The quality of animal-based food
related to animal production and processing conditions

Summary of the collective scientific report produced by INRAE

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Summary of the collective scientific assessment produced by INRAE at the request of the French Ministry of Agriculture and Food and the French Agency FranceAgriMer

May 2020

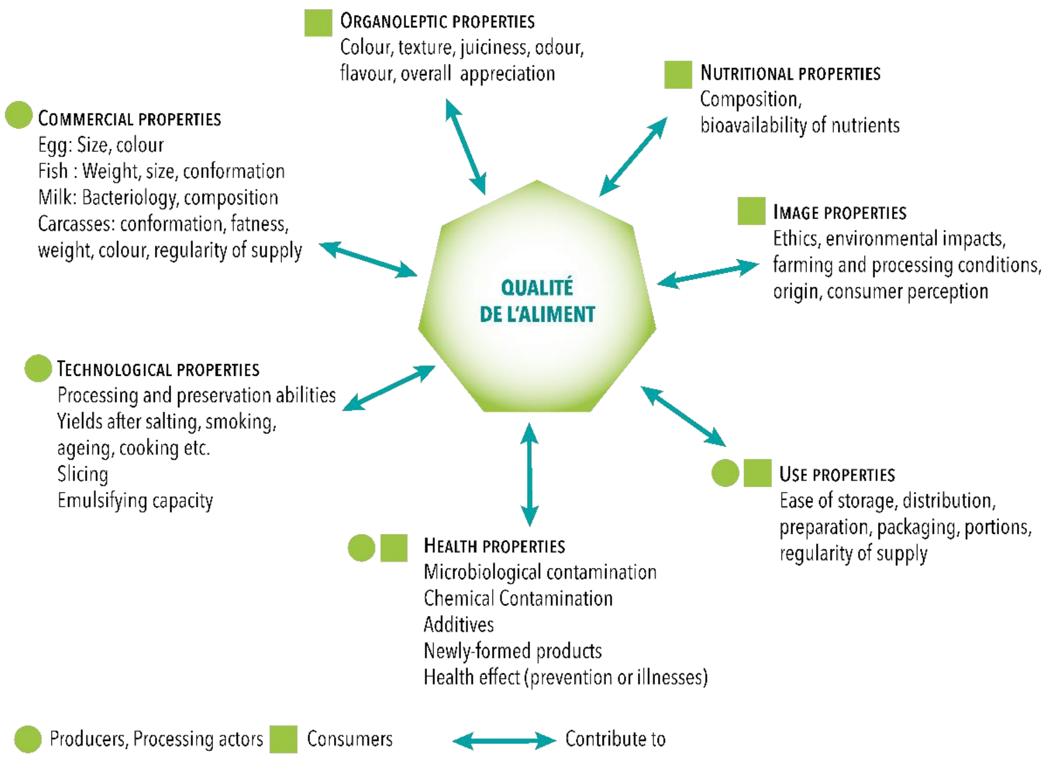
Consumption of animal-based food is currently questionned in terms of human health, ethics and the environment. As a result, the Ministry of Agriculture and Food and the French agency FranceAgriMer requested an assessment on the quality of animal-based food. This request complements a previous collective scientific assessment on the environmental, economic and social impacts and services provided by European livestock farming. The objective is to characterise the quality of food products according to animal production and food processing conditions. This study focuses on the determinants of the properties that constitute quality: organoleptic, technological, commercial, use, image, nutritional and health properties. The scope of this assessment covers the main animal-based food produced and consumed in Europe: beef, sheep, pork and poultry meat, milk (from cow, sheep and goat), eggs, fish meat, and the foodstuffs resulting from their processing such as dairy products, processed meat products, ready to eat dishes, etc. Seafood products have not been studied, nor certain products from terrestrial species with a low consumption level (rabbits, game, etc.). This assessment focused on the foods, rather than dietary regimes or the role of animal-based foods in the diet.

1 The analysis of quality through seven properties

The quality of a product is defined by the set of properties that allow it to satisfy the expressed or implied needs of a user (AFNOR, ISO9001). In this assessment, quality has been broken down into seven properties (Figure 1): organoleptic, sanitary and nutritional properties all directly related to consumption; commercial, technological and use properties, which depend on the practices of professional stakeholders and consumers; and image properties that cover the ethical, cultural and environmental dimensions associated with the way a food is produced and processed, as well as its origin. The latter plays an important role in foodstuff perception by consumers and is particularly valued in products with quality labels.

While some properties can be measured relatively easily, such as nutritional composition and degree of contamination, or have recognised indicators for their assessment (colour, pH, etc.), others are more difficult to assess. For example, the methods for assessing use properties are still not well formalized. The criteria and indicators used for the image properties are numerous and complex to define, and the result of the comparison of different products can depend on the chosen functional unit. Some organoleptic (odour and flavour) and technological properties are also technically difficult to predict from the raw material. Some tools aggregate different elements. The Nutri-score, a nutrition labelling system affixed to the packaging of pre-packaged foods, for example, draws on criteria related to food composition. The Meat Standard Australia (MSA) is a consumer information and payment system for livestock farmers, developed in Australia, and is based on a predictive model of meat quality that integrates organoleptic properties. No system assesses all properties jointly and it should be noted that multi-criteria approaches are still rare.

Figure 1. The seven constituent properties of the quality of animal-based food. Source: ESCo.



2 The context of consumption

2.1 Questions raised in western countries regarding animal-based food

Compared to the global average, the dominant western diet is characterised by its high proportion of animal-based food. This high consumption is being challenged in terms of (i) human health, a high level of meat consumption being associated with an increased risk of certain chronic diseases, (ii) ethics, with increased societal concern for animal welfare, including the conditions of production, transport and slaughter, and (iii) the environment, due to its impact on the climate, and intensive use of natural resources. These concerns are directed at a sector in which highly contrasting production and processing models coexist.

2.2 Evolving policies

For health and environmental reasons, large international organizations, such as the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO), recommend reducing the share of animal-based food in human diets. At the French level, in 2019, Santé Publique France updated the nutritional recommendations for adults, stating, for the first time, a weekly quantity of red meat and processed meat that should not be exceeded, and introducing specific recommendations for legumes and both wholegrain and lightly refined cereal products because of their high fibre content (Table 1).

