vicentina Crudo di Cuneo
Portugal	Presunto de Barrancos / Paleta de Barrancos Presunto do Alentejo / Paleta do Alentejo
Spain	Dehesa de Extremadura Guijuelo Jamón de Teruel/Paleta de Teruel Jabugo Los Pedroches

https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/geographical-indications-register/.

Practice (IFIP 2016) are potassium, calcium and magnesium chloride; they must be labelled as additives. In addition to its technological role as a salt, sodium nitrite (additive) acts as a preservative and contributes to the characteristic colour of cured products and to their flavour. Sugars (dextrose, sucrose, lactose, etc.) influence the development of colour and flavour. Phosphates are only allowed as additives in standard ham (0.5%) and choice ham (0.2%), and are very little used in France. Reducers and antioxidants (additives), such as ascorbic acid, erythorbic acid, sodium or potassium ascorbate and erythorbate, promote the formation of nitrosomyoglobin (from nitrite salt), a characteristic pink pigment that is then stabilised by heating. Aromatics, spices, condiments, flavour enhancers, aromas, and smoke flavourings are authorised additives whose maximum contents depend on the type of ham. Other permitted ingredients for standard ham include gelatine (and rind), pig's blood protein and gelling agents (additives).

A mixing stage enhances penetration of the salt into the muscle fibres and the formation of "kneading silt" (water, salt and solubilised proteins) which coagulates during cooking and then forms a gel ensuring that the product will hold its shape. Cooking is done with water or steam. Smoking can be done before cooking (but involves several manipulations) or after cooking (easier but gives a less marked taste). The heating scale (time/temperature) depends on the target pasteurisation value.

Dry-cured ham

Before salting, the ham is pressed (usually mechanically) in order to eliminate residual blood from the femoral artery and vein and to avoid the development of undesirable flora; this also reduces the thickness of the ham and favours the penetration of salt. The objective of salting is to allow the ham to absorb the amount of salt necessary for stabilisation at low temperatures in the surface muscles. There are two techniques*: i.* soft salting (Italian technique, the most used in France, especially for Bayonne ham): a quantity of salt proportional to the weight of the fresh ham (50 to 60 g/kg) is added once or twice (Sabio et al. 1998; Petrova et al. 2015). The ham is first rubbed mechanically with a salt mixture and then the salt is applied to the muscle masses and the head of the femur to prevent putrefaction. The hams are stored flat in a salt cellar (temperature $\leq 3\,°C$, relative humidity 85–95%) for 14 to 21 days depending on their size. *ii.* buried salting (Spanish technique used for Serrano STG and Iberian PDO hams): this technique consists in covering the hams, partially or completely, with salt. They are first rubbed with a mixture of salt, sugar and saltpetre before being piled up in successive layers for a period of approximately 1 to 1.5 days/kg. A resting phase at a low temperature ($\sim 4\,°C$) allows the absorbed salt to be diffused and homogenised in the different muscle masses and constitutes an important drying stage: for mild salting techniques (Italian or French), the ham loses half of its total water, i.e. 15 to 17% of its initial weight. A drying phase reduces water activity, allowing proteolysis and lipolysis reactions to participate in the typicity of the ham. Drying is carried out at a fairly high relative humidity (generally 65 to 80%) and a moderate airspeed to prevent excessive surface drying (crusting).

After approximately 25% weight loss (about 20 weeks), the muscle surface is partially or totally covered with a mixture of pork fat, possibly seasoned, in order to slow down the drying process, avoid surface crusting or the formation of 'cracks', and prevent the growth of mites.

The last stage is ripening, during which the ham will develop its sensory characteristics (colour, texture, taste), while water loss is moderate. Ripening lasts several weeks or even months for certain hams, which will then have more intense flavours; it is carried out in a cellar under temperature conditions that depend on the sensory characteristics sought, such as 12–13 °C for mild flavour (Italian technique) or 14–18 °C or even up to 22 °C for a more pronounced flavour (Iberian hams).

