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Review: Quality and authentication of organic animal products in Europe

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ABSTRACT

The 'organic' label guarantees a production process that avoids the use of synthetic fertilisers, pesticides and hormones and minimises the use of veterinary drugs; however, consumers are demanding guarantees regarding food quality. This article reviews the current state of knowledge on the quality of organic animal products, including the authentication of their organic origin. Quality has been considered as an integrative combination of six core attributes: commercial value, and nutritional, sensory, technological, convenience and safety attributes. The comparison of these attributes between organic and conventional animal products shows high heterogeneity due to variability in farming pratices in both organic and conventional systems. To overcome this, we pinpoint the farming practices underlying the differences observed. This enables light to be shed on the consequences of possible trajectories of organic farming, if specifications are relaxed or tightened up on commitments concerning farming practices that impact product quality. Two recent meta-analyses showed better nutritional attributes in organic milk and meat linked to their higher poly-unsaturated fatty acid (**PUFA**) content, particularly n-3 PUFAs. Regarding safety, we point to a lack of integrated studies quantifying the balance between positive and negative effects. Organic farming reduces the risk of drug residues and antibiotic resistance, but both outdoor rearing and a frequently longer rearing period increase the animals' exposition to environmental contaminants and the risk of their bioaccumulation in milk, eggs, meat and fish flesh. We highlight antagonisms between quality attributes for certain animal products (lamb, pork). In general, attributes are more variable for organic products, which can be explained by lower genetic selection (poultry), lower inputs and/or greater variability in farming conditions. However, the literature does not address the implications of this greater variability for the consumers' acceptability and the necessary adaptation of manufacturing processes. Further research is needed to document the impacts on human nutritional biomarkers and health. Methods used to authenticate organic origin are based on differences in animal diet composition between organic and conventional systems, but their reliability is hampered by the variability in farming practices.

Implications

The 'organic' label guarantees a production process but consumers are demanding guarantees regarding food quality. This review highlights heterogeneity from studies comparing the quality of animal products in organic vs conventional systems, which stems from the huge diversity of farming practices in both organic and conventional systems. We endeavoured to overcome this difficulty by pinpointing the farming practices and conditions underlying the differences observed, shedding light on the consequences of possible trajectories of organic farming, if specifications are relaxed or, on the contrary, tightened on commitments concerning farming practices impacting the quality of products.

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Introduction

Demand for organic animal products is surging across Europe, backed up by European public policy that endorses organic farming systems as part of the European Commission's "Farm to Fork Strategy for a fair, healthy and environmentally friendly food system" in support of the wider EU Green Deal (EC, 2020). Consumers choose organic food to stay healthy, to steer clear of contaminants, to eat better-quality and better-tasting foods, and for ethical motives (environmental consciousness and animal welfare) (Baudry et al., 2017a). Price remains a huge barrier to buying organic and a significant proportion of consumers show moderate confidence in the information provided on organic products and express doubts that the product is fully organic (Agence Bio, 2019). EU regulation on organic agriculture is designed to assure that organic systems use environment-, health- and animal welfare-friendly methods. Organic livestock farmers commit to respect specifications governing animal care, welfare, feeding and housing. Organic specifications ban the use of chemical fertilisers, pesticides and hormones and heavily restrict the use of synthetic drugs and food processing additives. Organic regulations and associated inspections guarantee certified-organic foods are produced in systems that adhere to these methods (production process guarantees), but consumers are demanding clearer and tighter guarantees on product quality and associated production and processing conditions (EC, 2021). Here, we review the state-of-the-art of science on the quality of organic animal products. The paper covers the impacts on human health and the possibilities of authenticating the product as organic. Product quality is considered as a combination of six attributes: commercial value, nutritional, sensory, safety, technological and convenience (Prache et al., 2022a).

A pluridisciplinary scientific expertise

This paper summarises the main lessons regarding the quality of organic animal products from collective scientific expertise dedicated to the quality of animal-source foods (Prache et al., 2020a and b). This expertise was carried out by INRAE, at the request of the French Ministry of Agriculture and FranceAgriMer (public agency dedicated to trends and challenges in agriculture). Twenty public scientists were involved including specialists in cattle, sheep, pig, poultry and fish farming, food processing, economy, sociology, law, human nutrition, toxicology, epidemiology, microbiological and chemical food safety. The bibliographic collection was compiled by searching the Web of Science™ and PubMed databases. The collection was assembled from the initial research and monthly literature watch conducted by two librarians as well as references from the experts.

Variability in findings from comparisons between organic vs conventional animal products

The heterogeneity of farming practices in both organic and conventional systems puts substantial limits on efforts to extrapolate findings from research led in different countries and contexts. This same conclusion surfaced in two meta-analyses (Srednicka-Tober et al., 2016a; 2016b) which compared the nutritional properties of organic vs conventional meat and dairy, and in a systematic review (Van Wagenberg et al., 2017) focused on the sustainability of organic vs conventional livestock systems. The diets fed to organically farmed ruminants generally contain more forages and less concentrates, but the reverse is true in some settings, as in certain intensive organic dairy (Kusche et al., 2015) or sheep farming systems where organic lambs are produced outside the grazing season, or due to harsh cold climate conditions or parasitism (Prache et al., 2009; Srednicka-Tober et al., 2016b). There are also certain non-organic but extensive ruminant farming systems, with livestock fed nearly a 100% grass-based diet (Priolo et al., 2001; Schwendel et al., 2017; Benbrook et al., 2018; Davis et al., 2020; Prache et al., 2021b). Daily time at pasture, length of the pasture-finishing period for meat animals, nature of the pasture, dietary proportions of fresh and conserved forages and of concentrate can also prove extremely variable in both organic and conventional farming systems. All of these factors affect the quality of ruminant products (Priolo et al., 2001; Martin et al., 2019; Prache et al., 2021b). The heterogeneity of the results observed for pigs indicate that pork quality attributes are not directly determined by the specifications set by organic production standards, but rather depend on on-farm factors (pig genotype, feeding, housing conditions…) that the farmer adopts to meet the specifications. Consequences of these on-farm factors on the various pork quality attributes are detailed in the sections below and summarised in Table 1. Results show that, ultimately, the quality of organic pork products can be better—or, conversely, poorer—as compared to conventional production.

Organic farming in Europe compels a core model of production standards that was recently updated (EU regulations 2018/848 and 2020/464 coming into force in January 2022). However, there are national disparities and specificities in the way member states apply the EU-scale regulation (Prache et al., 2020b). In France, the National Institute for Quality and Geographical Indications publishes guidance to iron out interpretative differences between people involved in the organic commodity chain—including the certification agencies and authorities. However, this is specific to France; Germany, Italy and the three regional communities of Belgium also have their own transpositions of the EU regulation (Prache et al., 2020b), although these national/regional guidelines are not inventoried at the pan-European level. Some of the features are gathered by the commodity chains, but have not been studied in the scientific literature. Divergences in standards stem from definitional issues (definition of a slow-growing strain, of a 'region' relating to the feed origin), interpretational issues (density calculated with or without aviary space, outdoor access for poultry; in pig housing, proportion of the outdoor area with shelter (roof) and with concrete floor, nose ring for sows (with procedures to take into account animal pain); withdrawal period after administering a veterinary drug) and administrative authorisations for exemption (grazing or mowed grass) (Prache et al., 2020b). For example, slaughter age for organic broilers is at least 81 days in France, but just 70 days in the EU regulations, which could have a huge impact on meat quality (Baéza et al., 2022). In addition, cultural differences, especially in hedonic assessments of sensory attributes (Prache et al., 2021b), add a further layer of complexity. All variations in livestock farming practices, organic production standards implementation, and cultures ultimately converge to complicate the task of analysing the published science and generalising findings. We overcame this difficulty and gained genericity by pinpointing the farming practices and conditions underlying differences in product quality attributes observed in the published studies.