The dietary changes advocated also require a rebalancing between plant and animal protein sources. The WHO recommends a balance between the two sources, i.e. 50% of proteins of plant origin and 50% of protein of animal origin, whereas the western diet in France and other Western European countries contains approximately 65%-70% animal protein. European countries are thus gradually adopting protein strategies aimed firstly at reorienting animal feed towards a local supply of protein-rich plants and secondly at developing plant proteins for human consumption. In France, the national strategy on plant proteins, on which discussion was launched in 2019, includes a focus on the development of plant proteins in human food. This strategy is in line with the provisions of the Egalim law and the recommendations of the French National Alimentation and Nutrition Programme (PNAN).

Category	Objective	Recommendations
Fish	AIM FOR	Twice weekly (fatty fish once a week)
Dairy products	AIM FOR	Twice daily
Processed meat	REDUCE	Maximum 150 g per week
Fresh meat	REDUCE	Maximum 500 g per week (pork, beef, veal, mutton, lamb, offal)
		Favour poultry
Legumes	INCREASE	Minimum twice weekly
Lightly refined cereals	INCREASE	Daily

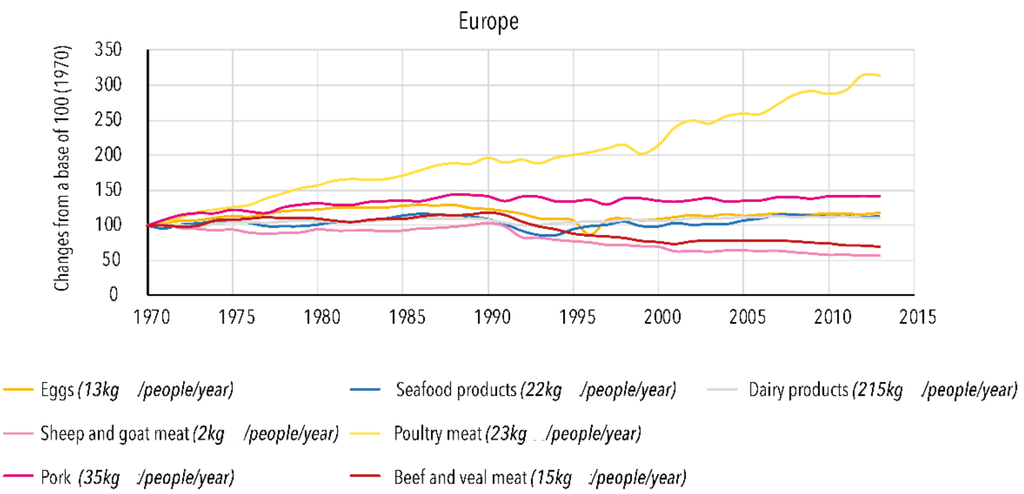
Table 1. PNNS (French National Nutrition and Health Programme) recommendations for adults with respect animal-based foods and their possible substitutes.
Source: https://www.mangerbouger.fr/content/download/46573/889419/version/2/file/dt05-17719-a_400x600_plv_medecin_om_bd%20%281%29.pdf.

At the same time, and in response to criticisms of the animal product sectors, French operators in these sectors drew up, in 2017 and at the request of the Ministry of Agriculture and Food, sectoral plans in order to take better account of societal and environmental issues, in particular by upgrading the range of products quality. Some of these plans, such as the plan for the beef and veal sector, take into account the downward trend in red meat consumption.

2.3 Overview of consumption

The consumption of animal-based food is increasing at a global scale (forecast increase of 20-30% within 10 years) with a very heterogeneous geographical distribution. The OECD countries, South-East Asia and China increased their meat consumption since the 1970s, whereas consumption in the rest of the world has changed very little and remains at low levels. In Europe, the consumption of meat, eggs and fish is stagnating or declining except for poultry. A French person eats yearly an average of 7.6 kg (carcass equivalent) less meat than 20 years ago, a decrease mainly due to beef and veal (Figure 2). This trend is consistent with a recent international study showing that the relationship between meat consumption and gross domestic product follows an inverted U-shape. Although general trends can be seen in the world's major regions, the breakdown of consumption between the different food categories is nevertheless very heterogeneous depending on the country, even within the European Union. The Irish and Finns are the biggest drinkers of milk, while the Greeks stand out for their consumption of cheese, and the French are the biggest consumers of butter. The French and Irish eat much more beef than other Europeans, while Germans and Spanish clearly prefer pork. This diversity is also observed at the individual level: there is no such thing as a consumer with a fixed profile, but rather consumer profiles that vary according to purchase and consumption situations.

Figure 2. Trends in the consumption of animal-based food between 1970 and 2013, in kg/person/year (base 100 = 1970). Notes: Sea products = Fish and seafood; Dairy products = Milk, for drinking as well as processed (excluding butter); meat data are in kilogram of carcass weight equivalent (kg c.e.). Source: Ourwolrdindata.org



Within the European population, we are seeing the promotion of dietary changes that reduce, or even eliminate, animal proteins, and which are driven in particular by vegetarian, vegan and animal-rights movements. There is no precise definition or quantified characteristics of so-called 'flexitarian' diets, which designate diets with differing degrees of reduction in the consumption of meat-based foods, but their promotion is a sign of a dietary transition towards diets that include more vegetable proteins.

3 Effects on human health

3.1 Contribution to nutritional requirements

The nutritional value of animal products is based on their high protein content (of high nutritional value) and on a specific supply of fatty acids, minerals and vitamins. They are indeed the major food providers of long-chain n-3 PUFAs (polyunsaturated fatty acids, also called omega 3) and vitamin B12, and that they provide large amount of minerals (iron, calcium, zinc, iodine) that are easily absorbed during digestion.

The great variation in the lipid content and fatty acid profile may lead to contrasting health effects. A high proportion of omega-3 polyunsaturated fatty acids (n-3 PUFAs), as found in the flesh of fatty fish or foods derived from animals fed with plants rich in omega-3 (grass, some oilseeds), is beneficial for health (development of the nervous and cognitive system in children, reduction of chronic diseases). By contrast, the deleterious effects of some saturated fatty acids, even if these effects are sometimes questioned, leads to recommending a consumption of saturated fatty acids of less than 12% of total energy intake.

