



# The state of the art of food ingredients' naturalness evaluation: A review of proposed approaches and their relation with consumer trends

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## ABSTRACT

**Background:** Food naturalness has been the subject of several recent studies and is a key trend in the food industry. There is currently no comprehensive legal definition of food naturalness, which is a multi-faceted and complex principle composed of many aspects. Naturalness-influencing aspects constituting naturalness of food ingredients are similar to those already investigated for finished food products.

**Scope and approach:** Two research questions are posed in this review:

- To what extent are the naturalness criteria for food ingredients set by ISO technical specification 19,657 “Definitions and technical criteria for food ingredients to be considered as natural” in line with the latest trends in consumer studies, reviews and reports on the topic?
- What aspects contributing to naturalness of food ingredients are the most present across food ingredients' categories?

The first question is answered through a review of governmental sources and scientific literature related to food naturalness and its evaluation. The second question is addressed through four case studies.

**Key findings and conclusions:** ISO TS 19657 evaluates food ingredients' naturalness and only partially fulfils consumers' requests. To build up a more comprehensive evaluation system, other aspects e.g. farming practices should be taken into consideration. The case studies presented in this review paper highlighted this need for a more extended basis for naturalness evaluation of food ingredients. A gap between technical and safety need for processing and consumer perception of processing in relation to naturalness emerged.

## 1. Introduction

The topic of food naturalness has been the subject of several research investigations in the last 30 years (Bender, 1989) and received increasing attention in the latest 15 years, drawing from the work of Rozin and co-workers (Rozin, 2005, 2006; Rozin et al., 2004; Rozin, Fischler, Morin, & Shields-Argelès, 2009; Rozin, Fischler, & Shields-Argelès, 2012). The trend in research followed the trend of the natural claim on the market. In fact, consumer interest for naturalness is

being addressed by industry as a current and future trend on the market (Ingredion, 2019, p. 2020; Kerry, 2017). Food naturalness can be considered as a perception (e.g. Murley & Chambers, 2019) and different aspects contribute to its development among consumers. These aspects and their contribution to the definition of naturalness have been subjected to recent reviews (Asioli et al., 2017; Román et al., 2017). A very broad overview on food naturalness contributors is thereby offered. In particular, in the recent work by Román and colleagues (Román, Sánchez-Siles, & Siegrist, 2017), the different contributors to

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naturalness are classified as “how the food is grown”, “how the food is produced” and “the final product”. Asioli and colleagues, (Asioli et al., 2017), instead, considered natural food as part of the “clean label” concept, including various intrinsic and extrinsic food products’ characteristics. Food can be perceived as natural, if the different naturalness-influencing aspects found in the above-mentioned reviews are correctly addressed throughout the product development and production pipeline.

A fundamental underlying aspect that must be considered in the matter around food naturalness discourse is the vagueness and indistinctiveness of the concept, enhanced by a simultaneous lack of regulatory definition of the term. This poses a risk of deception and therefore leaves ground for potentially diverse and ambiguous interpretations, plaintiffs’ complaints and consequent court cases (Parasidis, Hooker, & Simons, 2018). In EU and US some definitions are available: in relation to meat products in the US (Food Safety and Inspection Service, 2013) and referring to natural flavourings in the US and EU (21CFR101.22 and regulation EC no. 1334/2008 annex 2, respectively).

On the other hand, in the past years there has been increasing interest in understanding how different aspects of food naturalness interact, in order to establish evaluation systems accordingly. Heeres and colleagues (Heeres, Jong, Hübner, & Wassink, 2013) tried to make use of the European regulatory framework in order to understand whether an ingredient or a food product could be labeled as natural. Sanchez-Siles and colleagues developed a Food Naturalness Index (Sanchez-Siles et al., 2019) based on the results of the systematic review from a previous work (Román et al., 2017), which allows to evaluate food products’ naturalness based on label information.

The International Organization for Standardization (ISO) released the technical specification (TS) 19,657 “Definitions and technical criteria for food ingredients to be considered as natural” in 2017 (ISO/TC 34 Food products, 2017). The focus of this specification is on food ingredients. This document aims at establishing a “level-playing field and fair practices in business-to-business relationships”. This document is for B2B use and benefits ingredients’ suppliers and purchasers in establishing a common definition of what is a natural food ingredient. This type of interpretation adds up to guideline documents that have been issued by governmental institutions of some countries in the past, who attempted to put forward some criteria for defining food naturalness (CFIA, 2017; Food Safety Authority of Ireland (FSAI), 2015; FSA, 2008). It must be noted that these documents are not binding regulations, but only constitute guidelines for interpretation and approach for the benefit of food businesses.

Therefore, food and food ingredients’ naturalness is currently envisioned on one side by the consumer’s interest and perception of food and food ingredient’s naturalness and, on the other side by the presence of technical indications on how to achieve naturalness on a global scale and across different ingredients’ categories. This review aims at investigating this gap between the consumer perception and the technical prescriptions proposed by ISO TS 19657, in the field of food ingredients’ naturalness. This is done by responding to the following questions:

- To what extent are the naturalness criteria for food ingredients set by ISO in line with the latest trends in consumer studies, reviews and reports on the topic?
- What aspects contributing to naturalness of food ingredients are the most present across food ingredients’ categories?

The questions were addressed through a review of consumer studies related to different aspects of food ingredients’ naturalness. It is implied that food ingredients respond to naturalness requirements and principles that are similar to the ones of finished products, therefore relevant studies that investigate perception of finished food products are included in the review. Differences and exceptions are highlighted accordingly.

In order to answer the first question, three different types of sources

(reviews on food naturalness, food naturalness evaluation systems and guidelines from governmental institutions) are compared, in order to scope out the naturalness-influencing aspects that are applicable to food ingredients. The scope and criteria of the ISO technical specification are briefly presented, followed by a thorough analysis of the topics thereby considered and the ones not considered, in relation to the naturalness concept. In the second part of the review, four case studies are presented, that test the ISO technical specification criteria and the need for an extended view, tailored for the type of ingredient. The purpose of the case studies is also to answer the second review question. In fact, different naturalness-influencing aspects are expected to emerge across different case studies. This would then allow an evaluation of the presence and impact of naturalness-influencing aspects in a varied spectrum of food ingredients.