Quality attributes of organic vs conventional animal products

Commercial quality attributes

As organic ruminant systems use more forage (especially grazed pasture) and less concentrates and veterinary drugs, organically reared ruminants could be more heavily exposed to weather, diet and parasite hazards. Organically farmed sheep and cattle are therefore at greater risk of presenting a lower carcass weight and

Table 1
Carcass and pork quality from different organic pig production systems compared with conventional production: effects of farming practices.[1]

Quality attributes	Indoor organic (home-grown feedstuffs, imbalanced in AA[2]) vs conventional Individual pens (2.5 m^2/pig) in both systems (Sundrum et al., 2011)	Indoor, organic diet (main protein sources: faba bean, pea, lucerne meal, soybean cake) vs conventional (soybean meal, synthetic AA) Collective pens (1.2 m^2/pig) in both systems (Quander-Stoll et al., 2021)	Organic (EU regulation: indoor straw bedding + outdoor area, 2.2 m^2/pig; organic feed: no synthetic AA + roughage) vs conventional (concrete floor, 0.7 m^2/pig) (Alvarez-Rodriguez et al., 2016)	Organic (indoor pen + outdoor area) + organic feed, either ad libitum without roughage (A) or restricted + ad libitum roughage: barley/pea silage (B) or restricted + ad libitum roughage: clover grass silage (C) vs conventional (Hansen et al., 2006)	Extensive outdoor organic (KRAV Swedish certification: 150 m^2/pig + hut with straw; feed: wheat, oat, peas, no synthetic AA) vs conventional (indoor, conventional feed) (Jonsall et al., 2002; Olsson et al., 2003)
Carcass commercial value	↘ lean meat content ↘ loin muscle area	= lean meat content ↘ loin muscle area		lean meat content: = for A, ↘ for B and C	↘ lean meat content
Nutritional (loin meat or backfat)		↘ MUFA[3] and ↗ PUFA[3] proportions (backfat)	= SFA[3], MUFA and PUFA proportions ↗ n-3 PUFA proportion ↘ n-6/n-3 PUFA (loin)	SFA and MUFA proportions: = for A, ↘ for B and C; PUFA proportion: = for A, ↗ for B and C (backfat) TBARS[4] content: = for A, ↗ for B and C (loin)	
Sensory	↗ intramuscular fat content[5] (loin)	= lightness ↗ pigment content ↗ intramuscular fat content = shear force (loin)	= lightness, ↘ redness but ↗ colour intensity ↗ intramuscular fat content (loin)	= lightness and redness for A, B, C intramuscular fat content: = for A, ↘ for B and C Tenderness, juiciness: = for A, ↘ for B and C (loin)	= lightness and redness ↘ intramuscular fat content ↗ shear force = tenderness, meat taste, off taste and off flavour ↘ juiciness (loin)
Technological		↗ pHu[6] (loin, ham) = drip and cooking losses (loin)	↘ pHu, = drip loss (loin)	= pHu and drip loss for A, B, C (loin)	↘ pHu, ↗ drip loss (loin)

[1] Organic farming corresponding to official EU specifications or experiments addressing only some practices related to organic farming (e.g. organic vs conventional diet composition).
[2] AAs = amino acids.
[3] SFAs, MUFAs, PUFAs: Saturated, monounsaturated, and poly-unsaturated fatty acids, respectively.
[4] TBARSs: Thio-barbituric acid reactive substances, indicator of lipid peroxidation.
[5] An increase in intramuscular fat content is favourable for meat texture (tenderness, juiciness).
[6] pHu: ultimate pH.

insufficient carcass fatness (Srednicka-Tober et al., 2016b; Prache et al., 2021b). Pasture-fed lamb also presents a greater risk of softer subcutaneous fat (Prache et al., 2011), which may be due to a higher proportion of legumes in the swards (Lourenco et al., 2007). Turning to cows' milk, Srednicka-Tober et al. (2016a) showed no significant difference between organic vs conventional systems for milk fat and milk protein content, even if heterogeneous results were reported. Results for somatic cell counts in raw milk are inconsistent (Srednicka-Tober et al., 2016a; Van Wagenberg et al., 2017).

In pigs, many factors including genotype, housing conditions (ambient temperature, pig space allowance), feeding level and diet composition can modulate body fatness in organic production (Lebret and Čandek-Potokar, 2021). Especially, the greater difficulty to balance nutritional supplies with animal requirements, particularly for amino acids (**AAs**) because of the ban of synthetic AA in organic production, can lead to lower lean accretion and higher fat accretion, thus reducing the carcass leanness and its market value (Sundrum et al., 2011; Table 1).

For broiler meat, conventional systems outperform organic systems on carcass and breast muscle yield, as the strains used for organic production have undergone less intensive genetic selection for lean meat production (Petracci et al., 2017). The carcass is also leaner, as the stocking density is lower and the broilers have free-ranging access to outdoors, both allowing higher locomotion activity, which reduces body fatness (Baéza et al., 2022). The bones are firmer, the skin thicker and tears less on defeathering, as a result of later slaughter age and higher locomotion. There was no major difference observed in egg commercial quality attributes between organic and conventional systems (Nys et al., 2018).

As regards farmed fish, the growth of organic ones was found sometimes higher, due to lower animal density or different feed ingredients (Trocino et al., 2012; Lerfall et al., 2016a), or not different (Di Marco et al., 2017). Some studies reported an impact on fish morphology (Lerfall et al., 2016b) or the occurrence of deformities or fin splitting (Di Marco et al., 2017). This may be related to lower density in organic systems, which promotes natural behaviour including territoriality and possible aggressive interactions. Organic products consistently carry price premiums over conventional products, for milk (from 0% to +84%), beef (+12% to 25%), broiler meat (around double the price) and eggs (2.4 times the price) (Van Wagenberg et al., 2017).