Vitamin B12, which is involved in fetal development and cognitive functions, is exclusively provided by animal-based food. The exclusion of animal products from the diet therefore requires the intake of supplements fortified with vitamin B12. Epidemiological studies have shown that vegetarians do not experience more health problems than non-vegetarians even though they have lower levels of micronutrients in their body reserves, however vegans have a higher prevalence of deficiency for some nutrients including vitamin B12.

The amino acid profile of proteins in animal-based food is balanced with respect to human dietary requirements, and these proteins are highly digestible. Due to the presence of indispensable amino acids (which must be supplied through the diet), they are particularly suitable for certain populations such as seniors, growing children and athletes. Minerals of animal origin are highly bioavailable compared to those of plant origin. The presence of meat, dairy products and seafood in the diet helps prevent deficiencies in iron, calcium and iodine respectively. For example, to absorb 100 mg of calcium, one would need to eat 30 g of Emmental cheese, 500 g of cabbage or 2 kg of spinach.

3.2 Effects on Chronic Diseases

Nutritional epidemiology studies allow associations to be established between the consumption of animal-based food and increased or reduced risk of certain chronic diseases, such as diabetes, obesity, cancers, cardiovascular disease (CVD) and neurodegenerative diseases (Alzheimer's disease and related disorders). These relationships are qualified by the level of evidence associated with the results. The associations vary, depending on the type of product, the disease or the level of evidence.

For example, consumption of dairy products is associated with a decreased risk of colorectal cancer (compelling level of evidence), breast cancer (suggested) and an increased risk of prostate cancer (suggested) (Table 2).

An identified gap is that epidemiological studies do not consider the variability in the composition of products, which in turn depends on their production and processing conditions. Furthermore, the long-term health effects of avoiding the consumption of animal products are not yet well known.

Food category	Cancer	CVD	ADRD
Processed meat			
Red meat			
Poultry meat			
Eggs			
Fish			
Dairy products			

Table 2. Level of evidence of associations between the consumption of animal-based food and chronic diseases: Cancer, Cardiovascular disease (CVD) and Alzheimer's disease and related dementias (ADRD). Suggested evidence levels are not shown.

Legend

Increased risk with convincing evidence

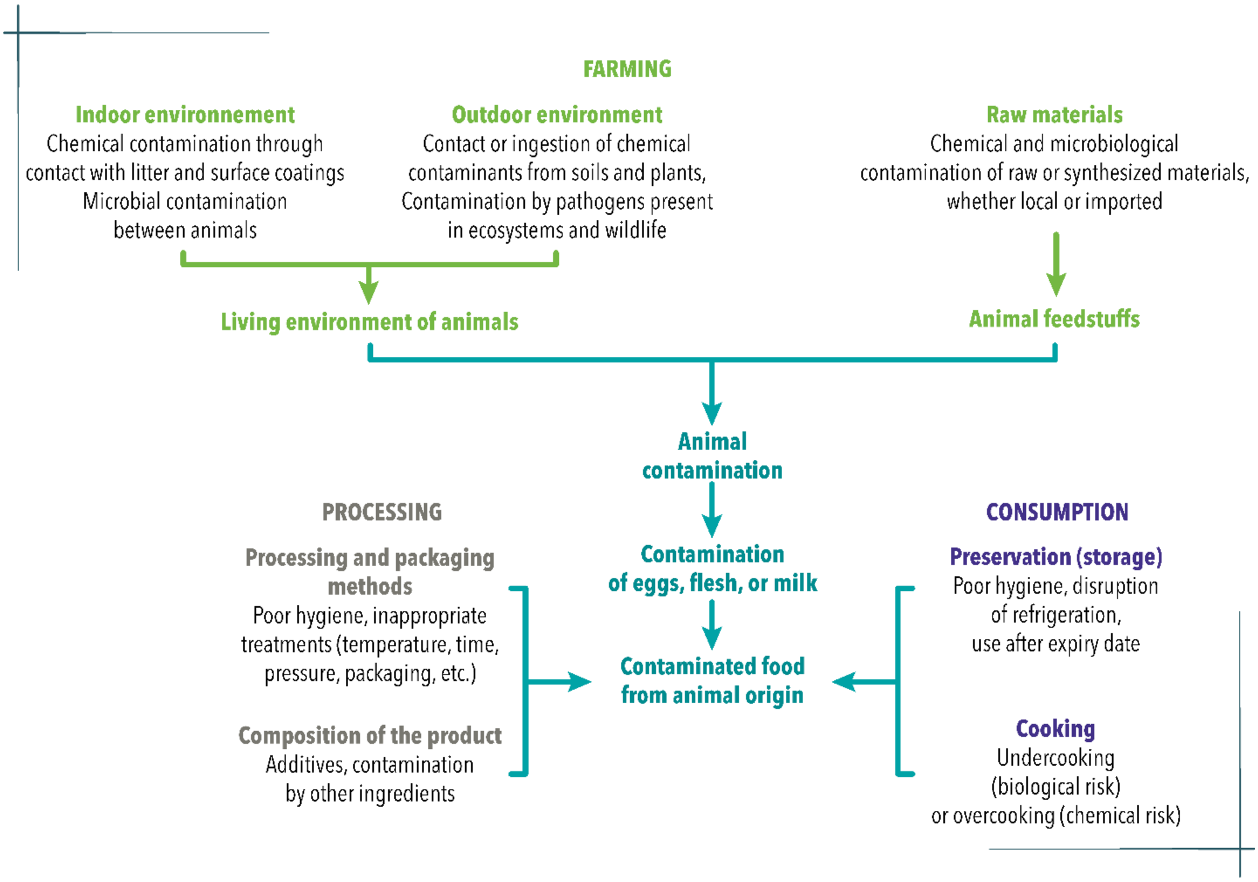
Increased risk with likely evidence

Decreased risk with likely evidence

3.3 The sanitary properties of food: microbiological and/or chemical hazards from various sources

Possible contaminations of animal-based food are related to the environment, as well as animal feeding, food processing, and consumption practices (Figure 3). The specific issue of antibiotic use raises the dual questions of residues in food and the development of antibiotic resistance. Few studies provide data on drug, pesticide or other micropollutant residues in animal-based foods. Meat, eggs and their preparations (raw or undercooked), and fish (farmed fish are not distinguished in the statistics) account for 70% of the total collective toxic infections caused by food pathogens such as Salmonella or Campylobacter, as officially reported over the period 2006-2015. Nevertheless, studies show that the actual incidence of these toxic infections is likely to be underestimated. As for chemical pollutants, animal-based food is the largest contributor of persistent organic pollutants such as dioxins, furans and polychlorinated biphenyls (PCBs) in human food.