### 1.1. Review methodology

Literature search by means of databases (Web of Science, Scopus, Google scholar, Google) has supplied the background information and the state of the art of current research in the food ingredients’ naturalness field. Search terms were derived from the evaluation of the latest reviews, naturalness evaluation systems and governmental guidelines on food naturalness. Information was collected with broad inclusion criteria in terms of time range and types of documents (industry reports and grey literature were included), using keywords as described above: food, food ingredient, natural, naturalness. These terms were also combined with the related aspects: processing, process, consumer, consumer perception, organic, farming practices, animal welfare genetic modification, GMO, GM and similar. Information collected was in English.

### 1.2. Overview of naturalness-influencing factors

In Table 1, the content of the above-mentioned reviews, are summarized. The aim is to provide an overview of the most important naturalness traits, as considered in these documents. Only the relevant parts of these documents, that can apply to food ingredients independently of the scope of the document, are cited in the table.

The naturalness influencing factors highlighted in the first column of Table 1 have been gathered considering the content of the mentioned references. The aspects present in different references were then grouped together. The naturalness-influencing aspects presented in Table 1 are all applicable to food ingredients. The full analysis is presented as annex in the supplementary material. Two aspects are mentioned in all the evaluated documents: processing and GMO. Other aspects are related to natural and artificial ingredients, farming practices, environmental aspects and nanomaterials and are not mentioned in all the documents evaluated.

In the next section, each of the naturalness-influencing aspects are reviewed and compared to the content of the ISO TS 19657.

## 2. Part I – to what extent are the naturalness criteria for food ingredients set by ISO in line with the latest trends in consumer studies, reviews and reports on the topic?

### 2.1. ISO TS 19657 – a content overview

ISO TS 19657 is based on a few criteria, within a specified application range. In this section, the application range and the criteria are analyzed and the underpinning principles are made explicit, in order to be able to compare the ISO naturalness concept with the current knowledge on the subject.

As mentioned above, the specification applies to the Business to Business (B2B) food ingredients’ trade. ISO TS explicitly removes from its scope genetic engineering and agricultural practices (such as organic). This is a major exclusion, considering the importance that the

**Table 1**

Overview of naturalness-influencing aspects and their presence in different types of sources that consider food naturalness.

Type of reference	Peer-reviewed reviews			Peer-reviewed naturalness evaluation systems		Governmental guidelines	
Reference Scope of the document	Román et al. (2017) Finished food products	Asioli et al. (2017) Finished food products	Heeres, Jong, Hübner, & Wassink, 2013 Finished food products and food ingredients	Sanchez-Siles et al. (2019) Finished food products	Food Standards Agency (FSA, UK), 2008 Finished food products and food ingredients	Food Safety Authority of Ireland (FSAI), 2015 Food	Canadian Food Inspection Agency (CFIA), 2017 Food
Raw materials (natural vs artificial)	Yes	Yes	Yes	Yes	Yes	Yes	No
Processing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Farming practices - organic	Yes	Yes <sup>a</sup>	No	Yes	No	No	No
Farming practices - pesticides	Yes	No	No	Yes	No	No	No
GMOs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Environmental aspects	Yes	Yes	No	No <sup>b</sup>	No	No	No
Nanomaterials	Yes <sup>c</sup>	No	No	No	Yes	No	No

<sup>a</sup> Organic food is considered under the same “Clean label” review.<sup>b</sup> Intentionally excluded from evaluation.<sup>c</sup> Mentioned as content of a reference analyzed in the systematic review.

concepts of organic and genetic modification have within the food naturalness discourse (as seen below).

ISO TS excludes from its scope bottled drinking waters, natural mineral waters and flavourings. In fact, both categories already have a regulatory definition (e.g. natural flavourings are defined in 21CFR101.22 in the US and regulation EC no. 1334/2008 annex 2, in the EU).

The technical specification puts forward 3 criteria for ingredients' naturalness.

- Criterion 4a indicates that a natural ingredient is meant to be sourced from “plant, algae, fungi, animal, microorganism, mineral deposits or sea water” and adds that fossil fuels shall not be used as a source.
- Criteria 4 b and c define how the naturally sourced raw materials have to be processed, in order to produce a natural ingredient. In particular: physical, enzymatic and microbiological can be used. The last two should “not be used to deliberately produce substances that do not occur in nature”. It is also specified that pH adjustments are allowed. Criterion 4c focuses on those cases, when processing is not of any of the above-mentioned types (e.g. chemical processing). These processes shall be used only “to meet food safety and/or regulatory requirements” and when none of the physical, enzymatic or microbiological alternatives are applicable. It is also stated that in any case the constituting component/s of the ingredient/s should not be altered by the process.

Other remarks integrate the criteria: addition of water and removal of one or more constituent from the food ingredient “do not impact the consideration of the food ingredient as natural”. This implies that, for examples washing or drying procedures that, voluntarily or not, increases the moisture content of the ingredient during its processing, does not influence the naturalness of the food ingredient examined. Similarly, when impurities are filtered out of an ingredient, no influence on food ingredients' naturalness is exerted.

In the next sections the naturalness-related topics emerging from literature as mentioned in Table 1 are highlighted and compared with ISO TS 19657.

## 2.2. Raw materials (natural vs artificial)

The ISO TS 19657:2017 draws a clear line when it comes to the raw material sources that allow an ingredient to be defined as “natural”. The

proposed list of sources reflects all common sources of food ingredients; only fossil fuels are explicitly excluded from the acceptable sources.

A relevant criterion applicable to evaluation of food ingredients' naturalness is provided by the Food Safety Authority of Ireland (Food Safety Authority of Ireland (FSAI), 2015) (see supplementary material for details): if some food ingredient could be obtained in two different versions, one that follows certain naturalness criteria and one that does not, only the first would be considered natural, as it differs from the second because of its “naturalness”. Hence, this criterion introduced the concept that the naturalness of a food ingredient can be also a relative factor when more or less natural or “artificial” versions of the same ingredient do exist.

Plant origin food can be perceived as more natural than animal origin food by consumers (Rozin et al., 2012). Similarly, it was found that fruits and vegetables were recognised to be the food categories mostly linked to naturalness (in terms of specific words used for naturalness definition) (Balzan, Fasolato, Cardazzo, Penon, & Novelli, 2017).

Given the complexity of concepts associated with natural and artificial sources of food ingredients, it is deemed necessary to further delve into what are to be considered the boundaries.