The total duration of processing varies according to the specifications. It is a minimum of 210 days for Serrano TSG, 7 months for Bayonne GPI, 12 months for Parma PDO (can go up to 30 months) and Corsican PDO dry-cured ham, 20 months for Noir de Bigorre PDO (can go up to 36 months), 20 or 24 months (or even up to 36 months) for Iberian hams or Barrancos PDO (Portugal).

To sum up, the conditions and duration of the different stages, in particular the salting method, the composition of the pork fat mixture used to cover the muscle surface, and the duration and kinetics of the temperature during drying and ripening give the product's specific sensory characteristics:

- For the Spanish technique: a deep red colour, firm, lean, partial melting of the fat which diffuses into the lean, more or less pronounced oxidation of the fatty acids giving a full-bodied flavour.
- For the Italian technique: a lighter red colour, less oxidised fat, milder flavour.

Fermented meat products

For fermented meat products, the process consists of a number of steps: acidification by fermentation of sugars, reduction of water activity by the addition of salt, and drying by evaporation of water. These physicochemical conditions inhibit the growth of aerobic bacteria by creating an anaerobic environment. Furthermore, the addition of nitrate or nitrite inhibits microbial growth, and a smoking step can reinforce this in some recipes. There is a wide variety of fermented sausages (Toldra and Hui 2014). Most often they are produced with two-thirds lean meat (pork or beef) and one-third fat, almost always pork fat. The meat is cut and mixed with lard, spices, salt, sugar, nitrite salt, and lactic acid bacteria mixed with other bacteria such as *Staphylococcus xylosus* or *S. carnosus*. After stuffing into natural or synthetic casings, the fermentation process takes place. The lactic acid bacteria convert the sugar into lactic acid, which leads to a decrease in pH from about 5.8 to 5.3–4.6, depending on the amount of sugar present. The drying and ripening phase is carried out in temperature- and humidity-controlled drying rooms. These various processing methods are associated with different genetic types or breeds and different production methods of the animals dedicated to the production of dry-cured ham, therefore amplifying the typicity of each product.

All these processes, briefly presented here, are the result of unique know-how often developed in a particular region, mainly in the Mediterranean area, where the environmental conditions (hygrometry, altitude, etc.) have for centuries been adapted to the production of these foods.

Health issues

Health issues should be considered on the basis of benefit/risk. It is well established that the macro/micronutrient profile of meat/processed meat may meet certain nutritional recommendations. A nutritional study on some traditional and representative Italian dry-cured hams (Modena, Nazionale, Parma, San Daniele), cooked hams (Cotto, Scelto, Alta Qualità), and smoked ham (Speck) yielded data on macronutrients (protein, lipid, moisture), energy, trace elements (Fe, Zn, Cu, Mn, Se), B vitamins (B1, B2, PP, B6, B12) and vitamin E level. Smoked and dry-cured ham were the richest sources of Fe, Zn and Se and, among vitamins, dry-cured ham had the highest level of B2, PP, B6 and B12; cooked ham provided the lowest energy intake. The contribution of ham to the recommended dietary allowances of micronutrients ranges between 12 and 30%, depending on the nutrients considered (Lucarini 2013).

But the composition of processed meats is very diverse considering the non-holistic processing described above, the percentages of lean meat, fat, salt and additives being examples. The percentage of lipids varies from 2% in superior cooked ham to 30% in sausages. Therefore epidemiological data, often aggregated under the term 'processed meat', should be considered with caution. Nevertheless, some elements of the composition have been shown to be harmful to our health if consumed in excessive quantities. The study of possible leverage is necessary and fundamental.