Nutritional quality attributes

Milk

An important research effort was recently carried out on cow's milk. The meta-analysis by Srednicka-Tober et al. (2016a) worked with more literature than Palupi et al. (2012), using 170 mainly Europe-based studies comparing organic vs conventional cow's milk. It concluded that organic milk had a healthier fatty acid (**FA**) composition than conventional milk. Actually, organic milk had a higher proportion of n-3 poly-unsaturated fatty acids (**PUFAs**) (+56% on average), including alpha-linolenic acid (**ALA**; +69% on average) and long-chain (**LC**) n-3 PUFA (+57% on average). There was no difference in protein and fat contents, and in saturated FA (**SFA**), monounsaturated FA (**MUFA**) and n-6 PUFA proportions. Organic milk also had better n-6:n-3 PUFA (-71% on average) and linoleic acid (**LA**):ALA ratios (-93% on average), indicating higher nutritional value of organic than conventional milk. Benbrook et al. (2018) and Davis et al. (2020) however pointed out that there was scope to further improve the FA-profile of milk through increasing forage in dairy diets. Srednicka-Tober et al. (2016a) calculated that consumption of half a litre of full-fat milk (or equivalent fat intakes with dairy products) provided 16% (39 mg) vs 11% (25 mg) of recommended daily LC n-3 PUFA intake with organic vs conventional milk. Organic milk also had a higher vitamin E content (+13% on average). These compositional differences were associated to feeding differences, with higher grazing/-conserved forage and lower concentrate/maize silage diets and generally higher proportions of forage legumes in organic systems (Bahar et al., 2008; Prache et al., 2011). Forage legumes are leafier and hence more lipid-rich than grasses and transit faster through the rumen thus undergoing less advanced biohydrogenation (Lourenco et al., 2007). Nevertheless, the source-material studies included in the meta-analysis by Srednicka-Tober et al. (2016a) reported heterogeneity in the results, which the authors explained by the huge diversity in farming practices in both organic and conventional farming systems. The differences between organic and non-organic milk are thus narrower, or even non-existent, if the non-organic milk comes from an extensive grassland-based system (Schwendel et al., 2017; Pustjens et al., 2017). The question of whether intensifying farming practices affects the quality of organic milk was studied by Kusche et al. (2015). They showed that replacing part of dietary fresh pasture with maize and grass silages and increasing concentration levels to raise per-cow yields on organic farms brings organic milk FA composition closer to that of conventional milk. Srednicka-Tober et al. (2016a) noted the small number of studies on processed dairy products. However, they found similar trends for fat composition parameters (total n-3 PUFA and LC n-3 PUFA), which is unsurprising, given that milk processing techniques have little or no impact on dairy product FA-profile (Lucas et al., 2006). These authors also inventoried studies comparing the nutritional quality attributes of sheep and goat milk and dairy products in organic vs conventional systems, but there were too little comparative data to draw robust conclusions. This meta-analysis further concluded that organic milk had a higher iron (Fe; +20% on average) and lower iodine (I; −74% on average) and selenium (Se; −21% on average) contents than conventional milk. The higher Fe content was considered without nutritional impact for consumers, as milk is not a staple source of iron. The reasons put forward to explain the lower I content of organic milk were i) organic systems use less concentrate feed, ii) unlike organic concentrate, conventional concentrate is routinely packed with mineral supplements, and iii) organic systems make less use of I teat disinfection. The reasons put forward to explain the lower Se content of organic milk were the lower concentrations of added Se in organic feed supplements and in organic fertilisers. The authors added that the impacts of I and Se are largely inconsequential and that it is relatively easy to supplement human diet with both elements. They calculated that replacing half a litre of conventional full-fat milk with organic milk would reduce daily intake in iodine from 88% to 53% and in Se from 13% to 11% of recommended daily intake. The meta-analysis found non-significant differences in organic vs conventional milk for other vitamins (A, C, D3) and minerals (Ca, Cd, Co, Cu, Mg, Mn, Mo, P, K, Na, Zn), as well as for lead (Pb), the latter being always below the regulatory threshold concentrations.

Meat

Srednicka-Tober et al. (2016b) is the first meta-analysis published to date. It compiled the results of 67 studies giving compositional data comparing organic and conventional beef, lamb or goat, pork and poultry meat. Only certain groups of FA were analysed, as the number of datapoints was insufficient to meaningfully analyse individual FA and mineral, antioxidant, vitamin, metal and pesticide concentrations. The authors first pooled data from all animal species and analysed the outcomes species-by-species on a far smaller number of studies. When pooling all animal species, they concluded that organic meat had higher proportions of PUFA (+23% on average) especially n-3 PUFA (+47% on average) and lower proportions of C14:0 (-20% on average) and C16:0 (-10% on average). However, this meta-analysis carried a potential bias, as the organic meat was leaner on average than the conventional meat, which may partly explain the higher proportions of PUFA and n-3 PUFA in the organic meat. As animals increase in carcass fat, the proportion of storage lipids (high in SFA) increases relative to membrane lipids (high in PUFA), which means that leaner animals have higher relative proportions of PUFA (De Smet et al., 2004).

Regarding ruminant livestock, the reasons put forward for these organic–conventional differences for meat, like cow's milk, were a higher proportion of dietary forage, especially grazed pasture, and legumes in the forages. Organic production standards demand pasture grazing, whenever practicable, and restrict the dietary proportion of concentrate to a maximum of 40%. Many conventional systems make no such commitment, unless they are required by certain non-organic official quality sign production standards. However, the FA composition differences in this meta-analysis were narrower than the differences measured in studies comparing meat from cattle or sheep finished on grass vs concentrate/-maize silage-based diets, independent of organic certification (Berthelot and Gruffat, 2018). These authors showed concentrations of total n-3 PUFA and LC n-3 PUFA eicosapentaenoic, docosapentaenoic and docosahexaenoic acids were 2.3-fold, 3.1-fold, 2.3-fold and 2.0-fold higher, and n-6:n-3 PUFA ratio 72% lower in grass-finished vs maize silage-finished beef. Furthermore, Provenza et al. (2019) observed knock-on effects on plasma concentrations of docosapentaenoic and docosahexaenoic acids in consumers. The lower concentrations of nutritionally valuable FA and the broad heterogeneity in the results may be explained by the variability in farming practices, especially feeding, in both organic and conventional farming systems. There is therefore substantial scope for improving the concentration of beneficial FA in meat from both organic and conventional systems. Note that as these FA composition differences between organic and conventional meat are mainly linked to feeding regimens and especially the higher use of forage and pasture grazing in organic farming, there is a risk of variability in these quality attributes tied to the variability in grassland characteristics and management practices.

For broiler meat, the authors concluded that organic chicken had higher proportions of PUFA (+40% on average), n-3 PUFA (+66% on average), n-6 PUFA (+50% on average) and LA (+10% on average), and lower proportions of SFA (essentially C14:0; −65% on average) and MUFA (−20% on average). Note that the bias on FA composition profile linked to total fat content of the meat was particularly strong for chicken, as organic chicken meat had 50% less fat. Organic production use breeds with low growth rate that are more active than breeds selected for high growth rate and used for conventional production. Moreover, organic chickens are reared at low density with an outdoor access that favours locomotion activity, altogether leading to less fat deposition (Baéza et al., 2022).