Naturalness has been found to be “persuasive” and to have an “ideational”, “not instrumental” origin (Li & Chapman, 2012; Rozin et al., 2004). For this reason, the origin of the food ingredient and the processes it undergoes (as described in the next section) strongly shape naturalness perception, and “nature-equivalent” may end up not being the same as natural. In fact, both the studies by Rozin and colleagues (Rozin et al., 2004) and Chapman and colleagues (Li & Chapman, 2012) found that between naturally or chemically synthesized vitamins, respondents displayed natural preference. Similarly, a preference for natural sweeteners and colourants compared to artificial ones was found in another study (Bearth, Cousin, & Siegrist, 2014). A report by Nielsen (2016) stated that artificial ingredients are the ones that consumers avoid the most and Kerry reported consumer avoidance of synthetic or chemical-sounding ingredients (Kerry, 2017). Coherently with the previously listed results, Schoubye Andersen and Holm identified the concept of Purity-based naturalness, that equates a non-natural product with an artificial product (Schoubye Andersen & Holm, 2018).

These conclusions support the fact that the preference for a natural food ingredient is ideational. In fact, modern health worries were found to be significantly related to a preference for foods with natural additives, as opposed to food containing synthetic additives (Devcich, Pedersen, & Petrie, 2007). Conversely to the previously considered results, a

study concerning food additives found that synthetic or nature-identical substances would not make a difference in perceived naturalness in a group of consumers (Siegrist & Sütterlin, 2017).

The observed preference for ingredients that have a natural origin can also influence the way they are combined into a formulation or a product. Declaring artificial ingredients in a product claimed as “natural” decreases the perceived naturalness (Murley & Chambers, 2019). An all-natural label on peanut butter jars was also indicative of a product likely to use fewer artificial colours, artificial preservatives, and genetically modified ingredients according to another study (Liu, Hooker, Parasidis, & Simons, 2017). Similar conclusions were drawn also by Berry, Burton, & Howlett (2017).

It can be concluded that consumers tend to natural preference for ideational reasons. As a consequence, the whole natural versus artificial ingredients paradigm is highly unbalanced and hardly any compromise can be accepted (e.g. the one of a “natural-equivalent” (Li & Chapman, 2012; Rozin et al., 2004)). ISO considers in its criteria a non-natural ingredient what “is not already in nature”, therefore overcoming the “natural-equivalent concept”. In parallel, the document clearly states what are the sources that can be considered as “natural”.

### 2.3. Food ingredient processing

ISO TS 19657's position on processing is rather open and interpretative, but with clear starting points, as outlined in the criteria 4 b and c described above.

It can be observed that no reference is made to the degree of processing or to specific processes (e.g. sterilization, hydrogenation, etc.). Furthermore, chemical processing is never explicitly mentioned.

As can be seen in Table 1, both Asioli et al. (2017) and Román et al. (2017) considered process as part of the food naturalness definition. Early studies observed that, from a consumer's perspective, food naturalness is associated with the idea of “unprocessed” (Lockie, Lyons, Lawrence, & Mummery, 2002; Roininen, Lähteenmäki, & Tuorila, 1999; Rozin et al., 2012). Similarly, on industrial level, the current trend towards “clean label” ingredients calls for minimal processing (Ingredion, 2019, p. 2020).

Food processing has been reported to have a detrimental effect on naturalness perception (Coppola & Verneau, 2010; Evans, de Challemaison, & Cox, 2010; Rozin, 2006) and a higher impact on naturalness when compared with content (ingredients and raw materials) (Evans et al., 2010; Rozin, 2005). An association between “ultra-processed” food and presence of artificial/non-natural ingredients has also been reported (Ares et al., 2016).

Different processes' influence on naturalness perception have been found and are listed in Table 2, together with the aim of the process. This was done in order to highlight the gap between the perceived naturalness and the purpose of certain processes. Chemical processes (and potentially chemical content/presence of chemicals) in relation to a food ingredient have been found to be detrimental to food naturalness perception. In fact, “chemical changes are more potent than physical changes” (Rozin, 2005). Drawing a similar conclusion, another study added that while different physical changes can exert different effects on food naturalness, chemical processes always exert negative effects on food naturalness (Evans et al., 2010). On the other hand, no exclusion criteria regarding physical processes are set in the ISO TS 19657, therefore processes such as irradiation (see Table 2) could be accepted, despite negative naturalness perception from consumers (Coppola & Verneau, 2010). Increased levels of perceived naturalness were identified when a product is hand-made, as compared to machine-made (Abouab & Gomez, 2015). In a study submitted to FDA regarding the perception of labelling “natural” and “healthy”, the United States' Corn Refiners Association included a study on a sample of 1200 US consumers (Lusk, 2019). Thereby it is concluded that there is a conceptual gap between food ingredients and processes carried out to obtain them, as often ingredients are perceived as natural, but the processes used to

**Table 2**

Consumer perception of certain processes used in food ingredients' manufacturing and their technological function.

Process	Aim of the process (es)	Consumer perception	References
Chemical processes	Removal of unwanted substances, purification/refining, compounds synthesis	Against nature	Evans et al. (2010)
	Removal of unwanted substances, purification/refining, compounds synthesis	More detrimental to food naturalness than physical process	Evans et al. (2010)
	Removal of undesired substances	bleaching/ decolouring is not seen as natural	Lusk (2019)
Physical processes	Size reduction	chopping, grinding and slicing were considered as natural	Lusk (2019)
	Microbial reduction	In the specific case of food irradiation, considered as unnatural as genetic modification	Coppola and Verneau (2010)
	Microbial reduction	In case of novel technologies (high-pressure processing and pulsed electric fields), naturalness of the obtained product was seen as an advantage, nevertheless safety perception of the processes was low	Nielsen et al. (2009)
Use of enzymes	Processing aids	The use of enzymes is acceptable when it is essential or necessary to food. Other functions such as aesthetic are deemed as not useful	Kantar Public and FSA (2017)
Extraction of fractions/ isolation	Purification	Having to further process an ingredient to extract fractions (wheat flour vs gluten) negatively impacts the perception of natural.	Chambers and Castro (2018)
Hand-made vs Machine-made grape juice	Edible juice	Processing by hand increase levels of perceived naturalness	Abouab and Gomez (2015)
Dairy processes	Safety, physical and chemical transformations	processing has a minimal influence on perceived naturalness compared to other food categories	Coppola and Verneau (2010)
Novel technologies	Not available	Tendency towards a “simpler and more natural past” as opposed to the tendency towards technological innovations that increase naturalness	Biltekoff (2010)

obtain them are not. In that study the examples of sugars and vegetable oils are made; processes such as crystallization or bleaching/decolouring are used, respectively. These processes are not seen as natural while the products are. On the other hand, processes like chopping, grinding and slicing were considered as natural. The same study indirectly confirmed the applicability of the conceptual schemes of Román et al. (2017) and Asioli et al. (2017), considering that naturalness is a multi-faceted concept, where, hypothetically, an ingredient could rank high on some aspects (e.g. “minimal processing”) but low on some others.



