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Abstract

There are time-tested assessments for the environmental and economic aspects of sustainability. Its societal aspect has mainly been approached through the assessment of animal welfare. However, the intrinsic quality of milk is seldom taken into account. We developed a participatory construction method for the overall assessment of intrinsic milk quality in its different dimensions (sensory, technological, nutritional and health), according to the fate of the raw milk. Two assessment models were developed, for semi-skimmed standardized ultra-high temperature (UHT) milk and for pressed uncooked non-standardized raw milk cheese. They were constructed by a participatory approach involving experts in the dairy sector with the aim to obtain a diagnostic tool that could be used in the field to help farmers to manage the quality of their milk (by prioritizing improvements on major problems). They were shaped from prerequisite specifications (limited costs and time of application, desire to obtain a transparent tool with all the steps kept visible) and current technical and scientific knowledge. They were based on indicators obtained from raw bulk tank milk analyses (30 for UHT milk and 50 for cheese assessments), which were then aggregated into criteria, principles, dimensions and overall intrinsic quality at farm level. The assessment models had parts in common, e.g. same four dimensions, common indicators for health and nutritional dimensions. They also had process-specific features: units chosen, criteria, indicators and weightings in relation to the final product specifications. For instance, sensory and technological dimensions are more complex and preponderant in the cheese assessment (3 principles for cheese vs. 1 for UHT milk in both dimensions). Another example is the lack of microbial pathogens (as potential health risk for consumer) in the UHT milk assessment because of pasteurization. The assessment models then underwent a sensitivity analysis and an application in 30 farms in indoor and grazing periods to finally obtain overall UHT milk and cheese quality scores at a one-year level. The tool was found to be applicable at farm level. However, we observed low overall quality scores with a narrow dispersion, characteristic of a severe evaluation. Even so, the assessment models showed up seasonal differences of the UHT milk and cheese quality at both overall and dimensional levels. In the light of new scientific knowledge and future quality objectives, these are adaptable to other dairy products allowing for their specific features.

Keywords: Dairy cows, cheese and ultra-high temperature milk, bulk tank milk, multicriteria assessment model, participatory approach

Implications

This article presents the development of two intrinsic quality of milk assessment models according to milk fate (ultra-high temperature milk or raw milk cheese) and following a participatory approach. It is the first multicriteria assessment of the intrinsic quality of milk with the definition of principles to evaluate four quality dimensions (sensory, technological, nutritional, and health), criteria and indicators to be considered, and rules to interpret them. The approach followed is adaptable to other dairy products, allowing for the specific features of the product and the demands of the stakeholder group seeking to develop it.

Introduction

In a context of a continuous decrease in the number of dairy farms, their assessment for sustainability is a crucial issue. There are time-tested assessment methods for the environmental and economic aspects of sustainability (Halberg et al., 2005; Zahm et al., 2008), but the assessment of its social aspect is more complex. Social sustainability has two levels: social sustainability within the farm (quality of life, working conditions...) and social sustainability external to the farm, constantly evolving with values and concerns of the society (Lebacq et al., 2013): the main societal expectations are animal welfare and intrinsic product quality. There has been a significant development of tools for assessing animal welfare (Botreau et al., 2008), but the intrinsic quality of milk is seldom taken into account in assessment methods (Lebacq et al., 2013). A few evaluation methods for the intrinsic quality of milk have been proposed (Harris, 1998; Müller-Lindenlauf et al., 2010; Zucali et al., 2016) with few chosen indicators (3–8 depending on the method), and mostly related to health (somatic cells count, protein and fat contents, milk fat composition or total bacterial count), and technological dimensions (microorganisms) of quality. Intrinsic quality can be defined as a combination of sensory, technological, nutritional, and hygiene dimensions (Coulon, 2008) and the quality expectations are not the same according to the fate of the milk (Prache et al., 2020). However, these existing evaluations address quality on targeted aspects and without considering the fate of the milk. The aim of this study was to develop a participatory construction method for the overall assessment of intrinsic milk quality taking into account all its dimensions depending on the fate of the raw milk. Ultimately, the goal is to obtain an assessment model that could be used in the field to help farmers to manage the quality of their milk.

Material and methods

The multicriteria assessment model of the intrinsic quality of milk was constructed in three steps (Lairez et al., 2015) from the participative approach : definition of the scope, definition of the conceptual and methodological frameworks and validation of the assessment model (Figure 1).

The different steps of the assessment model construction

Step 1 - Definition of the scope of the assessment

The first step was the definition of the scope of the assessment by the experts, described by the object to be evaluated and its spatial and temporal scale, the aim of the assessment and its future users, and its prerequisites (e.g. financial and time costs, ability to run it).