For pork, results varied widely between studies. Srednicka-Tober et al. (2016b) found proportionally lower MUFA and higher PUFA, but there were too few studies to rule on the proportion of n-3 PUFA. Karwowska and Dolatowski (2013) (not included in the meta-analysis) showed a lower proportion of PUFA and n-3 PUFA, associated with lower lipid oxidation in organic pork after 7 days storage. In contrast, Alvarez-Rodriguez et al. (2016) found equivalent proportions of SFA, MUFA and PUFA but a higher proportion of n-3 PUFA and a lower n-6:n-3 PUFA ratio in organic compared with conventional pork. Srednicka-Tober et al. (2016b) underscored that, unlike for ruminants, there were little data from controlled experiments to explain the results for monogastric meats. They explained the differences found between organic and conventional meat by the fact that organic standards for monogastrics prescribe free access to forages, which increases the proportion of PUFA. They also noted that organic standards-compliant soya meal had to come from cold-pressed oilseed and so had a naturally higher oil content than the chemically extracted soya meal used in conventional systems. This feedstuff essentially delivers n-6 PUFA, which could explain the higher proportions of LA and n-6 PUFA found in organic chicken meat. Furthermore, regular dietary delivery of an n-3 PUFA-rich feed supplement to monogastrics can repeatably and controllably increase their meat n-3 PUFA concentrations (Baéza et al., 2022; Lebret and Čandek-Potokar, 2021). Based on the species-stratified results of their meta-analysis and meat consumption in the EU, Srednicka-Tober et al. (2016b) calculated that switching from conventional to organic meat would increase PUFA and n-3 PUFA intake from meat by 17% and 22%, respectively, without change in dietary n-6:n-3 PUFA ratio.

Eggs

Egg nutritional attributes depend on the composition of the hen's diet independently of the housing system (Nys et al., 2018). Few studies have produced documented comparative FA composition data on organic vs conventional eggs. A recent study showed that giving layer hens free-ranging access to pasture improved the yolk FA-profile and antioxidant content (Mugnai et al., 2014): yolk from organic eggs had higher concentrations of n-3 PUFA, especially ALA and docosahexaenoic acid, and lower concentrations of n-6 PUFA, which translated into a lower n-6:n-3 PUFA ratio (in ranges that went from 8.6–11.5 to 1.9–3.6 depending on the season). It also had higher alpha-tocopherol, flavonoids and carotenoids contents, all of which are antioxidants. However, although this nutritionally beneficial FA-profile in organic eggs, differences remained low and the FA-profile of yolk was still less favourable for human nutrition compared to the profile achieved by recomposing the layer-hen feed, independently of organic vs conventional system (Prache et al., 2020b).

Fish

Lerfall et al. (2016a) reported higher PUFA content and lower n-6:n-3 PUFA ratio (0.30 vs 0.83) in organic vs conventional fillet from farmed Atlantic salmon, due to the higher dietary proportion of marine origin ingredients in organic salmon diet. Two studies compared the FA-profile in organic vs conventionally farmed sea bass flesh, with divergent results: LC n-3 PUFA content was higher in organic sea bass according to Trocino et al. (2012), but was lower in the study by Di Marco et al. (2017). This divergence came from compositionally different feeds, as in the study by Di Marco et al. (2017), the organic feed contained fish meal and soya (which has no LC n-3 PUFA) whereas the conventional feed did not contain soya. It thus emerges this commodity chain features a degree of variability in farming practices, especially feed composition, in both organic and conventional systems, which precludes any meaningful conclusions.

Sensory quality attributes

Organic ruminant feeding includes a greater part of forage than conventional production, leading to potentially dark meat (Priolo et al., 2001; Prache et al., 2021b). Crucially, a higher risk of off-flavours has been reported in organic lamb (Prache et al., 2011), as organically farmed lambs are more frequently pasture-finished, on pastures that have a higher proportion of white clover, and organic lambs are slaughtered at later age (Prache et al., 2021b). Note, here, that flavour liking and sensitivity to flavour intensity vary strongly between countries (Prache et al., 2021b).

Some studies found little difference in organic vs conventional cow's milk and dairy products on flavour, texture (Schwendel et al., 2015; Smigic et al., 2017), and volatile compounds

(Schwendel et al., 2017). Gallina Toschi et al. (2012) also showed that consumers and trained sensory panels failed to differentiate yogurt made with organic vs conventional milk. Other studies reported that raw organic milk was creamier and tended to have stronger 'hay' and 'grass' flavour notes than conventional milk (Bloksma et al., 2008). Regardless of production system, organic or conventional, a stronger odour of milk and cheese (more intense 'animal' notes) has often been reported when cows are pasture-fed vs fed on conserved forages (Manzocchi et al., 2021).

In monogastrics, the constraints that come with organic standards on organic-compliant feedstuffs potentially affect the sensory attributes of the meat (Lebret and Čandek-Potokar, 2021). The greater risk of deficient intake in limiting AA in organic pork can lead to higher intramuscular fat content (Sundrum et al., 2011; Quander-Stoll et al., 2021), which is positive for key sensory traits (tenderness, juiciness) of the meat (Lebret, 2008; Table 1). On the opposite, the need to include forages in the diet may be associated with limited supply in concentrated feed (i.e. feed restriction), leading to reduced intramuscular fat content with negative impact on pork tenderness (Hansen et al., 2006). Other on-farm factors tied to organic production principles can also influence these quality attributes. Studies reported that compared to conventional pork, outdoor-raised organic pork scored lower on juiciness associated with a lower ultimate pH (**pHu**) and higher moisture loss, but without significantly affecting consumer preference in blind taste tests (Jonsall et al., 2002; Olsson et al., 2003). These examples illustrate how the sensory attributes of organic pork are largely dependent on on-farm practices (i.e. feeding regimen and housing) in interaction with breed genotypes (Lebret and Čandek-Potokar, 2021). The divergent impacts of farming practices on carcass and meat quality of organic pork are summarised in Table 1.

Organic broilers are slaughtered at a later age than standard broilers, and so their meat is darker, redder, firmer and less juicy with a more pronounced flavour (Baéza et al., 2022). As artificial colourings are prohibited in organic production standards, organic eggs can have a paler yolk (Nys et al., 2018); similarly, the colour of organic farmed salmon fillet is modified, but this difference is strongly mitigated by the salting-smoking process (Lerfall et al., 2016a and b).

Technological and convenience quality attributes

Organic farming uses slow-growing broiler strains not selected for breast muscle yield and slaughtered at a later age than conventional broilers. Compared to conventionally farmed chicken, organic chicken presents breast muscle with a lower pHu, which results in lower water-holding capacity and consequently lower postprocessing technological yield (Baéza et al., 2022). Organic chicken thus had inferior technological quality attributes to conventional broiler meat (Castellini et al., 2002). Likewise in pork, a lower pHu, associated with lower processing yield, was reported from organic pigs reared outdoors (Olsson et al., 2003) or indoors on deep bedding with access to outdoors (Alvarez-Rodriguez et al., 2016) compared to conventionally farmed pigs. This could be explained by higher muscle glycogen stores in response to lower ambient temperature (Lebret, 2008). By contrast, Quander-Stoll et al. (2021) reported a higher pHu in loin and ham from pigs reared indoors and fed on organic vs a conventional diet. These authors associated the higher pHu with reduced muscle glycogen as a result of higher crude fibre content in the organic diet. However, this did not affect other quality traits such as drip and cooking loss (Quander-Stoll et al., 2021). This again illustrates the indirect effect (via on-farm factors) of organic-system production on meat quality attributes, and the greater variability in characteristics of organic meat associated with greater variability in organic farming conditions (housing: space allowance, ambient temperature; feeding, etc.; Table 1).

There is very little published science on the convenience attributes of organic animal products. In ruminants, pasture-feeding (which organic standards endorse) increases meat and dairy oxidative stability, due to the antioxidants found naturally in pasture herbage (Provenza et al., 2019; Gruffat et al., 2020). This effect is also observed in pigs reared in extensive systems with access to rangeland, whatever the production system (organic or conventional) (Lebret and Čandek-Potokar, 2021; Lebret et al., 2021). In farmed fish, Lerfall et al. (2016b) and Di Marco et al. (2017) did not observe any difference in product freshness, shelf life and colour stability during storage between products originated from organic vs conventional systems.