A declared process advantage, such as reduced energy consumption, is not very important in food choice, when a product is already perceived as natural (Loebnitz, Loose, & Grunert, 2015). Therefore, process-related claims about food ingredients may have a different impact, depending on the overall ingredient perception. In this sense, it is relevant to consider that regulatory prescriptions about ingredient labelling and related claims can have a role in naturalness perception of the ingredient itself. In fact, labelling a fraction (gluten) versus labelling its ingredient or raw material of origin (wheat flour) negatively impacts the perception of naturalness (Chambers & Castro, 2018). This finding suggests that there could be a “hidden” idea of processing included in the name of refined ingredients. In addition to this, regulatory prescriptions (e.g. Regulation (EU) 1169/2011) may require the statement of a certain process as associated with an ingredient (e.g. hydrogenated fat), which might fuel this idea.

Processing contributes to shape the perceived naturalness of food ingredients, but at the same time its main function is to make food matrices edible, stable, safe, tasty, palatable and qualitatively acceptable. As expressed in Table 2, this is sometimes not the view of consumers. One study found that, within a group of mothers, there was the idea that processed implied unnatural which was in turn equated to “unhealthy” (Moscato & Machin, 2018). On the other hand, there is a technical, regulatory or safety need for food processing and this may generate a discrepancy between consumer perception and the need for edible and safe food ingredients. This concept is expressed in the ISO TS 19645, as certain processes shall be used only to meet safety and regulatory requirements. However, peer-reviewed literature on the influence of technical need of processing on consumers’ naturalness perception is lacking. A report investigated public perception of food additives and enzymes in the UK (Kantar Public & FSA, 2017). A tendency to have a lower acceptance towards food additives rather than to enzymes emerged, due to their “unnaturalness”. However, study participants felt that “... their use [of enzymes and food additives] was more acceptable when they served what was perceived to be an essential or necessary function in the food, and less acceptable when they served purposes which were seen to be less necessary such as for aesthetic reasons”. It could be therefore argued that naturalness perception of a certain food ingredient may be related to its own functionality, and a similar concept may apply for processing (e.g. enzymes used as processing aids). This also stresses how providing ingredient information to consumers (particularly on processing) may influence food ingredients’ naturalness perception and/or the overall acceptance.

#### 2.4. Genetic modification

ISO TS 19657 does not include any criteria involving genetic modification. However, it is mentioned that genetic modification can be subject to regulations and/or other requirements. Awareness and perception of genetically modified food may be influenced by regulations, such as labelling requirements of genetically modified foods. EC Regulation 1830/2003 regulates labelling of GMOs. Labelling of food stating that it contains GMOs is mandatory in case of adventitious or unavoidable presence of GM-derived material in excess of 0.9% per ingredient.

In the US, USDA ruled out only in late 2018 the National Bioengineered Food Disclosure Standard (USDA, 2018). This rule provides for mandatory labelling of food ingredients deriving from Bioengineered raw materials from the list included in the regulation and for an accidental presence of more than 5% of GM material per ingredient. Consequently, consumers’ exposure to GM labelling in Europe and in the US was different.

In the last 20 years, several studies investigated consumer perception of genetically modified food and, in particular, its correlation with food naturalness. The importance of the trend made the “non-GMO” claim one of the most sought-after by consumers together with natural claims (Kerry, 2017; Punt, Venus, & Wesseler, 2015). In fact, naturalness and

lack of genetic modification of food were found to constitute an underlying driver for food choice (Renner, Sproesser, Strohbach, & Schupp, 2012). Preference for food naturalness has been related to an increased willingness to pay for non-GMO foods (Hartmann, Hieke, Taper, & Siegrist, 2018). In fact, even consumers that display preference for genetically modified food showed a level of preference for naturalness similar to those who rejected genetically modified food (Chambers & Castro, 2018). As a consequence, a natural claim on food products implies that no genetic modification associated to the food is expected (Berry et al., 2017; Liu et al., 2017).

The contrast between genetic modification of food sources and naturalness perception was highlighted as early as 1999 (Bredahl, 1999), and later on discussed in several other studies (Lusk, 2019; Rozin, 2005; Rozin et al., 2012). In a study on South Korean consumers, the cluster of “Naturalness seekers” was identified, representing 28% of the respondents. Their attachment to the concept of food naturalness makes them extremely sensitive to GM content of food and its labelling (Onyango, Govindasamy, Hallman, Jang, & Puduri, 2006). Similarly, clusters of consumers that were more concerned with naturalness, displayed a lower acceptance of the use of genetic modification techniques (Sajdakowska, Królak, Zychowicz, & Jezewska-Zychowicz, 2018) or considered genetically modified foods as less natural (Chen, 2011; Connor & Siegrist, 2010). Finally, lack of naturalness was identified as reason for decreased benefits perception of a hypothetical genetically modified corn variety, compared to the perception of a traditional variety holding the same properties (Siegrist, Hartmann, & Sütterlin, 2016).

Staple foods (e.g. tomato, butter) were found to be perceived as more natural and their GM counterparts as less natural and that this is less acceptable than for “less necessary” products (e.g. Fish fingers) (Tenbült, de Vries, Dreezens, & Martijn, 2005). The examples proposed in this study do not consistently compare “necessary” and “less necessary” ingredients. However, a different naturalness perception of genetically modified food ingredients, depending on their category, type or even function is suggested.

On more technical grounds, it has been observed that *cis*-genetic modifications appear less unnatural than *trans*-genetic modifications to the consumers (Kronberger, Wagner, Nagata, & Kepler, 2014). In conducting a study on preference between *cis* and *trans*-genetic modifications of food, it was concluded that naturalness played a role in the overall consumer perception and preference for genetic modification (Hudson, Caplanova, & Novak, 2015).

Based on the reported studies it can be argued that, as in the case of processing, providing information to consumers regarding biotechnology may play a role in their naturalness perception.

#### 2.5. Farming practices

Farming practices have been considered in the reviews by Asioli and colleagues and Román and colleagues (Asioli et al., 2017; Román et al., 2017) as well as in the Food Naturalness Index (Sanchez-Siles et al., 2019). ISO TS 19657 willingly excludes farming practices from its scope. The use of pesticides and the regulation of organic products are subject to very different regulatory frameworks around the world, which makes it difficult to draw a general line for indication. However, it appears that different aspects relating to farming practices are important to consumers and that these aspects should therefore be considered for inclusion in a general framework for food ingredients’ naturalness evaluation.