Figure 3. Microbiological and chemical contamination pathways in animal-based food



The influence of food processing on the chemical risks is still poorly documented, as it is rarely studied at the household level. Little is known about the toxicity and level of exposure to compounds neoformed during cooking and smoking, nor about the cocktail effect relating to possible interactions between chemical contaminants. Moreover, these interaction effects have been linked to the risks arising from packaging materials in contact with food. Additives used in the formulation of food may also be involved in possible interaction effects.

4 The effects of production and processing factors on the quality

Many factors influence each property, and factor may affect several properties. The multiplicity of factors, their combinations, and possibly their interactions and interdependencies, make it possible to state that quality is developed all along the production and processing chain.

4.1 Numerous factors along the entire food production and processing chain

These factors, or determinants of quality, operate at the various stages of food production and processing. These range from the characteristics of the animals, the conditions in which they are reared, transported and slaughtered, the conditions in which the food is processed, preserved, and sold, and finally prepared in commercial or domestic settings, and consumed. Some stages of the chain are particularly important to the quality properties of animal-based foods, and may represent either a risk of adversely affecting certain properties or, on the contrary, an opportunity to improve or correct a property.

Farming practices are particularly relevant for certain properties, especially image. Research reveals that consumers, on average, not only have a positive attitude towards more welfare-friendly farming systems with outdoor access and sufficient space, but are also willing to pay a higher price for products from such systems. Farming practices also influence sanitary properties. Animals raised indoors, especially when the animal density is high are more susceptible to contagious diseases, atmospheric pollution and chemical contaminants in their feed. On the other hand, farming systems with access to the outdoors are more exposed to environmental contaminants.

The animal's diet is a key determinant of the nutritional, organoleptic, commercial and some technological properties of animal-based food. Given that one of the nutritional benefits of animal-based food is their n-3 PUFA content, animal sectors are seeking to increase the content of n-3 PUFAs in their products. It can be promoted by the ingestion of grass, especially pasture, but also by further enriching animal diets with certain oils and seeds (e.g. flaxseed) or ingredients of marine origin (e.g. fish). However, this enrichment may cause defects in organoleptic properties (rancidity) and use (preservation). This enrichment must be limited and be associated with an antioxidant (vitamin E, for example) which may be of natural (grass), synthetic or microbial (GMO) origin.

The pre-slaughter and slaughter phases are crucial. As sources of stress, shortcomings in animal handling at loading and transport, as well as the slaughter processes can have deleterious effects on organoleptic properties (such as tenderness), and on technological properties (such as cooking yield). The issue of animal welfare, especially during transport and at the abattoir, is also crucial for the image properties of the product. Finally, poor control of evisceration jeopardises meat safety.

Processing techniques are primarily intended to preserve the food. The industrial processes of cooking, salting, smoking, fermentation etc. derive mostly from traditional practices. On the other hand, industrialization has enabled the fractioning of food raw materials into ingredients which are then assembled or reassembled, offering a very wide range of food formulations (Figure 4). The addition of additives in particular can modulate the properties that constitute quality, either to accentuate them (salt and sugar: flavour enhancers), or to compensate for defects (e.g. flavours) or to extend the shelf life (e.g. nitrite salts). However, this approach has led to the standardisation of the agricultural raw material supplied to the industry and, further up the supply chain, to a reduction in both animal biodiversity and the diversity of farming practices. Furthermore, the diversification of processed products raises questions about their classification. EFSA thus indicates whether the products are raw, derived or composite (FoodEx2). The Nutri-Score classifies food products according to their nutritional composition, while the Nova classification is based on the degree of formulation of a product, stigmatizing highly processed products. The concept of ultra-processing is controversial: some scientific communities prefer the term ultra-formulation, which is more in keeping with the criteria of the Nova classification, which does not consider the transformation processes themselves.

The lack of data in the literature prevents an assessment of the impact of household processing practices on food quality.

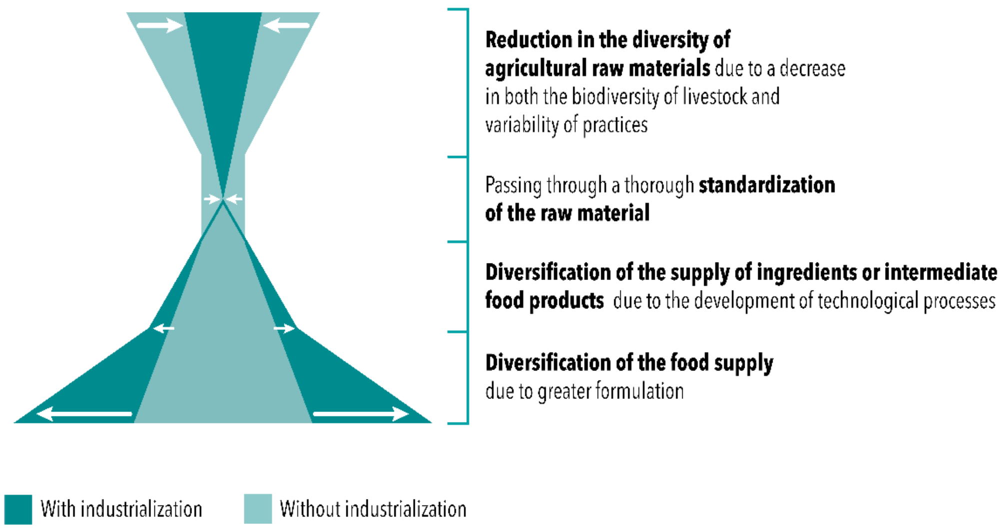


Figure 4. Consequences of agro-food industrialization on diversity along the agro-food chain.