Safety quality attributes

These quality attributes are a leading concern in both the regulations (where organic agriculture is to prioritise "the use of processes that do not harm the environment [or] human health"; Council Regulation (EC) No°834/2007) and for consumers (Baudry et al., 2017a). Organic vs conventional comparisons on food safety came up with divergent results for different risks. There is a patent lack of integrative studies quantifying the balance between positive and negative effects and ranking the risks in relation to amounts consumed. Organic farming reduces the risks of drug and antibiotic residues (Smith-Spangler et al., 2012; Van Wagenberg et al., 2017), but it also keeps animals longer on-farm with free access to outdoors, which could increase their exposure to environmental contaminants and thus the risk of bioaccumulation in animal products (Dervilly-Pinel et al., 2017).

Microbiological hazards

Studies have targeted the predominant hazards for each animal species. For milk, the review by Van Wagenberg et al. (2017) shows no differences between organic and conventional systems, and as do the handful of studies on beef and eggs. For broilers, studies showed a higher prevalence of *Campylobacter* in organic vs conventional farms (Van Wagenberg et al., 2017) and a greater risk of *Campylobacter* contamination in organic vs conventional broiler meat (Baéza et al., 2022), as the birds spend longer on-farm with free-ranging outdoor access. Studies were split on the organic vs conventional differences in risk of *Salmonella* in broilers: some found a higher prevalence in organic systems, whereas some found a lower prevalence and others still report no difference (Baéza et al., 2022). Studies found no differences between conventional vs free-range systems on prevalence of *L. monocytogenes* in broiler chickens (Van Wagenberg et al., 2017). In pork, this review showed a greater risk of *L. monocytogenes* contamination in organic systems. These authors however flagged the fact that most studies lacked correction for biases from confounding effects, typically processing-line hygiene.

Chemical risks

Chemical contaminants in animal products are not intrinsically linked to the farming system *per se*, but result from a nexus of interactions: the exposure-source vectors (via the environment, diet, contact materials and contact surfaces in the livestock barns), contamination levels in each of these sources or timeframe, and livestock-system productivity level. An early exploratory review (Smith-Spangler et al., 2012) showed broiler meat from alternative systems contained less drug residues and detectable pesticide residues than meat from conventional systems. A later study on a large sample set of both organic and conventional beef, pork and chicken farmed in France (Dervilly-Pinel et al., 2017) observed that all samples were below detection limit for the 121 monitored pesticides or coccidiostats; antimicrobial substances were detected in only 11 out of 126 samples, without any difference between both production systems. In contrast, organic samples contained higher traces of environmental contaminants (dioxins, polychlorobiphenyls, hexabromocyclododecane, As, Cd and Pb), although all levels were far below regulatory limits. The reasons put forward to explain this greater bioaccumulation of environmental pollutants in organic meat were higher exposure due to outdoor free-ranging access, for longer on-farm rearing. For these same reasons, higher contamination was also found in *Label Rouge* pork and poultry (Dervilly-Pinel et al., 2017). Very little work compared chemical risks in organic vs conventionally farmed milk (Van Wagenberg et al., 2017). For table eggs, a farming system effect was clearly demonstrated on levels of the most closely monitored contaminants (polychlorodibenzo-dioxins and –furans, and polychlorobiphenyls): eggs from production systems providing free-range access to outdoors, including organic systems, showed on average higher and more variable contamination levels than eggs from indoor systems (EFSA, 2012). These differences did not occur systematically, as access to outdoors is only one factor that can be compounded by a genotype- and management-related vulnerability (exploratory foraging behaviour and rate of lay). Greater exposure can therefore be compounded by greater vulnerability in free-ranging systems (whether they are organic or not), that are less-productive, as the hens are slower to excrete pollutants *via* the eggs. Studies showed that free-range eggs can contain more dioxins due to greater contact with soil, a potentially significant dioxin reservoir (Waegeneers et al., 2009). Research has also demonstrated a correlation between polychlorodibenzo-dioxins and –furans, polychlorobiphenyls, polybromodiphenylether and Pb concentrations in eggs and in the soil (Wageneers et al., 2009). Most samples in Europe that overshoot the regulatory thresholds for persistent organic pollutants in eggs tend to come from backyard hens and rarely from professional operations with outdoor access (Prache et al., 2020b).

The organic standards governing salmonid farming pre-empt the potential for farm-ecosystem contamination by setting prerequisite classification of watercourses or otherwise analysis of water concentration for Hg, Pb, Cu, Zn and cyanide compounds, as well as a risk assessment for persistent organic pollutants. However, there is still no published scientific data as an evidence base for assessing the impact of these obligations on fish flesh contamination. Beyond water quality, the level of persistent organic pollutant contamination in flesh from carnivorous farmed fish, like salmonids, sea bass and seabream, is also largely dependent on the composition of the feeds, fishmeal and fish oil being the ingredients that contain the highest levels of accumulated persistent organic pollutants compared to terrestrial plant ingredients. Here, a greater risk has been pointed for organic aquaculture, as the organic standards impose a minimum dietary proportion (40%) of fishmeal for carnivorous fishes, higher than the level currently practised in conventional farming (28% and falling) (Mente et al., 2011). The fact that environmental pollutants accumulate throughout the trophic chain makes it harder to control the risks of fish feed contamination in organic aquaculture except preselecting fishmeals by geographic origin or treating fish oils. There are very few scientific studies comparing contaminant levels in organic vs conventional fish, but EFSA (2012), albeit on small sample populations, showed higher levels of polychlorodibenzo-dioxins and –furans and dioxin-like polychlorobiphenyl contamination in organic vs conventionally farmed salmon. However, the trend towards increasing terrestrial plant-based ingredients in conventional salmon farming could emerge fresh risks associated with other pollutants such as pesticides, mycotoxins, and polycyclic aromatic hydrocarbons.

Human health

Reducing antibiotic resistance is a major public health challenge, and currently, all animal sectors are committed to reducing the use of antibiotics. In organic production, this commitment has been included in the specifications since their creation. Organic livestock systems thus use less antibiotics (Van Wagenberg et al., 2017) which reduces bacterial resistances to antimicrobials compared to conventional systems—this holds true for dairy farms as well as for beef cattle, broilers, pigs, layer hens and fish (Smith-Spangler et al., 2012; Van Loo et al., 2012; Van Wagenberg et al., 2017).

There are still relatively little scientific publications on the effect of eating organic food on human health. Recent studies comparing ‘high’ vs ‘low’ consumers of organic food found beneficial effects of eating more organic food, including lower risk of diabetes (Sun et al., 2018; Kesse-Guyot et al., 2020), metabolic syndrome (Baudry et al., 2017b), obesity (Kesse-Guyot et al., 2017), and developing cancer (Baudry et al., 2018a), with beneficial blood fatty acid profiles (Baudry et al., 2018b). Some of these studies did not separate animal-derived products from plant-derived products. Other studies considered the various animal-derived products. Baudry et al. (2017b) thus showed that eating organic dairy was associated with prevalence of metabolic disorder, whereas eating organic meat was not, and Sun et al. (2018) showed that the frequency of organic dairy and egg purchase was associated with prevalence of diabetes, whereas the frequency of organic meat purchase was not. Likewise, Kesse-Guyot et al. (2020) observed that eating organic meat, fish and dairy was not associated with risk for diabetes. Nevertheless, the evidence base is still too small to draw robust conclusions.