The first naturalness-influencing aspect related to farming practices is organic. The relation between organic and food ingredients’ naturalness already emerges in early studies (Lockie et al., 2002; Roininen et al., 1999; Schifferstein & Oude Ophuis, 1998) and has been confirmed throughout the years in many others. Rozin and colleagues (Rozin et al., 2012) found that biological/organic were among the most associated words (top 10) with natural in France, Germany, Italy, Switzerland, the

U.K., and the U.S.A., showing geographical consistency of the relation. Similar conclusions in these respects were drawn when studying a sample of Dutch consumers (Hilverda, Jurgens, & Kuttischreuter, 2016) and Italian students (Balzan et al., 2017). Hemmerling and colleagues evaluated “how organic tastes like” and “natural taste” was part of the expected taste characteristics (Hemmerling, Asioli, & Spiller, 2016).

In some of these studies it has also been highlighted that the two concepts can get so close in consumers’ perception, that they can get to be (conf-)used as synonyms (Amos, Hansen, & King, 2019; Gifford & Bernard, 2011; Li & Chapman, 2012; Lockie, 2006). People with a preference for naturalness look for organic food products and ingredients (Bäckström, Pirttilä-Backman, & Tuorila, 2004; Hasselbach & Roosen, 2015; Onyango et al., 2006; Schoubye Andersen & Holm, 2018) and are even willing to pay a higher “organic premium” for these products and ingredients, in comparison with other groups of consumers (McFadden & Huffman, 2017). Consequently, a natural claim on a food would increase the perception that that food is likely to be organic (Berry et al., 2017).

Consumer perception is also dependent on awareness of the analyzed subjects and inconsistencies can be found: a sample of consumers considered modern farming methods as not natural, while more than three quarters of the surveyed respondents found that organically farmed crops were natural (Lusk, 2019). At the same time, more than a half of the surveyed consumers considered organic pesticides and mutagenesis (a crop breeding method allowed under organic production) not to be natural.

The use of pesticides, hormones and antibiotics across the supply chain is the second naturalness-influencing aspect related to farming practices. In fact, presence of pesticides and other types of residues in food ingredients and in foods in general, can be related to chemical content, which is deemed as unnatural by the consumer (e.g. (Briz et al., 2008)). In fact, a study by Dickson and colleagues confirmed that a negative attitude towards chemical content can be related to natural preference, which in turn constitutes a strategy to avoid chemical content according to the consumer (Dickson-Spillmann, Siegrist, & Keller, 2011). According to consumers, these chemicals could also in fact be being used “without any limit” even by local farmers (Zafra Aparici, Muñoz García, & Larrea-Killinger, 2016).

This tendency was further confirmed in a study observing that consumers’ Food Naturalness Interest increased the probability of choosing non-hormone milk as opposed to the hormone variety (Lusk et al., 2015).

Expectations regarding pesticides content of food and ingredients defined as natural therefore are built up. Branding food as “all-natural” leads consumers to believe that it contains fewer (or no) pesticides (Dominick, Fullerton, Olynk Widmar, & Wang, 2018; Liu et al., 2017; Lusk, 2019) and no preservatives, no hormones and no antibiotics (Dominick et al., 2018). Pesticide treatments have been found to be dismissed by consumers as non-natural practices even when it comes to organic pesticides (Lusk, 2019).

The third aspect that relates farming with naturalness of food ingredients is animal welfare, which has been a rising topic in the latest years. Increasing exposition of animal husbandry conditions in media coverage determined spreading of awareness and opinion development in consumers (Roosen, Dahlhausen, & Petershammer, 2016). It appears that also the ways in which farm animals are treated touches upon the naturalness of the products of their exploitation. In fact, when people talk about animal welfare, they may refer to it as animals having access to “natural” living conditions (Spoonner, Schuppli, & Fraser, 2014). This was found to be extremely important for a certain cluster of consumers, defined as “naturalists” (Prickett, Norwood, & Lusk, 2010). Preference for naturalness in consumers was also found at the same time to be associated with a higher tendency to stigmatize animal husbandry practices (Roosen et al., 2016).

Overall, farming practices can be considered as a very important component of food ingredients naturalness. The use of chemicals

(pesticides, hormones and antibiotics), organic production methods and animal welfare are of great concern for consumers and they associate it with naturalness. Therefore, naturalness of crops, milk, eggs, as well as naturalness of the ingredients that derive from them, can be related to farming practices.

## 2.6. Nanotechnology

Nanotechnology is not addressed by ISO TS 19657. Given that nanotechnology applied to food is a frontier of innovation and a rising regulatory theme (Special Eurobarometer Wave EB91.3 Food safety in the EU Report Fieldwork, 2019), even though currently no engineered nano-ingredients are available on the European market (Rincon, 2019). Regulation (EU) no. 2015/2283 specifically addresses nanotechnology in food, laying down the definition of “engineered nanomaterial”. The Regulation stresses the intentionality of the presence of the nano-material: “any intentionally produced material that has one or more dimensions of the order of 100 nm or less or that is composed of discrete functional parts, either internally or at the surface, many of which have one or more dimensions of the order of 100 nm or less, including structures, agglomerates or aggregates, which may have a size above the order of 100 nm but retain properties that are characteristic of the nanoscale. Properties that are characteristic of the nanoscale include: those related to the large specific surface area of the materials considered; and/or specific physico-chemical properties that are different from those of the non-nanoform of the same material”.

A few studies point out a contrast between the perception of food nanotechnology and naturalness. Perceived naturalness was inserted as part of a conceptual framework for definition of public perception of food nanotechnology (Oluwoye, 2015). Those consumers for whom naturalness is important, have been found to perceive more risks and less benefits related to food nanotechnology (Siegrist, Stampfli, Kastenholz, & Keller, 2008). Naturalness plays a role in consumers’ willingness to buy food supported by nanotechnology, as naturalness-devoted consumers show some levels of resistance to novel technologies (Sodano, Gorgitano, Verneau, & Vitale, 2016). Most of the consumer studies investigating food nanotechnology perception focus on safety and health perception aspects (e.g. Pew Research Center, 2018; Siegrist et al., 2008; Special Eurobarometer Wave EB91.3 Food safety in the EU Report Fieldwork, 2019). Food nanotechnology applied to ingredients is an important research topic for food ingredient development and literature suggests that naturalness plays a role in the acceptance of such kinds of ingredients.