Salt intake

Chronic overconsumption of sodium has led to its designation as a nutrient of public health concern. Sodium is an essential nutrient, mostly ingested as salt (sodium chloride or NaCl). Average sodium intake ranges from 3 to 6 g per day (7.5–15 g/day of salt) in most countries, with regional variations. Excess NaCl intake increases the risk of health conditions such as hypertension and cardiovascular disease and processed meat products have been identified as a major contributor to dietary sodium in European countries, milk/dairy products and bread/cereals/bakery products. Current epidemiologic evidence indicates that an optimal sodium intake is in the range of about 3-5 g/day, as this range is associated with the lowest risk of cardiovascular disease in prospective cohort studies. The WHO (2012) has recommended a sodium intake for adults of 2 g sodium/day, which is equivalent to 5 g salt/day. According to O'Donnell et al. (2014), who conducted randomised controlled trials comparing the effect of low to moderate sodium intake on the incidence of cardiovascular events and mortality, more interventional studies are required to truly define the optimal intake range.

Lipids - quantity and quality

The number of lipids and a fat profile rich in saturated fatty acids (SFA) are also incriminated in an increased risk of cardiovascular disease, obesity, and diabetes (Prache et al. 2022). However, the profile of fatty acids in monogastrics is strongly linked to farming systems. The incorporation of n-3 PUFA-rich seeds (flaxseed, seaweed, …) into farm animals' feed increases the n-3 PUFA content of meat. This strategy is interesting because the composition of fatty acids deposited in the muscles is directly related to the nature of the fatty acids ingested.

Most of these studies have focused on enhancing the PUFA content, thereby indirectly lowering the SFA content, and lowering the n-6/n-3 FUFA ratio. Several of these approaches have been implemented in commercial practice, meaning that there are nowadays omega-3-enriched meat products on the market and that there is more variation in meat fatty acid composition than generally anticipated. Unfortunately, few intervention studies have investigated the impact of fatty acid consumption on cardiovascular health (Delgado et al. 2021).

Additives

Among the additives frequently found in processed meat products are sodium nitrite (E250, preservative), potassium nitrate (E252, preservative), nitrate (E252, preservative), sodium acetate (E262, preservative), ascorbic acid (E300, antioxidant), sodium ascorbate (E301, antioxidant) and ascorbate (E301, antioxidant), sodium erythorbate (E316, antioxidant), metal salts of diphosphates (E450, emulsifiers/preservatives), triphosphates (E451, emulsifiers/preservatives), carrageenans (E407, emulsifiers), and carminic acid (E120, colour). Some health effects have been suggested for several of these additives. For example, potassium nitrates and sodium nitrites are used as food additives to stabilise meat products (Menard et al. 2008). These compounds have been associated in prospective cohorts with mortality (nitrates/nitrites from preserved/processed meat) (Etemadi et al. 2017) and with gastric and pancreatic cancers (Song et al. 2015; Quist et al. 2018). Experimental studies have suggested associations with the development of colorectal (Santarelli et al. 2010) and oesophageal carcinomas (Endo et al. 2010), while others suggest potential cardiovascular benefits *in vivo* (Machha and Schechter 2011; Ahluwalia et al. 2016). Nitrites - including in the form of food additives - contribute to the formation of nitrosamines, some of which (volatile ones) are carcinogenic. In 2017, the EFSA concluded that some epidemiological studies had found evidence linking (i) dietary nitrites and gastric cancer and (ii) the combination of nitrites and nitrates from deli meats and colorectal cancer (Mortensen et al. 2017). However, the European Food Safety Authority (EFSA) recommended further epidemiological and experimental studies to clarify the biochemical mechanisms underlying exposure to nitrites, nitrates, and nitrosamines and their effects on health. Exposure simulations carried out by the EFSA suggest that a relatively large proportion of the population is likely to exceed the acceptable daily intakes (ADIs) of nitrites and nitrates from all sources (food additives, natural occurrence in food/drinking water and environmental contaminants). For nitrates in the form of additives (E252), current exposure levels are below the ADI, but for nitrites, as an additive (E250) the ADI would be exceeded in children. Cross et al. (2010, 2011) investigated red and processed meat intake in relation to cancer incidence in a cohort of more than 300,000 men and women enrolled in a National Institutes of Health study. They concluded that a decreased consumption of red and processed meats could reduce the incidence of several types of digestive cancer.

What are the possible levers?