Step 2a - Definition of the conceptual framework

The overall quality had to be defined in several *dimensions* or qualities, then subdivided into *principles* and *criteria* (and *subcriteria* if needed) that itemized the principles into more concrete categories. Criteria were assessed by *indicators* that were measurable (= raw data) and that had to meet four conditions (Lairez et al., 2015): scientific relevance, feasibility, clarity and interpretability. We then checked that the hierarchical structure respected the scope choices (step 1; Figure 1), especially the indicators that had to fulfil strict specifications in terms of feasibility and cost. If possible or necessary we then simplified the structure in that sense.

Step 2b - Definition of the methodological framework

The methodological framework of the assessment is defined from the previously built hierarchical structure to interpret and aggregate the indicators up to the overall assessment (Figure 1). We decided to use the CONTRA tool, an aggregation method based on a decision tree using fuzzy sets (Bockstaller et al., 2017; Botreau et al., 2018). This tool requires the setting of a few parameters to interpret and to aggregate the indicators up to the overall assessment. In our case, a common quantitative scale for the scoring was defined: from 0, worst possible quality score, to 10, best possible quality score.

Interpretation of the indicators. For each indicator, threshold values to delimit the favourable class (above which the score will be 10/10) and the unfavourable one (below which the score will be 0/10) had to be defined. In the fuzzy zone (between the two classes), the element to be interpreted (indicator value, criterion or principle score, generically called ‘input variable’) is considered to be part of both classes with different degrees of membership. CONTRA then aggregates these two membership degrees to produce an intermediate score for each input (Bockstaller et al., 2017), thus limiting the risk of a threshold effect induced by the drop from one class to another.

Aggregation of scores. CONTRA aggregates indicators’ scores to produce the criterion score (and so on until the overall quality score). This aggregation relies both on weightings (is one indicator more important than another?) and management of compensations between indicators (do we want to be severe by limiting the possibility of compensating for a bad score on one indicator by a good one on another?). Other specific settings that are not presented here were also defined (refer to Bockstaller et al., 2017).

Thus, three types of parameter had to be defined: threshold values, weights and rules for compensation management.

Step 3 - Validation of the assessment model

Sensitivity analysis. For a better overview of the assessment tool's behaviour, a sensitivity analysis was performed using the screening method initially developed by Morris (1991) and modified by Campolongo et al., (2007), known as the elementary effects method. For each input variable, the method calculates two indices, μ (assessing the overall influence of the input on the final result of the assessment) and σ (estimating both the nonlinearity of the impact and interactions with other inputs). A high value of μ indicates a marked overall influence on the output (total effect). A high σ indicates either a non-linear effect on the output, or involvement in interaction with other inputs (higher than one-order effects). More details are given in Supplementary Material S1.

Test of the assessment model on dairy farms. In addition, the behaviour of the models was also checked through a test on 30 commercial farms. Farms characteristics are presented in Table S1, they were selected to cover a large diversity of farming systems (plain and mountain, intensive and extensive…). Bulk tank milk samples were collected in July (grazing period) and in January-March (indoor period) in a tank containing an even number of milkings (2, 4 or 6) except in two farms equipped with a milking robot. A 1.2 L sample of milk was directly collected in the tank after 5 min agitation using a sterile sampling rod through the manhole. The sample was kept between 0 and 4°C during the transfer to the lab within 18 h. Twelve and nine indicators were analysed on fresh milk within 48 h after sampling and on frozen milk samples (–20°C), respectively (Table S2). Some of the analyses were performed by private laboratories, using mostly routine methods. The others were performed by research laboratories using reference methods (e.g. gas chromatography for milk fatty acids, FA). When data were missing (some analyses were not carried out because sampling and analysis of bulk tank milks occurred before the assessment model had been finalized), they were approximated by existing equations or assigned a unique mean value for all the farms obtained from the literature or databases (Table S2). The two assessment models were then applied to those 30 farms.

The participative approach for the construction of the multicriteria assessment model

The construction of the assessment model was based on a participative approach with the consultation of scientists and stakeholders of the dairy sector. This approach is based on the confrontation of diverse points of view to reach a consensus that satisfies the whole group (bottom-up approach) within focus group meetings, and so allows a better adoption of the tool by the stakeholders who helped to build it. The people involved in the process, later called ‘experts’, were divided into 2 groups: (i) Leader group composed of researchers on milk quality (2 people) and stakeholders (2): representative of the cheese sector and one from a private company. They participated in the specific steps identified in Figure 1; (ii) Specific experts group according to the indicators addressed, who participated in one or more ad hoc meetings composed of researchers on specific milk compounds (2) or on milk technology (2), technologists (1), doctors and nutritionists (4), farm advisors (2), representatives of the cheese sector (2), process manager within a dairy company (1). They participated in the specific steps identified in Figure 1.