## 2.7. Other naturalness-influencing aspects

Regulatory topics, in particular compulsory labelling prescriptions, may influence the perceived naturalness of food ingredients, through the possibility of making claims (e.g. Liu et al., 2017) or, for example, defining how an ingredient should be named on the label (e.g. through E-numbers). In fact, “Natural”-phrased claims regarding food products in certain food categories have been found to boost acceptance, while scientifically-phrased claims were found to negatively impact acceptance in food categories responding to “hedonic needs” (Aschemann-Witzel & Grunert, 2017). Furthermore, it was found that whenever an ingredient is described with a name taken from the common language, it is perceived as more natural than when it is called with its scientific equivalent (Chambers & Castro, 2018) or the equivalent E-number (Evans et al., 2010; Siegrist & Sütterlin, 2017). Process indications as associated to food ingredients (e.g. hydrogenated fats) may also have an influence on food naturalness perception, given the effects that processing has (see section above). GMO claims can be detrimental to naturalness perception. Therefore, different compulsory prescriptions may represent an important variable in evaluating the naturalness of a food ingredient.

Environmental and more in general sustainability aspects can be

related to the concept of food naturalness, nevertheless scarce literature supports this correlation. It must be noted that [Asioli et al. \(2017\)](#) [Román et al. \(2017\)](#) included environmental aspects in their reviews ([Table 1](#)). The topic does not currently appear as important in defining naturalness of food ingredients however, its importance will surely emerge in the coming years.

## 2.8. Food ingredients' naturalness evaluation: key points

The first part of this review aimed at offering a comprehensive view on the topic of food ingredients' naturalness. Food ingredients' naturalness has been leveled up with the current knowledge and practice in food naturalness evaluation for finished products (e.g. [Sanchez-Siles et al., 2019](#)), starting from the technical criteria proposed by ISO TS 19657. The chapters above went beyond the ISO document and exposed the complexity and the number of interconnected players acting in the naturalness definition. This set of inter-correlations is presented and summarized in [Fig. 1](#). In this chart all the naturalness-influencing aspects found along the supply chain are placed together to provide conceptual framework for food ingredients' naturalness evaluation. It also provides an estimate of which aspects are expected to have a positive influence or a negative influence on the food ingredient's perceived naturalness.

Both Raw materials and Processing are composed of several aspects which may have all sorts of influences on naturalness perception. Nanotechnology plays a transversal role, as it may intervene throughout the production process as well as, potentially, in the farming/sourcing part. The food nanotechnology is an entirely novel in the naturalness perception conceptualization and it is fundamental that the few studies reviewed are followed up by further discussion. The interesting technological developments and possible innovations in this field should also take into account naturalness perception, which is a powerful consumer driver. Technical need permeates all steps of ingredients' production. In fact, each step towards the production of a food ingredient can be taken in a more "natural" direction, unless technical reasons prevent that from happening. The regulatory framework is represented as a boundary that should not be crossed and that sets the playground. Indeed, the regulatory framework is expected to have different effects on perceived naturalness, depending to its labelling prescription, the country

considered, etc.

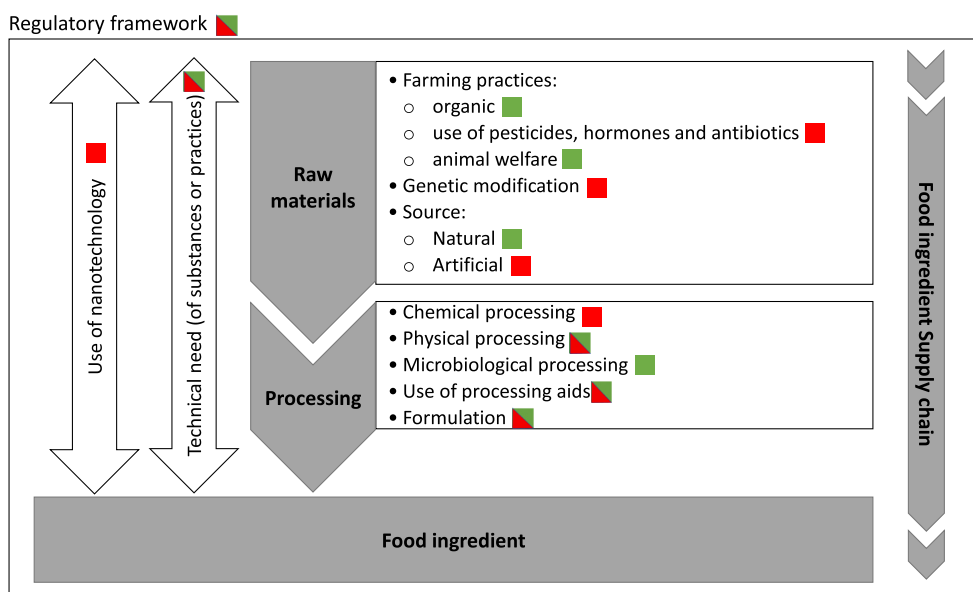
Literature displays a wide range of interpretations of the naturalness concept. When compared with recently proposed conceptual frameworks for food and food ingredients naturalness evaluation, ISO TS 19657 shows a focus on the "intrinsic" aspects of the food ingredient, where by intrinsic are meant those traits that "cannot be changed without also changing the physical product itself" ([van Trijp & Steenkamp, 2005](#)). In [Fig. 1](#) these aspects can be associated to the boxes "Raw materials" and "Processing". However, Raw Materials, Farming Practices and Genetic Modification are not dealt with in ISO TS 19657. Furthermore, chemical processing is not directly address in the ISO specification, but it has been proved to determine a decrease in perceived naturalness by consumers. ISO TS 19657 also considers the technical need of chemical processes in its evaluation of food ingredients, considering that they comply with naturalness criteria if they are done to fulfil regulatory or safety requirements.

The naturalness-related aspects that are not included in the ISO TS may nevertheless have a strong influence on consumers' naturalness perception. Concern for pesticides, hormones and antibiotics use and genetically modified raw materials have in fact a detrimental effect, as well as the use of nanotechnology. Indeed, the regulatory framework related to these aspects varies across countries, but this is independent of the naturalness aspect and shall therefore be taken into account in a thorough evaluation. This could in fact meet the sector-specific requirements indicated as suggested further development by ISO.

Finally, it can be observed that the specific applicability of this framework to ingredients determines exclusions, additions and rearrangements of naturalness-influencing aspects, when compared to other food naturalness frameworks such as the one presented in [Román et al., 2017](#), which is applicable to finished food products.

## 3. Part II: ● what aspects contributing to naturalness of food ingredients are the most present across food ingredients' categories?