Acceptability and consumer awareness

As detailed above, the manufacture of these traditional products is highly regulated and should be recognised as such by consumers. In Europe, the three types of food quality labels, PDO, PGI and TSG, were set up for a twofold purpose: (*i*). to protect producers of food with special qualities, and (*ii*) to aid consumers in their decision-making. But, Grunert and Aachmann (2016) reported, in their review of the literature, that the role of these quality labels in consumer decision-making at present is still relatively small. The specifications associated with labels provide assurances about the traceability of the product to an area of production and/or the application of a specific set of skills and know-how, as far as consumers are aware of them. In a qualitative cross-cultural study, using focus group methodology, Guerrero et al. (2009) raised the difficulties of simultaneously understanding the notions/concepts of tradition and innovation. Tradition is akin to habit and naturalness, origin and locality, processing and elaboration, and sensory properties, while innovation brings to mind novelty/change, variety, processing and technology, origin and ethnicity, and convenience. There is little room for manoeuvre, but innovations with tangible and relevant benefits without producing substantial changes in the product are well accepted (innovations in packaging, nutritional value and convenience). Consumers mostly show a low level of acceptability of innovations in traditional foods. However, they appreciate innovations designed to improve the nutritional value of food. The way to introduce innovations in the traditional meat product sector is by improving the properties of food, and following trends for healthier foods with limited influence on traditional characteristics. Therefore, the right direction in enhancing the nutritional value of traditional meat products is to choose solutions with a relatively low level of innovation. Conversely, it is clear that innovations that change the taste and appearance of traditional food are to be avoided. Therefore, acceptability to consumers is a prerequisite for each technological leverage to be used.

In a recent article, Di Vita et al. (2019) highlighted increasing awareness of health concerns for consumers of cooked ham. They demonstrated to consumers that the presence of high salt and nitrite levels discourages the intention to purchase, as does high-fat content. But at the same time, consumers attach importance to taste, colour and juiciness, which are strongly related to the above unhealthy compounds. The evidence reveals a certain discrepancy between sensory properties and health attributes, and this is difficult to manage without feelings of guilt.

Farming and genetic leverage

One approach to innovation could be through farming and breeding practices. Avoiding soybean in pig feed because of GMO and environmental issues is a first step in innovation on farms. As an example, a diet containing non-conventional vegetable protein sources (i.e. sunflower meal, faba beans, dehydrated alfalfa meal and potato protein), as compared to conventional soybean meal, may be used for heavy pig production serving as a raw material for dry-curing of hams. Moreover, the possible use of alternative locally grown protein sources in developing GMO-free feed formulations would meet the specification of PDO dry-cured ham (ref). In Spain, Iberian ham is an archetypal traditional meat product where the feeding-and-management system (acorn-fed or fodder-fed) generally determines the consumers' preferences. This is not *sensu stricto* innovation but rather a marketing strategy to integrate environmental and sociocultural values in a traditional product and define a link to current issues about agrosystems.