The focus group meetings (about 4 h long) were organized following the simplified DELPHI (Linstone and Turoff, 1975) method with only one round with phases of individual reflection of experts and phases of pooling/discussion (for more details, see Supplementary material S2).

Results

Definition of the scope of the assessment

During the first meeting, the experts defined the object to be evaluated as the bulk tank milk of a farm, safe for human consumption and thus complying with the relevant legislation). The intrinsic quality of bulk tank milk from the farm was evaluated at the year level.

The aim of the assessment was to propose an action-oriented diagnostic tool to be used by farmers to manage the overall quality of their milk (by prioritizing improvements on major problems). This had an impact on the setting of the following initial prerequisites by the experts: (i) transparency: to keep all the intermediary steps accessible and to make it possible to point out the strengths and weaknesses of the assessment, (ii) genericity and standardization: the assessment should be applicable to any dairy farm, independently of the local context, (iii) use in routine practice: this implies a limited cost (<100 €/year), a limited time for sampling/surveying (<1 h), the use of routine methods for milk analyses (chemical, microbial or spectral methods), and a time limit for processing the information (<1 h).

The sampling must thus be easy (a single milk sample taken from the bulk) and non-invasive (no measure on animals, only on milk).

To obtain an assessment at year level but to limit the costs, the experts decided to plan only two periods of assessment: grazing and indoor. The overall score at year level would be calculated from a weighted average of the two seasonal quality scores as follows:

Year quality score = [Annual part time spent in barn (%) × Indoor period quality score + Annual part time spent on pasture (%) × Grazing period quality score] / 100

The experts soon found that it was not possible to describe the dimensions at lower levels and define criteria of quality without taking into account the fate of the milk. Accordingly, two different products were targeted, and two assessment models were developed: one for semi-skimmed standardized ultra-high temperature (UHT) milk and the other for pressed uncooked non-standardized raw milk cheese, these having very different transformation processes and final desired characteristics.

Definition of the conceptual framework

Intrinsic quality defined through its different dimensions and according to the fate of the milk

The experts defined intrinsic milk quality as a combination of four major dimensions during the first meeting too: (i) sensory: ability of the milk to contribute to the organoleptic characteristics of the final product, (ii) technological: ability of the milk to be correctly processed into the final product, (iii) nutritional: ability of the milk to give a final product that contributes significantly to the coverage of consumers’ nutritional needs, and (iv) health: ability of the milk to give a final product that has potentially more beneficial and less deleterious effects on human health. The contribution of milk (bottled or carton, flavoured, concentrated or powdered milk and other milks) and cheese (ripened, processed, unripened fresh or other cheeses) to the total recommended daily intakes was calculated from data on recommended nutrient intakes by nutrient, the average intake of milk and cheese and the levels of these nutrients in milk and cheese (Agence française de sécurité sanitaire des aliments (AFSSA), 2009). Only those nutrients for which the contribution of milk and cheese exceeded 5% of the total daily intakes were kept in the nutritional quality part of the respective assessments. Constituents whose concentrations can be greatly increased or decreased by the process were also excluded. For instance, vitamins B were not taken into account in the cheese assessment even though cheese supplies them in abundance, these vitamins resulting mainly from synthesis by cheese flora (Reif et al., 1976) and not from bulk milk content.

From dimensions to indicators

Twenty-one meetings were needed to define the principles, criteria and indicators (together with their interpretation) for the two assessment models.

This construction was an iterative process, particularly in relation to the choice of indicators, which had to be both scientifically relevant and compliant with the specifications (limited cost and easy analysis, in particular). The hierarchical structure was thus simplified and the Leader group decided to do it with 3 possibilities for the indicators originally selected: (i) if the indicator was measurable (analytical cost and method available in private laboratories), then it was kept; (ii) if the indicator was not directly easily measurable but it could be predicted by analytical methods (e.g. prediction by mid-infrared method) or proxies that allowed to approach it (e.g. coagulase positive staphylococcus level to estimate biological toxins level (enterotoxins), *pseudomonas* level to estimate coming proteolysis intensity), then it was kept too; (iii) if the indicator was not directly measurable and there was no simplified analysis method or proxy that allowed to approach it, then it was deleted. If no indicator was retained for a branch of the structure, then the entire branch was deleted.