In the second part of this review, an analysis of the naturalness status of some ingredients that are used as case study examples is presented. The analysis is carried out as a comparison between the naturalness evaluation system provided by Heeres and colleagues ([Heeres, Jong,](#)



**Fig. 1.** Conceptual framework for food ingredients' naturalness evaluation. The red squares indicate the factors that are expected to negatively influence food ingredient's naturalness perception, while the green squares indicate factors that are expected to have a positive influence. The half-red half-green squares indicate factors that can have both positive or negative influence, on a case-by-case basis.

Hübner, & Wassink, 2013), the ISO TS 19657 and the framework presented in Fig. 1, in order to highlight the gaps and the potential improvement points. The evaluation system by Heeres and colleagues was chosen due to its applicability to food ingredients. The following case studies aim at highlighting the practical approach proposed by the framework depicted in Fig. 1 and, through that, at providing an answer to the review question.

### 3.1. Soy protein isolates

Soy protein isolates are the results of several steps of extraction starting from a plant raw material; the soybean (Deak, Johnson, Lusas, & Rhee, 2008). The bean is milled and the oil extracted, generally using hexane as a solvent. The proteins are extracted from the residual defatted soybean meal. Different types of extraction are reported: precipitation using acid and alkali, membrane processing like ultrafiltration and reverse osmosis and aqueous extraction (Deak et al., 2008). Soybean protein isolates are considered as a natural ingredient if tested through ISO TS 19657, as the proposed criteria are fulfilled. Similarly, all the processing techniques proposed are also in line with the requirements posed by (Heeres, Jong, Hübner, & Wassink, 2013). However, it can be noticed that consumers display concern for chemical processing and therefore the minimization of the use of chemicals in the process (e.g. by choosing physical processing technologies whenever possible) could represent a good industrial practice in naturalness terms.

If evaluated through the criteria proposed by (Heeres, Jong, Hübner, & Wassink, 2013), one possible pitfall emerges, represented by GMO content. In fact, soybean is traded globally and produced in high percentages (80% according to Tillie & Rodríguez-Cerezo (2015)) in its GM variety.

Sustainability and environmental aspects related to soybean farming could in principle also be raised, while harvesting regimes in terms of use of pesticides are adapted to the different countries in the world where soy is traded.

An industrial approach to soy flour naturalness preservation may therefore include, whenever possible, a minimization of chemical processing and rigid control of GM and/or a traceability control from the field, such as Identity Preserved schemes. Besides this, in order to meet consumers desire for less pesticides, farmer/processor/industrial user agreements across the supply chain may be established. Finally, the use of organic soy flour may enhance the naturalness perception of the ingredient, while simultaneously meeting the request for GMO avoidance.

### 3.2. Refined fats: the case of sunflower oil

Sunflower oil is a common food ingredient both in industry and in consumer's houses in many parts of the world. Being sourced from a seed, several processing steps are required in order to efficiently extract the oil. In Fig. 2 the process flowchart of sunflower oil is presented. If evaluated through ISO TS 19657, sunflower oil can be considered as a natural ingredient. The critical part, which is the chemical processing, can be accepted in this case as this is needed in order to obtain a safe and stable oil. Furthermore, this process complies as it does not alter the ingredient (oil remains oil). Hexane extraction is an authorized process according to annex II of regulation EU 1334/2008 and it is hence compliant with the criteria proposed by Heeres and colleagues. On the other hand, the ingredient does not comply with all the naturalness requirements thereby proposed. In fact, some of the processes required for oil extraction and purification are not included in the list provided by Heeres and colleagues. In particular, the following process are to be considered critical: decoloring, degumming, neutralization and deodorization.

In this case Heeres, Jong, Hübner, & Wassink (2013), proposed checklist for ingredients' naturalness interprets more closely the consumer's concern related to chemical processing, when compared with

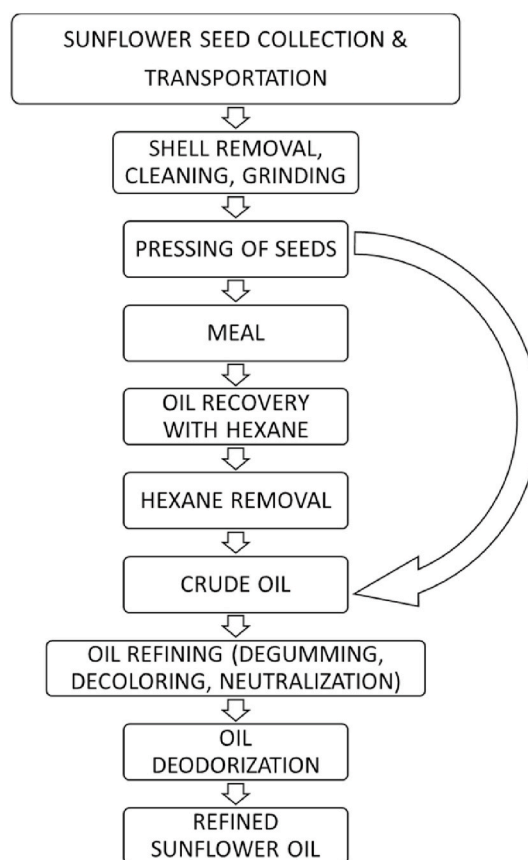


Fig. 2. Process flowchart of sunflower oil.

ISO TS 19657. On the other hand, the topic of need for processing is in this case preeminent, as refining is a necessary step for obtaining a stable oil deprived of undesired substances. In the case of the use of hexane for oil extraction from the meal, this practice is carried out in order to maximize the amount of the extracted oil, but still without “altering” the oil.

The other critical aspect in sunflower oil's naturalness is indeed related to the farming practices, as already observed in the soy flour example. Also in this case, the use of organic raw materials may increase the naturalness perception of the ingredient.

Processing and farming practices appear therefore critical concerning sunflower oil's naturalness. A gap between sunflower oil naturalness perception and the perceived naturalness of its manufacturing process was in fact already observed in (Lusk, 2019). Extending the case to fats of industrial relevance, it can be considered how processing stays central in fats' naturalness evaluation. For example, processes such as hydrogenation or inter-esterification chemically change molecular structures (of fatty acids and triglycerides, respectively), arguably influencing the nature of the original matrix.

### 3.3. Micro/nano cellulose ingredients

Micro/nano fibrillated celluloses are innovative food ingredients derived from the most common cellulose (Gómez et al., 2016). They can be applied as emulsifiers or thickening agents. Cellulose is normally derived from plant sources. To obtain micro- and nano-cellulose ingredients, further processes are needed, such as homogenization and microfluidization (Lavoine, Desloges, Dufresne, & Bras, 2012). Being innovative ingredients, in most cases up-scaling of the production process has not been yet achieved even at industrial level. This implies there is no uniformity in the processing methods reported in literature (Gómez



et al., 2016; Lavoine et al., 2012). In some cases, chemical pre- or post-treatments are reported.