Along with the traditional traits, swine breeding programmes for Italian dry-cured ham production have recently aimed to include novel phenotypes like the weight of trimmed or untrimmed legs. Palombo et al. (2021) have defined new quantitative trait loci and their potential use in future breeding programmes, but further research is needed to improve the reliability of genomic prediction. Although some research on the effect of genes on pork quality has been conducted, there is still a lack of information, especially regarding the traits of interest in dry-cured ham. This research was conducted within the 6th Framework Programme for RTD (Project TRUEFOOD—'Traditional United Europe Food', contract no. FOOD-CT-2006-016264), a wide-ranging study which simultaneously looked at different pig production and ham processing systems in three countries: France, Slovenia and Spain. The first results of these studies were published by Škrlep et al. (2010) who studied, in the three countries, the association of PRKAG3 Ile199Val, CAST Arg249Lys and CAST Ser638Arg polymorphisms with several green ham quality parameters (weight and fat thickness of ham and colour and pH of muscle) which are important for dry-cured ham production. The PRKAG3 gene codes for the γ subunit of adenosine monophosphate-dependent protein kinase, an enzyme that plays a key regulatory role in muscle cell energy metabolism. The CAST genotype marker significantly influenced cured ham moisture content and may therefore point to a possibility of reduced processing time. Significant associations between these polymorphisms and the quality parameters mentioned above were observed, although they differed according to the sample of pigs selected for ham production in each country, indicating a possible interaction with other genetic or environmental factors. The next step of the aforementioned project was to evaluate the effect of these polymorphisms on the quality traits of the dry-cured hams produced in each country using specific raw materials and processing conditions. The genotypes *PRKAG3 Ile/Ile*, *CAST249 Arg/Arg* and *CAST638 Arg/Arg*, and the haplotype *CAST249Arg–638Arg* were the most favourable for *Jamón Serrano* production (Gou et al. 2012). The 249Lys/638Arg haplotype presented the highest scores for sensory and processing traits whatever the salt content. In conclusion, this study identified the genotype (PRKAG3 and CAST) that is best adapted to producing French Bayonne dry-cured hams with reduced salt content without any deleterious effects on processing and sensory qualities (Santé-Lhoutellier et al. 2012). Finally, for Slovenian dry-cured ham 'Kraški pršut', a significant interaction of polymorphisms with a producer in the case of salt content, lipid oxidation (PRKAG3 Ile199Val), proteolysis index (CAST Arg249Lys) and pastiness (CAST Ser638Arg) was highlighted, indicating that genotype manifestation was reliant on the manufacturing practice.

In 2016, Pagliarini et al. (2016) investigated the role of pig genotypes (ILxLW cross-reference and Goland cross-commercial) on both sensory properties and acceptability of Toscano and San Daniele, each having a PDO. The study demonstrated that genotype had a marginal role in dry-cured ham sensory quality and acceptability. Indeed, the two dry-cured hams were better discriminated according to the denomination of origin, reflecting the different technology processes. Moreover, familiarity with the product was the best driver of dry-cured ham preference.

Processing

Salt reduction in processed meat is one of the more studied levers for reducing health risks such as hypertension. The nutritional point of view has been emphasised before, but the consequences for shelf-life, microbial safety and sensory properties should be considered. A recent study on traditional Slovenian dry fermented sausages reported that a halving of nitrite increased the production of biogenic amines in the product, including histamines, which are markers of meat alteration. Although generally appreciated, dry sausages containing 50% less nitrite presented a higher lipid oxidation rate (Škrlep 2012). Similar results were reported for the Portuguese traditional sausages catalão and salsichão (Laranjo et al. 2016). Processed meat products formulated with reduced amounts of NaCl usually have a shorter shelf-life, which is partially explained by a lower water activity and less inhibition of the growth of spoilage microorganisms. For food producers, when lowering salt content, it is necessary to investigate compliance with food safety criteria throughout the product's lifespan by performing challenge and shelf-life tests to check the quality of foods and to estimate the ability of foodborne pathogens to grow during the planned conditions of distribution and storage.

Clearly, there is a real interest in reduced-sodium meat products, as well as clean-label meat products containing natural compounds instead of additives, as witnessed by the presence of innovative and reformulated products on the market. Reformulation (including the use of ingredients from algae and plants) appears to have huge potential, although it is necessary to take into consideration its effect on sensory properties (colour, flavour, taste, …) and safety (Ferreira et al. 2022).

Unless the bacteriological quality of raw meat is premium, the combination of salt reduction and methodologies such as high-pressure processing (HPP) or ultrasound) could act in synergy and ensure safe foods. High-pressure processing is non-thermal pasteurisation and can contribute to food safety by inactivation of bacterial contaminants, by controlling spore-forming bacteria, as reported in cooked ham (Ramaroson et al. 2018). HPP applied to dry-cured hams resulted in an increase in saltiness, which is a potential argument for salt reduction. For the authors, understanding this phenomenon from an ultrastructural and molecular perspective could help to favour the use of HPP combined with reduced salt in dry-cured hams (Picouet et al. 2012).