Discussion on quality attributes of organic animal products

Antagonisms between different quality attributes

For some products, the organic label has been shown to have positive effects on some quality attributes but negative effects on others. Lamb offers an illustrative example of these antagonisms (Table 2). Although there are strong country-specific preferences in lamb meat quality, pasture-feeding lamb, which organic standards endorse, adds to its nutritional quality attributes, but may

Table 2
Effects of organic (vs conventional) farming on carcass and meat quality in pasture-fed lambs: an example of antagonisms between quality attributes.

Quality attributes	Effects (positive (+); negative (-))	Explanation
Nutritional	Healthier meat fatty acid profile: higher meat concentration of n-3 PUFA[1] and lower n-6 PUFA/n-3 PUFA ratio (+) (Bauchart et al., 2012; Kocak et al., 2016; Srednicka-Tober et al., 2016b)	Legumes (generally found in higher proportion in organic pastures) are more lipid-rich and undergo less advanced ruminal biohydrogenation than grasses (Lourenco et al., 2007)
Commercial	Increased risk of softer subcutaneous fat (-) (Prache et al., 2011)	Higher PUFA/SFA[1] ratio in subcutaneous fat linked to higher proportion of legumes in plant pastures (Lourenco et al., 2007)
Sensory	Increased flavour and risk of off-flavours[2] (-) (Prache et al., 2011; Kocak et al., 2016)	Higher meat skatole and indole content, linked to generally higher proportion of white clover in plant pastures (Schreurs et al., 2008)

[1] SFAs, PUFAs: Saturated and poly-unsaturated fatty acids, respectively.
[2] Depending on consumer preference, with strong country-specific preferences; however, in most markets, excessive flavour in lamb meat is undesirable (Prache et al., 2021b).

degrade its sensory (darker meat, higher risk of off-flavours) and commercial attributes (higher risk of insufficient carcass fatness) (Prache et al., 2021b). Organic production can amplify these antagonisms, due to the higher proportion of white clover generally found in organic pastures (Table 2). White clover is essential for organic ruminant farming, as it fixes nitrogen, and ingesting such forage legumes improves lamb FA-profile, as discussed (Prache et al., 2021b). However, grazing legumes may lead to softer subcutaneous fat (Lourenco et al., 2007; Prache et al., 2011). Most importantly, grazing white clover increases the risks of off-flavours, via an increase in the concentrations of skatole and indole, odour-taint compounds, in the lamb (Schreurs et al., 2008; Prache et al., 2011; Kocak et al., 2016; Prache et al., 2021b). Ongoing research is looking to get the benefits of white clover in pastures without the allied flavour defects. Routes being explored include using plant supplements with condensed tannins, which can reduce meat skatole and indole content without compromising its nutritional properties, using grain supplements, and switching to short-burst in-stall finishing, as skatole has been shown to be fairly quick to clear from body tissue (Prache et al., 2021b). Another route would be to educate consumers on the 'natural' characteristics inherent to pasture-fed lamb, especially in areas where stall-feeding lambs are more common.

In organic pig farming, it is hard to find the right balance of animal feed to meet nutritional requirements (especially AA). A misbalance can lead to increased carcass fatness and thus lower market-value carcasses, yet it can improve the pork sensory attributes. Pig breeds or genotypes not selected for growth efficiency and carcass leanness (i.e. 'local' breeds) have lower essential AA requirements compared with highly selected 'modern' breeds, and may therefore be more suited for low-input and organic systems (Čandek-Potokar et al., 2019). However, the overall higher production cost of local breeds and their higher carcass fatness, leading to products with different quality attributes than those of selected breeds (Lebret, 2008), need to be taken into account when designing an organic pig farming system. Free-range, outdoor rearing of organic pigs can impair the technological properties of pork (lower pHu) especially during the winter, but increases n-3 PUFA concentrations and therefore improves the nutritional attributes (Lebret and Čandek-Potokar, 2021; Table 1).

Greater variability in organic label quality attributes

The quality attributes of organic animal products generally show greater variability compared to products from dominant conventional systems (Petracci et al., 2017; Prache et al., 2020b; Lebret and Čandek-Potokar, 2021). This is explained by lower selection pressure on the strains or breeds used (especially for poultry), less inputs and/or greater variability in farming conditions. The literature shows greater variability in the commercial, technological and sensory quality attributes of organic broilers (Petracci et al., 2017). The strains of chicken used in organic farming have undergone less genetic selection, leaving populations that are more variable in terms of growth and meat yields. However, it is important to specify that the quality defects and myopathies observed since a decade in standard production systems using high growth rate strains selected for breast meat yield are not observed in organic production which uses low growth rate strains (Baéza et al., 2022). For pork, the variability in on-farm conditions (climate, physical activity, adequation of feed supply with nutritional requirements, housing type) inherent to alternative systems, including organic systems, drives greater variability in animal performances and the commercial, sensory, technological and nutritional quality attributes (Lebret, 2008; Prache et al., 2020b) (Table 1). Stakeholders (slaughterhouses, processors) have therefore to adapt to this greater variability of the raw material. It may be less problematic for consumers, as consequences on sensory quality attributes are not systematic, and also because much pork is consumed as processed products in Europe. A greater variability in the quality attributes has also been observed for organic eggs, which has been connected to lower control of meeting hens' nutritional needs (as 10–15% of diet comes from foraging outdoors; Prache et al., 2020b). For ruminants, lower inputs (concentrate feeds, synthetic drugs), more grassland-based farming practices and therefore more seasonal variability in animals' feeding diet (Chassaing et al., 2016), and variability in livestock performances inherent to grassland-based systems (Prache et al., 2021b) accentuate the variability in product quality, although this is also seen in extensive non-organic farming systems.

However, few studies looked at the consequences of this greater variability in quality of organic vs conventional products. What consequences for consumers? How can food manufacturing adapt to this heterogeneity in raw materials? This variability poses real challenges for the downstream processors. There is likely no one-size-fits-all solution; any solution will depend on type of product, purchase configuration (place, short/long food supply chains, opportunity), and type of consumer. Consumers do not necessarily want standardised-quality organic products, at least for unprocessed food products, and it is the dominant agribusiness channels that strive for homogeneous product quality to facilitate their commercial processes. Standardised commodity criteria may hold less importance in 'alternative' channels (short food supply chains, community-supported farmers markets, etc.) or for more rural community-minded consumers. It is also important to discriminate raw products from other products, because when foods come distributor-branded, consumers effectively expect a dependable and predictable level of product quality. Could greater variability be repurposed as an asset to differentiate products within the organic commodity chain, as is sometimes the case for some animal products under official signs identifying quality and origin? Some localised pork commodity chains consider the production-season variability in feed resources available to extensively farmed animals, and its impact on quality attributes, as an asset that they can leverage to diversify their products within an overarching Protected Denomination of Origin label (Lebret et al., 2021). Another route is also to better educate consumers on seasonality in quality and production-specific attributes.