From a naturalness evaluation perspective, this type of ingredients, if they are not chemically modified into new structures, can be considered as natural, according to ISO 19657 criteria. If evaluated through (Heeres, Jong, Hübner, & Wassink, 2013) proposal for naturalness evaluation, the critical points are:

- the cellulose source should not be genetically modified
- processes such as homogenization and microfluidization are not mentioned in the positive list of processes proposed

Extending the evaluation to additional considerations, it is important to highlight that this ingredient is a nano-technological application in food products. It has been pointed out previously in the review how this topic could be relevant for perceived naturalness of consumers.

Furthermore, this poses regulatory questions (e.g. labelling of “engineered nanomaterial” according to EU legislation). Specifically, if the ingredient is obtained from a natural source and does not undergo any intentional structural modification, it is not legally required to be qualified as “engineered nanomaterial” (the ingredient could currently be labeled as “fiber” in Europe. Regulatory influence of naturalness perception (as discussed i.e. in Sandin (2017)) could hypothetically come into discussion. In fact, if the ingredient undergoes further nano-engineering (e.g. modifying the molecular structure), labelling of nanotechnology would be needed. This could negatively influence the perceived naturalness of the ingredient.

Further understanding of the naturalness perception of such an ingredient is highly needed as it poses several potential pitfalls to a seemingly straightforward correspondence to the naturalness concept:

- should it undergo further processing, it should be claimed as “nano-engineered” on the label
- even without labelling, consumers showed concern for nano-materials in food
- chemically sounding ingredients may negatively impact naturalness perception (e.g. Evans et al., 2010)

### 3.4. Liquid egg white

Egg white is obtained from hen's egg white separation and pasteurization (Lechevalier, Croguennec, Anton, & Nau, 2011). It is used as an ingredient, mainly for its foaming properties (Lechevalier et al., 2011). This ingredient complies with ISO TS 19657 and (Heeres, Jong, Hübner, & Wassink, 2013) naturalness' criteria. In the broader naturalness picture offered in Fig. 1, further points of attention can be found:

- GMO: no egg product is genetically modified per se, as no genetically modified animals are legally authorized to be on the market except for one GM salmon variety in the US. Nevertheless, hens' feed may be GM contaminated (e.g. presence of soy/corn derivatives)
- Animal welfare: the debate over living conditions of farm animals is constantly pushing media and policy. According to some pieces of the above-reviewed literature, this may relate to naturalness perception in the consumer.
- Farming practices: concern over use of antibiotics and hormones in the poultry supply chain and use of pesticides in the feed supply chain as related to perceived naturalness has been analyzed in part 1 of this review. Addressing and controlling the use of these substances in the supply chains involved, may increase the perceived naturalness of the food ingredient.
- Organic: egg white with an organic attribute may presents to the consumer an enhanced perception of naturalness, as analyzed in the “farming practices section”.

The case studies proposed aimed at offering a broad view on the

world of food ingredients as well as the diversity of possible naturalness outcomes. All of the case studies were presented from a technical perspective, similar to the one offered by the ISO criteria, but integrating some aspects stemming from consumer perception and related to food naturalness, as indicated in Fig. 1. All the case studies presented showcased ISO TS 19675-conform ingredients. The main answer to the review question is therefore that almost all food ingredients may be “damaged” in their perceived naturalness, if all the possible influencing variables are considered. This also confirms the need for a broader view on naturalness, than the one proposed by ISO.

## 4. Conclusion

In part 1, the review considered the current knowledge related or applicable to food ingredients, in order to expand the concept of the evaluation of their naturalness. In fact, it can be concluded that the ISO TS 19657 interprets consumers' perceptions regarding naturalness of food ingredients in a correct but incomplete way. Based on the reviewed literature, it can be argued that more elements interact with naturalness perception. In particular, genetic modification, farming practices, organic attributes and presence of nanomaterials may play a role. Furthermore, some other aspects may be taken into consideration, for example, regulatory framework's influence on food ingredient's naturalness. Another example could be the presence of voluntary certification associated to the ingredient, that could influence its naturalness perception by expressing the application of certain practices. Technical need of processing as perceived by consumers is not yet thoroughly explored in literature. Further research in this sense is required, in order to fill this gap.

The case studies presented confirm the need for an expanded and integrated evaluation system, which shall go beyond the requirements of ISO by interpreting them and integrating them together with the naturalness-influencing aspects presented in this review. The example offered by NATCOL (2017) is indeed pertinent and it is specific for the food colours' sector. On the other hand, the criteria proposed by Heeres, Jong, Hübner, & Wassink (2013) or governmental guidelines such as CFIA (2017) alone do not suffice, if the aim is to obtain a comprehensive food ingredients' naturalness evaluation. The framework presented in Fig. 1 in this sense may represent the starting point for consideration of all the variables influencing food ingredients naturalness specifically. This implies that all categories of food ingredients may present naturalness issues that shall therefore be addressed by the business operators constituting the different supply chains, thereby including, for example, feed supply chain operators.

It also appears that there could be a role of information to consumers in this sense, that could change their perception in relation to food ingredients' naturalness. This is key, as perception of naturalness does not always relate with the technical and legal need for safe, stable and available food ingredients.

This review work presents the limitations that consumer studies on food naturalness have revealed. In fact, most of the studies reviewed have been conducted in EU, US or Australia. Scarce data cover Asian, African and South American countries. Another gap found is specific to some of the concepts put forward. The relation between food nano-materials and naturalness needs to be further studied, as well as influence of different types of processing and consumer awareness of it on naturalness perception.

The outcomes presented in this paper may benefit industry, which may find a further support in developing sector-specific interpretations as suggested in ISO TS 19657, as well as policy makers, which may look at this paper as a reference for further debate and elaboration of a still lacking comprehensive definition of “natural” referred to food and food ingredients.

## CRediT authorship statement

**Dario Battacchi:** Conceptualization, Methodology, Investigation, Writing - Original Draft, **Ruud Verkerk:** Writing - Review & Editing, Supervision **Nicoletta Pellegrini:** Writing - Review & Editing, Supervision, **Vincenzo Fogliano:** Writing - Review & Editing, Supervision and **Bea Steenbekkers:** Writing - Review & Editing, Supervision.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.tifs.2020.10.013>.

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