4.2 SIQOs: building quality through their commitments

At the junction of differing objectives, the production share of animal-based food under SIQO (official signs identifying quality and origin) are increasing. Indeed, in the face of consumer concerns about the food they eat, SIQOs are tools for restoring confidence by improving transparency on the production process. The development of these certified products enables the animal sectors to move upmarket and capture the resulting added value, and also enables local areas to integrate the positive externalities associated with these products. The five official signs are: OA (Organic Agriculture), PDO (Protected Designation of Origin), PGI (Protected Geographical Indication), TSG (Traditional Speciality Guaranteed) all of which are recognized in Europe, and the LR (Label Rouge), which is a French specification.

The SIQOs are strictly regulated by specification commitments, and are subject to controls. It is possible to analyse the links between these commitments and the different properties that make up quality of the product under SIQO. The property common to all SIQOs is image. Indeed, the official labels make it possible to guarantee the credibility and reliability of the certified products, and thus to ensure their recognition by consumers. Although all of the properties are ultimately covered, each SIQO develops specific links with some of them: the OA is committed to aspects related to health properties by promoting "processes that do not harm the environment or human health (RCE834)", and the PDOs, PGIs and TSGs at a lower extent emphasise more organoleptic properties related to the typicity and specificity of the food products. It is possible to juxtapose the signs, brands or value-adding statements on the same product (for example PDO or PGI and OA), with the exception of the LR and PDO. However, the profusion of information, signs and certifications is a source of confusion for consumers.

The case of the Label Rouge is unique: unlike the other European signs, it is only recognized in France, and is defined in the regulations as "a superior level of quality" (Code Rural R641.2.8). By analysing the commitments in the Beef cattle LR specifications, it is possible to establish how they are linked to the various properties that make up quality, the most important of which are organoleptic and image properties. The quality of the product is developed throughout the production chain through initial choices (particularly the breed), commitments concerning the herd (rearing and transport conditions) and successive screening (sexual type, and characteristics of the carcass and meat), as well as commitments regarding the carcasses processing and ageing (Table 3).

Table 3. Improvement of meat organoleptic properties via the major commitments for LR Beef Cattle throughout the production chain (green: commitments regarding the herd, orange: screening by individual). The letters E-U-R-O-P describe the EU-wide carcass conformation grading.

Product development stages	Criterion	Common product	LR Commitment	Meat organoleptic properties
Type of animal	Breed	-	Beef cattle breed or even just 1 or a few breeds	Colour, juiciness, tenderness, flavour
	Sexual type	-	No uncastrated males	Tenderness
	Age at slaughter	-	Male: > 30 months Female: 28-120 months or more restrictive	Tenderness, colour
Farming practices	Grazing	-	> 5 months/year or even > 8 months/year	Colour
Pre-slaughter handling	Welfare	-	Max 24 hours between farm and slaughter	Colour, tenderness
Carcass	Conformation	All classes of conformation (E-U-R-O-P)	E-U-R (significant muscular development) possibly E-U or U-R	Little connection with juiciness and flavour
	Fattening	1 to 5	2 to 4	Tenderness, juiciness, flavour
	Ultimate pH	-	≤ 5.8	Colour, juiciness
Meat	Ageing	3 to 5 days on average	Grilling/roasting meat: > 10 days or even > 14 days	Tenderness, flavour

In general, the properties of organically produced animal-based food are more variable within a given food product category than those from conventional production. This difference can be explained by lower genetic selection (poultry), lower use of inputs (ruminants and monogastric animals) and/or greater variability in farming conditions (ruminants and monogastric animals). Furthermore, such farming conditions may be favourable for one species and adverse for another. In addition, there is a lack of integrated studies quantifying the balance between these effects. For example, organic farming reduces the risk of drug residues and antibiotic resistance, but the commitment for outdoor rearing and a longer rearing period increases the risk of bioaccumulation of environmental contaminants in milk, eggs and meat. The effects on image properties vary depending on the particular criterion under consideration (animal welfare, GHG emissions, surface area required) and the animal species. The results are therefore difficult to generalize. Two recent meta-analyses on milk and meat from different species show an improvement in nutritional properties linked to an increase in the level of PUFAs, particularly n-3 PUFAs, but the results vary in relation to the variability of rearing conditions (particularly feeding conditions). The results are more robust for milk than for meat due to the lower number of studies involved for the latter and a risk of bias related to the lower lipid content of organically produced meat. A recent pioneering epidemiological study on a cohort of French consumers did conclude that there are health benefits to a diet with a high proportion of organically grown foods from animal and plant origin. However, generalizing from these initial results still remains a challenge.

4.3 Authentication tools

The analysis of the literature shows that there are many more studies on the authentication of farming conditions and the origin of the animal from which the product is derived, than on the authentication of the conditions under which the product is processed and stored. While methods to control species adulteration (e.g. fraudulent mixing of meat or milk from different animal species) are currently in place, to date efforts on other authentication issues, such as grass-feeding, have largely been of a "proof of concept" nature. Comparisons have been made between extreme examples of product development or origin, which may favour their discrimination, with a relatively small number of samples. Research should now test the reliability of these methods under less contrasting conditions and on higher number of samples, and develop adequate datasets in order to move to the operational stage.

5 Compromises need to be sought

Some factors that influence the quality of animal-based food can result in tensions between different properties; the tensions currently under debate are presented here. On the other hand, there may also be synergies between properties and between production and processing stages; these are illustrated using the example of dry cured ham.

5.1 Factors that lead to tension between properties

Genetic selection of farm animals has focused on commercial properties such as muscle mass and growth efficiency. However, some animal species (chicken, pigs, and also fish) frequently show a destructuring of the muscle tissue, which compromises their appreciation by consumers and their suitability for processing. It even sometimes raises questions about the maintenance of the physiological function of the muscle tissue in the living animal, and thus its health status. Although still poorly understood, researchers have suggested that this may be due to over-selection towards heavy, fast-growing animals with high meat or flesh yields.