Authentication of organically farmed animal products

In view of the price differential between organic and conventional products (Van Wagenberg et al., 2017), farmers and consumers are worried about fraud (Agence Bio, 2019). To counter the risks of appropriation of the organic quality sign, studies have investigated the use of analyses to authenticate products as organically farmed. All the methods are based on diet composition differences between organic and conventional farming systems. Organic production standards impose certain farming practices (access to outdoors, pasture grazing in ruminants whenever practicable, limited proportion of dietary concentrate, minimum proportion of marine-organism fish meal in feeds for carnivorous farmed fish) and prohibit others (no synthetic pigments). These differences have strong knock-on effects on food-product composition, including in stable nitrogen (N) and carbon (C) isotope ratios, FA and volatile compounds profile, carotenoid concentrations and profiles that can serve as evidence to authenticate the production system (Table 3). Furthermore, differences in product composition induce differences in its optical properties that can also serve to back-authenticate animal diet and, therefore, production system (Table 3).

Table 3
Analytical methods for the authentication of organic animal products.

Analytical method	Product	Underlying explanations - Points of caution	References
Stable N isotopes	Beef and lamb	Higher proportion of legume in grasslands - Variability and seasonality in animal feeding practices modulated by tissue turnover rates. Variability in the results between studies. The level of fertilisers use may modulate the reliability of the discrimination.	Bahar et al. (2008); Boner and Forstel (2004); Devincenzi et al. (2014); Moloney et al. (2018)
	Pork	Differences in the nature of the fertilisers used to produce the feeds - Variability in the nature (proportion of legumes) and availability of the forages and in the animal's foraging behaviour.	Zhao et al. (2016)
	Eggs	Free-ranged hens can ingest insects and worms - Variability in hen's exploratory behaviour. Ability to discriminate from free-range non-organic eggs?	Rogers (2009)
	Fish	Minimum dietary proportion of fish meal for carnivorous fish species.	Molkentin et al. (2015)
Stable C isotopes	Meat and dairy from ruminants	Less dietary use of maize - Ability to discriminate from low-input non-organic?	Stergiadis et al. (2015); Liu et al. (2018); Kaffarnik et al. (2014); Pustjens et al. (2017); Boner and Forstel (2004); Bahar et al. (2008)
	Pork	Access to outdoors - Variability in the nature and availability of the forages and in the animal's foraging behaviour.	Zhao et al. (2016)
	Fish	Bioaccumulation of heavy isotope throughout the tropic chain for carnivorous fish species- Bias linked to fish tissue lipid content variability.	Molkentin et al. (2015); Verrez-Bagnis et al. (2018)
Volatile compounds	Dairy	Differences in diet composition - Ability to discriminate from low-input non-organic?	Stergiadis et al. (2015); Liu et al. (2018); Kaffarnik et al. (2014); Pustjens et al. (2017)
Fatty acids	Dairy	Differences in diet composition- Ability to discriminate from low-input non-organic?	Stergiadis et al. (2015); Liu et al. (2018); Kaffarnik et al. (2014); Pustjens et al. (2017)
	Pork	Differences in diet composition- Ability to discriminate from free-range extensive, non-organic?	Oliveira et al. (2015)
	Eggs	Differences in diet composition. Differences carry a risk of being not reproducible.	Tres et al. (2011)
	Fish	Differences in diet composition. Different fatty acids to be used depending on the fish species.	Molkentin et al. (2015)
Carotenoid pigments	Dairy	Higher proportion of dietary forage, especially grazed pasture - Ability to discriminate from low-input non-organic?	Stergiadis et al. (2015); Liu et al. (2018); Kaffarnik et al. (2014); Pustjens et al. (2017)
	Eggs	Use of synthetic dyes prohibited; free-ranged hens can eat grass - Lutein or dried forages can be added to layer hen feeds.	Van Ruth et al. (2013); Prache et al. (2020b)
	Fish	Use of synthetic dyes prohibited - Potential natural sources of astaxanthin.	Molkentin et al. (2015)
Trace elements	Eggs	Differences in diet composition.	Borges et al. (2015)
Spectral methods	Eggs	Differences in yolk composition due to differences in diet composition- Differences carry a risk of being not reproducible (hens' layer strain, age and diet were unknown).	Puertas and Vazquez (2019)

Stable N and C isotope ratios have been used to authenticate organic milk, pork, beef and lamb, fish flesh and eggs, but via different mechanisms for different products. For fish flesh and eggs, isotope fractionation leads to bioaccumulation of heavy isotopes in the trophic chain, which in turn leads to increasingly positive $\delta^{13}C$ and $\delta^{15}N$ in the products as the animal eats increasing amounts of animal-derived feed. This mechanism works for fish farmed in organic vs conventional aquaculture and for eggs from free-range (although not necessarily organic) vs cage hens. For meat and dairy from ruminants, the lower dietary use of maize silage leads to lower product $\delta^{13}C$ values, while the higher proportion of legumes in forages can lead to lower product $\delta^{15}N$ values (Devincenzi et al., 2014; Moloney et al., 2018). For organic pork, $\delta^{15}N$ values reflect differences in the nature of fertilisers used to produce the feeds (organic fertilisers are more ^{15}N-rich than synthetic fertilisers), while higher $\delta^{13}C$ values are explained by pigs getting access to outdoors, as grass and soil have high proportions of ^{13}C (Zhao et al., 2016).

Dairy and meat from ruminants

As organic farms are often characterised by a more extensive, grassland-based management system, studies have used diet-related variations in product composition to discriminate organic dairy from dairy produced in conventional intensive systems based on heavy use of silage (especially maize) and concentrate feeds. The diet-feed differences led to differences in FA and volatiles profiles, carotenoid concentration, and stable isotope ratios in milk, and these tracers successfully discriminated organic vs conventional dairy products in a number of studies (for milk: Kaffarnik et al., 2014; Stergiadis et al., 2015; Liu et al., 2018; for butter: Pustjens et al., 2017). Similarly, studies showed that $\delta^{13}C$ values were lower and relatively invariant in organic beef (Boner and Forstel, 2004; Bahar et al., 2008). Results for N isotopes in beef were more variable, with $\delta^{15}N$ values frequently lower (Bahar et al., 2008) but sometimes near-identical (Boner and Forstel, 2004) in organic beef. However, as this discrimination frame was linked to differences in diet rather than production system *per se*, these methods became much less reliable when feeding regimes between organic and conventional systems overlap (such as with non-organic grassland-based systems) (Stergiadis et al., 2015; Schwendel et al., 2017; Table 3).

Pork

Oliveira et al. (2015) were able to 100%-correctly discriminate organic vs conventional pork from barn-reared or free-range farms using FA profiling. These results were explained by the strong correlation between diet composition and body tissue FA-profile in monogastrics where, unlike in ruminants, dietary PUFAs deposit directly into body tissues without undergoing biochemical changes (Lebret and Čandek-Potokar, 2021). Likewise, Zhao et al. (2016) 100%-correctly classified organic vs conventional pork based on the combination of stable N and C isotope ratios in defatted meat.