Ultrasound is non-invasive, accurate, fast, inexpensive and easy to implement online, but according to the frequency used ($<$100 kHz or $>$100 kHz) can modify the food physically, chemically and mechanically. The ultrasound parameters during processing affect salt diffusion, as well as the structure of the meat tissue leading to the reduction of salt and changes in hardness and water retention. Ultrasound has great potential in decreasing the addition of NaCl to processed meats, accelerating the brining process, mass transfer and curing process, and reducing cooking time. But the ultrasound parameters should be optimised to take into account the variety of cured meat products (Gomez-Salazar et al. 2021). Like HPP, ultrasound tends to increase lipid oxidation in products, and even protein, an outcome which is not sought from sensory and nutritional perspectives.

As a mechanical technique, Paredi et al. (2017) applied a pressure treatment to fresh hams before the salting phase, to reduce ham thickness and shape variability in order to equalise the time required for salt to penetrate inside the different muscles as well as to remove moisture. Using proteomic tools, the authors showed that the pressure treatment modified the type and the rate of proteins expelled in the exudate, indicating a faster loosening of the myofibrillar structure of dry-cured hams. But no modification of weight loss or final salt content with respect to non-pressed hams was observed.

Plant-based alternatives to nitrites in meat products

Consumers, partially aware of the risks of exposure to nitrites, are looking for natural alternatives denoted as healthier (Hung et al. 2016). As a result, manufacturers and scientists are looking for ingredients that can replace added nitrites. Plant extracts are chosen for their high nitrate content, particularly green leafy vegetables such as celery, lettuce, watercress, spinach, etc. Nitrate can be reduced to nitrite by a number of micro-organisms, which is a roundabout way of ultimately providing nitrite (Shakil et al. 2022). Another avenue is being explored with plant extracts rich in polyphenols, such as beetroot powder or grape seed to name just two. Antioxidant effects are targeted here. However, the sensory properties are often modified, which raises questions about the 'traditional' nature of such cured meats.

Alternatives to sodium chloride

Sodium intake is related to hypertension and cardiovascular disease. Therefore, various studies have examined the partial replacement of sodium by other cations such potassium, magnesium, and calcium. Fieira et al. (2015) evaluated the texture and sensory attributes of Italian salami following replacement of 60% of sodium chloride by potassium chloride; and partial replacement of sodium chloride by a mixture containing potassium chloride, magnesium chloride, and calcium chloride. As a consequence, a reduction in the sodium chloride content of over 25% was observed, complying with the requirements of the current legislation. But the textural properties with the second formulation were modified, with higher hardness and chewiness, thus departing from consumer expectations of such products. In the same vein, Zhang et al. (2020) showed that replacing sodium with potassium, magnesium, calcium or zinc in dry-cured pork loins had different effects on the proteolytic activity of cathepsin, and therefore on texture. In addition, the presence of potassium and magnesium increased bitterness, a perception that is not very positive.

Conclusions

To reconcile cured meat products with health concerns and culinary heritage is possible with subtle touches of innovation, including pig genetics, processing and reduction in salt content. The people of southern European countries appear to give the most priority to the pleasure aspect of their food and to labels of 'quality', and the least to health issues, which are strongly favoured by Americans in particular. Food labels indicating quality provide a product with legal protection against imitation throughout the market and eliminate the misleading of consumers by non-genuine products, which may be of inferior quality. These labels help producers obtain a premium price for their authentic products, and should provide consumers with clearer information about product characteristics and facilitate the identification of food products of certified quality. It appears that labels are a guarantee of quality and of traditions to which consumers are very attached. However, if there is innovation, the potential pitfall regarding its acceptance relates above all to consumers, because they say one thing and do another. There is a lack of literature that focuses on the influence of consumer involvement in food products (PDO, GPI, TSG) on consumer behaviour patterns.

Notes

1. https://openstax.org/books/introduction-anthropology/pages/14-3-food-and-cultural-identity
2. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:093:0001:0011:EN:PDF

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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