The fate of males is a major issue in the dairy and egg sectors which have specialized the animals' productive function, and in which only the producing females are of economic value. In the egg sector, male chicks are currently culled at birth. In the face of societal pressure, the French and German governments have announced a ban on the crushing of male chicks from 2021. Sexing *in ovo*, the use of strains with a dual purpose (eggs and meat) or mixed breeds (milk and meat) or even crossing between breeds are avenues that should be explored. In the goat sector, it is also difficult to value all male kids in the human food chain.

The castration of male pigs illustrates the conflict between image properties relating to animal welfare and some organoleptic properties, as the meat of uncastrated male pigs may have an undesirable odour and flavour. The surgical castration of pigs is declining in Germany, the Netherlands and France (where it will be banned from 2022 unless carried out with anaesthesia and analgesia) in favour of the production of entire males, which has long been common practice in some European countries (e.g. Spain, United Kingdom). Research is underway to predict smelly carcasses directly on the slaughter line. Immunocastration of male pigs provides an alternative, but is not widely used.

Protein feed for fish in aquaculture is usually of marine origin (fish oil or fishmeal) but is increasingly being replaced by plant-based feed (soybean, rapeseed, or lupin) in response to criticisms towards industrial fishing, the depletion of marine resources and the greater risk of chemical contamination. This feed substitution favours the image properties of the farmed fish, but modifies its nutritional properties. This reduces the flesh content of long-chain omega 3 fatty acids (EPA and DHA), which are beneficial to human health. The fatty acid profile can, however, be restored by a return to marine-sourced finishing feed before slaughter. On the other hand, while marine-based for plant-based feed substitution reduces contamination by trace elements and persistent organic pollutants, in particular polychlorinated biphenyls in fish flesh, it increases the risk of contamination by other pollutants, such as pesticides, mycotoxins and polycyclic aromatic hydrocarbons.

Sodium nitrite (and potassium nitrate) are used as preservatives in processed meats (use property) and to prevent the development of pathogens (sanitary property). These additives also have the capacity to stabilize the pink colour of cooked ham, and are powerful antioxidants. In 2017, EFSA (European Food Safety Authority) concluded that the levels of nitrosamines formed in the body from the food-added nitrite and nitrate at the permitted levels are of low concern for human health. However, in 2010, the IARC (International Agency for Research on Cancer) classified ingested nitrite and nitrate as "2A - probably carcinogenic". Research is currently focusing on the ways to reduce the risk of nitrosamines formation during the digestion of processed meat. This could include modifying the use of additives (addition of antioxidants), reducing the use of nitrite, or by substituting added nitrite with alternatives with comparable attributes (celery, organic acids). The potential health gain for consumers, as well as the effects of these alternatives on the properties that make up the quality of the processed meats, must be evaluated.

The grasslands of organic farms are often richer in legumes (especially white clover) due to the ban on the input of synthetic nitrogen. Legume consumption by the animal improves the nutritional properties of its meat: these plants are richer in leaves and lipids than grasses, and their retention time in the rumen is lower, which limits the biohydrogenation of beneficial fatty acids (PUFA n-3). The fatty acid profile of the meat is thus improved. However, in lamb, the ingestion of legumes may decrease the firmness of the subcutaneous fat and, particularly in the case of white clover, increases the risk of meat off-odour and off-flavour due to an increase in skatole (a smelly compound) content in the meat (Table 4).

Table 4. Effects of organic farming on pasture-fed lambs

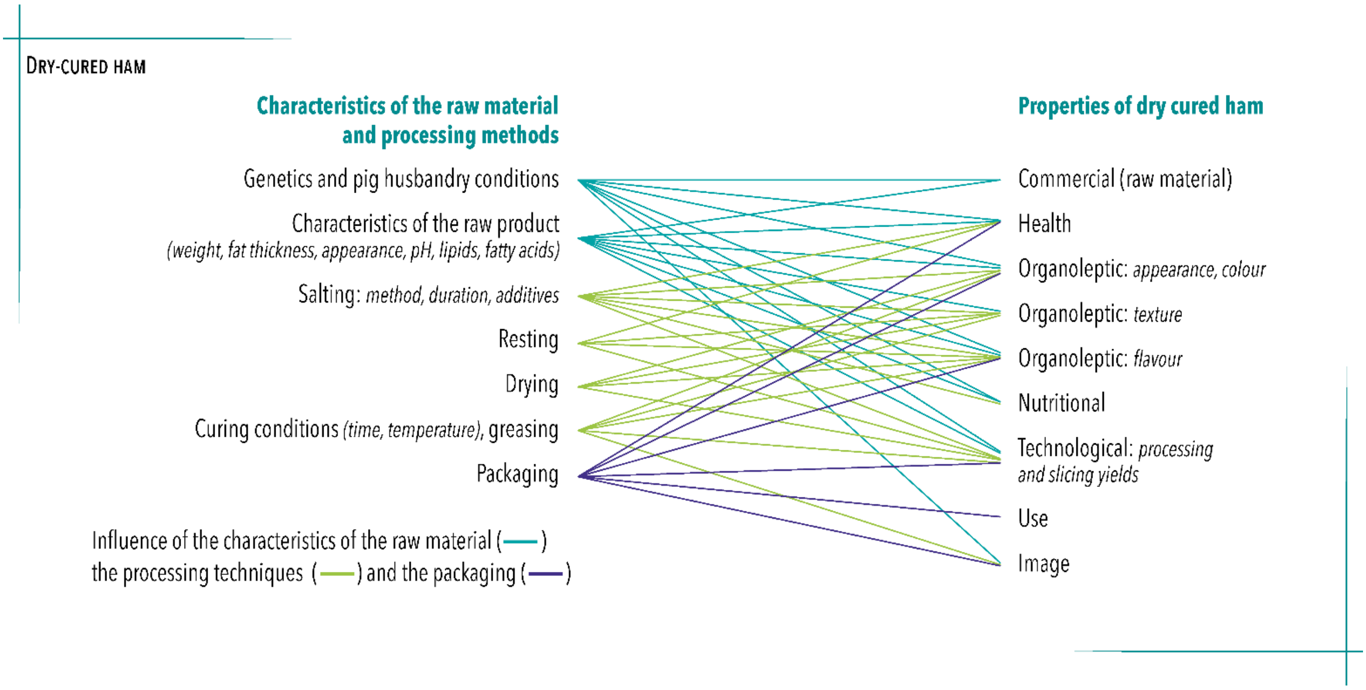
Properties	Effects (green = positive / orange = negative)		Explanation
Organoleptic	-	Increased risk of off-odour and off-flavour	Higher meat skatole content, linked to increased proportion of white clover in plant pasture
Commercial	-	Increased risk of less firm subcutaneous fat	Higher PUFA/SFA ratio in subcutaneous fat due to lower biohydrogenation of PUFAs in the rumen
Nutritional	+	Healthier meat fatty acid profile	Legumes richer in n-3 PUFAs, with less biohydrogenation in the rumen
Image	+	Greater environmental service	Nitrogen fixation by legumes
	-	Increased use of land surfaces	Lower yield of forage area