Eggs

The carotenoid profile of the yolk has been used to identify the farm system (organic, free-range and caged layers). Organic eggs featured higher lutein and lower cantaxanthin concentrations than eggs from other free-range or caged layers. This method has been large-scale-tested and successfully authenticated the eggs from EU organic farms (Van Ruth et al., 2013). The underlying reasons were i) cantaxanthin is prohibited in organic standards, hence the lower cantaxanthin concentration in organic eggs, and ii) hens that have free-ranging access to outdoors can eat vegetation, which is a dietary source of lutein (Nys et al., 2018). Cantaxanthin is probably the more reliable pigment for authentication purposes, as lutein or dried grass or alfalfa can be added to layer-hen feeds. FA-profile of the yolk also proved useful. One study on organic, free-range and caged-layer farms correctly classified 92% and 87.5% of organic vs conventional eggs based on the FA-profile of the yolk (Tres et al., 2011). However, given that the production system is not associated with any specifically defined lipid input, the FA-profile differences carry a risk of being non-reproducible, which would preclude generic applicability for routine authentication control. Stable N isotopes have also been singled out as informative markers for discriminating free-range vs battery-hen eggs (Rogers, 2009). Eggs from hens with free-range access tended to be more rich in ^{15}N than eggs from hens reared indoors, as free-ranging hens ingested more animal proteins (via insects and worms). However, this study failed to achieve perfect discrimination, probably due to inter-individual variability in exploratory foraging behaviour and thus in amounts of animal protein foraged. Note that Borges et al. (2015) discriminated organic vs conventional eggs based on content analysis of a set of 19 trace elements (As, Ba, Ca, Co, Cr, Cu, Eu, Fe, K, Mg, Mn, Na, Ni, P, Rb, Se, Tl, V, and Zn). Finally, UV–Vis-NIR spectroscopy on egg yolk lipid extracts successfully discriminated four layer-hen systems (organic, free-range, indoor free-run or caged layers; Puertas and Vazquez, 2019). The underlying mechanisms were likely differences in egg yolk composition due to the farming system, chiefly diet (FA and carotenoid profiles and cholesterol content). However, as eggs were purchased in supermarkets, layer strain, age and diet were unknown. These results, although promising, thus carry risks of biases and warrant further testing on bigger data sets to check for robustness.

Fish

The available science is based on the fact organic-standard aquaculture feeds have a different specific composition to conventional aquaculture feeds (minimum proportion of fish meal for carnivorous fish species and natural astaxanthin for salmonids, as mentioned above) that induces compositional differences in the fish flesh. Bioaccumulation of heavy isotopes throughout the trophic chain generates differences in δ^{13}C and δ^{15}N ratios between wild or organically farmed carnivorous fish (fed with largely marine-organism fish meal) vs conventional aquaculture (fed with largely terrestrial plant-based feed) (Bell et al., 2007; Moreno-Rojas et al., 2007; Morrison et al., 2007; Serrano et al., 2007; Molkentin et al., 2015). A point of caution: as differences in δ^{13}C has been shown to vary with fish tissue lipid content, then lipid content variability can lead to misidentify the production system (Verrez-Bagnis et al., 2018). Fish flesh FA composition is also influenced by the diet, as plant-based lipids are often packed with oleic and LA (an n-6 FA) and are very poor in LC PUFA. Combined stable C and N isotope analysis in defatted fish flesh discriminated organic vs conventional salmonid (trout and salmon) products, whether raw, smoked or graved (Molkentin et al., 2015). This study required a second analysis of stable δ^{13}C isotopes in fish lipids to further differentiate organic from wild salmon. It was also possible, based on fish flesh FA-profile, to discriminate organic vs wild-stock fish but using different key FAs for salmon and for trout (Molkentin et al., 2015). Analysis of the free astaxanthin isomeric pattern did not allow to consistently discriminate organic salmon, probably due to the many potential sources of astaxanthin (Molkentin et al., 2015). Ultimately, it was still compositional differences in organic vs conventional feed, and chiefly the proportion of marine-organism fish meal vs terrestrial plant-based feed ingredients that were used for discriminating organic vs conventional fish. Note that farmed fish feed composition has changed radically over the past decade and is likely to change further still (Organisation for Economic Co-operation and Development and Food and Agriculture Organisation, 2021), which means that the value ranges for the various target tracer compounds may need to be re-assessed to account for these potential shifts in fish feeding practices.

All of this body of research was generally grounded in differences in product composition that intersect with feeding regime differences between organically and conventionally farmed animals, which means there are points of caution to highlight: i) the variability in farming practices in both organic and conventional systems, and ii) the inter-individual variability in animal foraging behaviour and animal response, which create hard-to-control baseline variability (Table 3). Moreover, to date, most research has been conducted on a relatively small number of samples. Moving forward, the use of markers for system authentication purposes needs to address all the potential cofactors, compile the most comprehensively representative sample sets, and collect a suitably large mass of data. Finally, as the variability in organic-system practices could fuel doubts over how organic animals are actually farmed, approaches that specifically aim to authenticate farming practices, such as grass-feeding ruminants (Prache et al., 2020c), should be preferred.

Conclusions

One of the more pointful findings to emerge from this review is the large heterogeneity in results from studies comparing the quality of animal products in organic vs conventional systems, which stems from the great diversity of farming practices in both organic and conventional systems. Many studies exacerbate the differences by comparing products from 'extensive' organic farming systems against 'intensive' conventional systems, whereas the real picture is more nuanced. Furthermore, the quality gap between organic and conventional systems could change if 'certified-organic' grows into big business while the conventional farming 'greens' its practices. We endeavoured to overcome this difficulty and gain in genericity by pinpointing the farming practices and conditions underlying the differences observed in the published studies. There is a critical need for more data on all animal products (especially eggs, fish flesh, milk from small ruminants, and on the allied processed products). Furthermore, this variability in farming practices, which fuels consumer doubts over how organic products are actually farmed, also poses challenges for using product analysis to authenticate organic-system production. One way forward to reassure consumers about these farming practices could be through 'easy' labelling (as we see for eggs, for example) and authentication, such as grass-reared ruminants.

Another finding common to most animal products is the greater variability in quality of products from organic vs conventional systems, due to: fewer strain selection (broilers), lower inputs (concentrate feeds, synthetic vitamins and AA, veterinary drugs) for both ruminant and monogastrics, seasonal variability in the ruminants' feeding diet, variability in ruminant performances inherent to grassland-based systems, and greater variability in a spectrum of farming conditions (housing, feed resources, climate) for pigs. However, the scientific literature does not address the implications of this greater variability for the acceptability of raw organic products and for the adaptation of processing routes.

Looking ahead, the surge in consumption of organic products asks the question of whether and how organic farming is equipped to meet the challenge of upscaling production and processing capacity. Would big growth prompt organic farms to intensify their practices to increase per-animal or per ha productivity and meet the rising demand, with knock-on effects for product quality? Or conversely, will the risk be contained by organic consumers turning towards less animal-derived and more plant-derived foods (Baudry et al., 2019)? This review shed light on the consequences of possible trajectories of organic farming, if its specifications are relaxed or, on the contrary, tightened up on commitments concerning farming practices impacting the quality of products.

Ethics approval

Not applicable.

Data and model availability statement

None of the data used in this review were deposited in an official repository.

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Declaration of interest

None.

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