A compromise can be found by completing the lamb fattening process indoors with a finishing period in a sheepfold (3 weeks), as skatole has a low persistence in the tissues and this does not greatly degrade the fatty acid profile of the meat. Another possibility might involve increasing consumer awareness of the characteristics of pasture-fed lamb meat.

5.2 Taking advantage of synergies and overcoming antagonisms

Some products take advantage of naturally existing synergies between different properties, and between the production and processing stages. Dry cured ham provides a classic example of synergies between technological and organoleptic properties in particular. In addition, the quality of dry cured ham highly depends on the quality of the raw material, and thus relies on a synergy between production and processing. Extensive aging stages, specific genotypes or breeds together with extensive farming conditions, including the consumption of local resources, allows the properties of the raw material to be optimised, resulting in strong lipidic accretion, darker colour, and specific aroma and taste. These hams are therefore fattier, especially the fat cover (present under the rind), and better suited to drying. Thus, their technological properties are enhanced, while at the same time they develop very specific organoleptic properties. These synergies are even stronger when local breeds and older individuals (heavy pigs) are chosen. It should be noted that in extensive farming systems, the consumption by pigs of natural resources rich in both n-3 PUFAs and antioxidants allows for the natural enrichment of meat with n-3 PUFAs while preventing their excessive oxidation, thus avoiding possible antagonism with nutritional properties (Figure 5).

Figure 5. Influence of raw material characteristics and processing techniques on the properties of dry cured ham



The identification of antagonisms leads to the search for solutions to overcoming these conflicting effects. As detailed in the examples previously discussed, these solutions may involve striking a balance between the positive and negative effects (lamb rearing on grass with a final fattening period indoors) or finding a technical solution to counter deleterious effects (detection of odorous non-castrated male pig carcasses). However, these trade-offs are sometimes overcome by introducing new constraints, with effects that may themselves be open to criticism, as in the case of potential substitutes for nitrite. In conclusion, no system benefits all quality properties at the same time.

5.3 Multi-criteria approaches: in search of weightings and trade-offs

The various dimensions of quality can be in tension, as can the interests of the different stakeholders. This highlights the need to seek ways of compromising between the different properties and between different stakeholders, and to develop the tools to do so. The objective of multi-criteria analysis is to help a decision-maker make a choice in a multidimensional environment based on a decision-making process that determines the best solution or compromise, according to his or her preferences. The role of the decision-makers is paramount because the results obtained must be put into perspective according to the weightings and trade-offs assigned to the various criteria, and to the allocations and functional units chosen.

Many studies deal with sustainability at the farm level. Other, more recent studies focus more on processing (in particular cooking, packaging and preservation techniques). These enable the identification of processing scenarios that optimise the compromise between sanitary, use, image (especially environmental impact) and commercial properties (e.g. taking meat yields into account). These multi-criteria analyses, however, still struggle to encompass the continuum of operations from primary production to culinary preparation. A recent innovative study on a composite food (pizza) sought to identify the best compromise between the environmental, organoleptic and nutritional dimensions with an aim to reformulation, from 360 different formulations. It emerged that frozen pizzas offered the better compromise for environment and health. This example shows the value of developing methodologies and indicators to manage the numerous food product properties that must be balanced.

Multi-criteria analyses also show the changing power dynamics between stakeholders. This change in turn disrupts the trade-offs and weightings between the different properties. Consumers' expectations of ‘naturalness’ and their desire for greater ‘ethical value’ in their food stem from the link they make between health, ethics and food. Private initiatives have recently begun to address these expectations. The ‘C'est le patron? (*Who's the boss?*)’ brand, for example, makes it possible to set the level of commitment expected, and to calculate the ‘fair’ price based on the costs associated with different consumer choices. Digital technologies are in demand, particularly with the development of numerous mobile applications. One example, Yuka, is already in operation. It rates food products by combining their nutritional quality, based on the Nutri-Score (60%), additives (30%), and an environmental dimension through the OA or non OA certification of products (10%). Another project currently being developed by private actors "What's this product?" takes the multi-criteria approach further by identifying the best product according to the criteria that the consumer will have chosen in relation to his or her personal preferences. Nevertheless, the trade-offs incorporated into these different tools and applications require complete transparency regarding their specifications in order to provide a multi-criteria analysis valid for all.

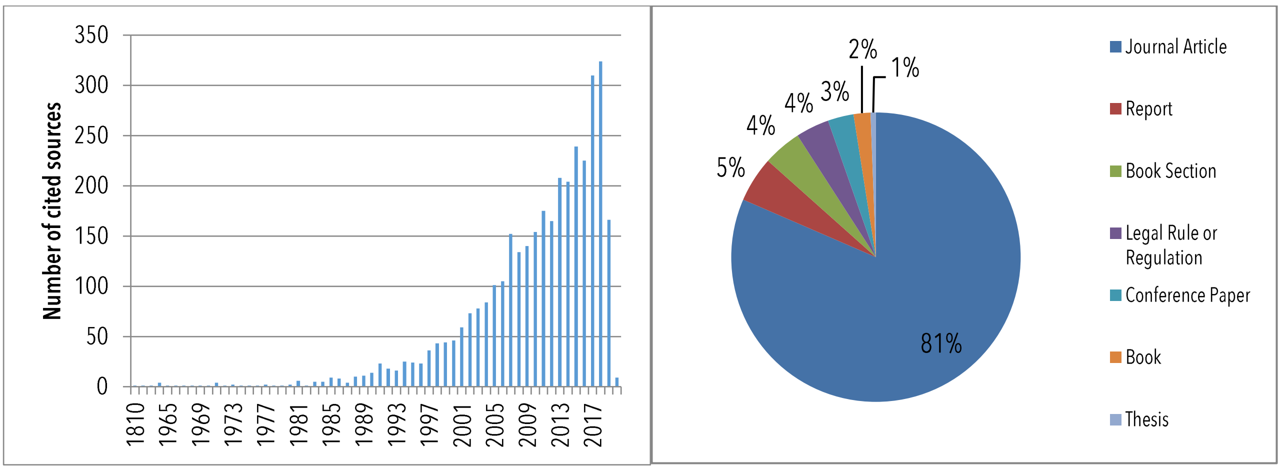
The collective scientific assessment approach (ESCo)

An ESCo consists of an overview and critical analysis of the current state of scientific knowledge. It provides an overview of the debates and controversies among scientific communities, the uncertainties that must be considered when interpreting the results, and the gaps in knowledge that should be addressed in future studies. The ESCo is therefore a reflection of the data and bibliographical references that are available. It does not formulate opinions or recommendations. The work is conducted based on a charter of scientific expertise, according to the general principles of competence, impartiality, plurality and transparency.

The group of experts brought together for this ESCo includes 20 researchers (40% of whom are external to INRAE). Their disciplines range from animal science, food science, human health, to economic and social sciences (Figure 6).

The bibliographic collection was compiled by searching the Web of Science™ and PubMed databases. The references were selected by the experts based on their disciplinary expertise. The final bibliography comprises approximately 3,500 references, 81% of which are primary articles, reviews and meta-analyses, 62% of which were published over the last 10 years. The collection was assembled from the initial research and monthly literature watch conducted by librarians (Girard A., Le Perchec S.), as well as references from experts.

Figure 6. Bibliography: temporal distribution of cited sources (left) and classification of documents (right)



6 Public policy options and research needs

This study has highlighted issues related to the production, processing and consumption of animal-based food. The table below lists the main options for public action and research needs, all of which reflect observed and analysed situations (Table 5).

Table 5. Policy Options and Research Needs

	Lessons from the ESCo	Public policy options	Research needs
Consumers	Increased consumer expectations on production and processing conditions, and need for reassurance Rapidly changing behaviours and consumer expectations	Information campaigns, labelling Observatory A system to anticipate trends in the consumption of animal-based foods	Anticipate changes in consumer expectations and behaviours Create innovative solutions Develop labelling systems Study new practices (such as eating less animal based origin but more substitutes) and their consequences
	Loss of culinary knowledge in favour of 'ready-to-eat' foods	Improve education	Assess culinary practices at home and promote participative action research to identify needs of consumers
Health	Current knowledge does not permit food production and processing conditions to be taken into account with regard to health effects		Better understand the links between health and food production and processing conditions, including ultra-processing
	Some food classifications are used for nutritional recommendations, labelling and digital technologies. However, they are still being debated in the scientific community.	Supervise/accompany the development of digital applications for food choices.	Refine methodologies and classifications, by taking into account the food production processes.
Production and processing	Commercial properties take precedence over the other properties that make up quality; the quantity produced is given precedence, with little consideration of other quality criteria, especially for standard products.	Support collective actions that incite all stakeholders to better take into account the different dimensions of quality Support the development of SIQOs and respect for animal welfare Support the transition of farming systems towards the production of quality animal-based origin	Take better account of the various aspects of quality, for example in consumer information, payment to farmers and genetic selection. Build/create transitions towards farming systems and practices favourable to the quality of animal-based origin
	Lack of information and research on the fate of animals that are not of value, given the current business models	Support stakeholders in the change to production systems that make better use of animals that do not fit into current commercial production models, thus keeping as many animals as possible in the food chain (short distribution chains, development of quality labels, etc.).	Develop innovative solutions to improve the value of animals of both sexes, and to extend the productive lives of females.
	Lack of meta-analyses on the quantification of the effects of production and processing factors on food quality		Carry out meta-analyses to obtain a more robust quantitative assessment of the effect of different factors affecting quality.
	Importance of the pre-slaughter and slaughter stages on meat and flesh quality	Limit stress by a better coverage of the territory by slaughterhouses.	Assess the risks (sanitary, animal welfare) associated with mobile abattoirs. Develop procedures to control these risks and better manage the by-products and waste produced during the slaughter process.
Quality Management	Emerging research on functional units that consider product quality. Many approaches only consider a single quality property, and do not integrate various properties; but multi-criteria approaches are being developed (none of which yet includes all properties). Only few minimally or non-invasive tools available to assess and manage variability in quality		Develop multi-criteria approaches and tools to manage antagonisms and the conflicts between quality properties and between stakeholders. Develop minimally invasive tools to assess and manage variability in quality.
	Increasing demand for guarantees on the production and processing conditions and on the origin of food.	Adapt controls consistent with the intensification of international trade.	Develop and test authentication methods that are transferable to operators.

For more information

Prache S. et Santé-Lhoutellier V. (lead scientists), Adamiec C., Astruc T., Baeza-Campone E., Bouillot PE., Clinquart A., Feidt C., Fourat E., Gautron J., Girard A., Guillier L., Kesse-Guyot E., Lebret B., Lefevre F., Le Perchec S., Martin B., Mirade PS., Pierre F., Raulet M., Remond D., Sans P., Souchon I., Donnars C., 2020. La qualité des aliments d'origine animale selon les conditions de production et de transformation, Synthèse de l'expertise scientifique collective, INRAE (France), 111 pages.

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