The UHT milk conceptual framework was structured into 4 dimensions, 9 principles (1–4 per dimension), 27 criteria (plus 13 sublevels), and 28 indicators (Figure 2). The cheese conceptual framework was structured into 4 dimensions, 11 principles (2–3 per dimension), 27 criteria (plus 15 sublevels and 6 sub-sublevels), and 50 indicators (Figure 3).

Definition of the methodological framework

Interpretation of indicators

For a majority of indicators, the thresholds were defined during the consultation process. However, for most of the nutritional and health indicators no consensus was reached and experts were only able to define the global sense of interpretation (e.g. lower is better) but not the thresholds. These were therefore defined from the analysis of a database of around 1300 individuals (Coppa et al., 2013; Chassaing et al., 2016): the 0/10 score was defined as the 2.5th percentile and the 10/10 score as the 97.5th percentile of the values of this database for indicators interpreted as 'higher is better' (and the opposite for 'lower is better' indicators), and then discussed and validated with the experts (Table S3).

Aggregation of inputs

Nine meetings were then needed to aggregate indicators, criteria, principles and dimensions: definition of weightings (7 meetings) and compensation rules (2 meetings) by the experts.

Weightings. The UHT milk assessment model was principally based on nutritional quality (weighting of 40%), which took into account the mineral, protein, and vitamin inputs. Then came health quality (30%), predominantly based on the impact of lipid content on health. Lastly, the technological (20%) and sensory (10%) qualities were characterized by only one principle each: stability and suitability for preservation, and taste, respectively. The cheese assessment model was largely based on sensory (35%) and technological (30%) qualities. Sensory quality was mainly based on flavour (flavour defects from non-desirable microorganisms) of the final cheese. Technological quality was predominantly evaluated by the cheese yield capacity and drainability. Health quality (20%) was mainly based on the effects of the bioactive components (especially lipids) and nutritional quality (15%) based on energy and macro-element inputs. All weightings for UHT milk and cheese are given in Figures 2 and 3, respectively.

Compensations. The decision was collectively made to limit compensations to promote an overall quality without bad results on some inputs. Two main rules were defined by the experts whatever the final product:

(i) the more heterogeneous the input scores, the more limited the compensation. This means that with the same average score, the more heterogeneous the milk was over the inputs to be aggregated, the lower was the aggregate score;

(ii) the lower the input scores, the more limited the compensation: higher severity when globally input scores are bad.

Validation of the assessments

Sensitivity analysis of the assessment models

The results obtained on the seven most influential indicators on the overall score for both models are presented in Table 1 (for more details, see Tables S4 and S5). For both assessment models, the μ were all of the same order of magnitude so no indicators predominated in their influence on the overall score. However, some indicators were more influential than others. The most influential indicator in both assessments was the Pseudomonas level. This indicator was present and influential in all four dimensions of the two assessments. It was the only indicator for sensory dimension for milk assessment and the most influential in the sensory dimension of the cheese assessment.

The other most influential indicators of the overall UHT milk quality score were initial pH, calcium, β-carotenes, vitamin B2 and lactose concentrations. They were also among the most influential indicators of the main dimensions: calcium and vitamin B2 concentrations for nutritional dimension score; β-carotenes and lactose concentrations for health dimension score, and initial pH and Pseudomonas level for technological dimension score.

The other most influential indicators of the overall cheese quality score were the casein concentration, total bacteria count, α-linolenic acid (ALA), urea and calcium concentrations. Caseins were present in three of the four dimensions, health, nutritional and technological, and the most influential indicator of both these last dimension scores. The other most influential factor in the cheese nutritional dimension score was the ALA concentration, whereas it was urea concentration for the cheese technological dimension score. For the sensory dimension score, Pseudomonas level and the total bacteria count were the most influential indicators.

The most influential indicators of the health dimension score were not included in the most influential indicators of the cheese overall score but were β-glucuronidasepositive E. coli level ($\mu = 1.78$, $\sigma = 4.00$; Table S5) and β-carotene concentration ($\mu = 1.7$, $\sigma = 0.86$; Table S5).

Test of the assessment models on dairy farms

The ranges of values obtained for indicators from the milks collected in the 30 farms are presented in Table S3, covering fairly well the range defined by the thresholds for each indicator. Mean quality scores of the 30 farms are presented in Table 2 and in Figures S1 and S2.

At year level, cheese and UHT milk global quality scores were of 3.5 ± 0.7 and 2.6 ± 0.5 out of 10 (mean ± SD), respectively, with a narrow variability and a maximum that did not exceed 5 for both assessment models. At dimension and season scales, the variability increased, with a broader observed distribution of the scores. When considered at season level, quality scores were higher in grazing than indoors for the cheese and UHT milk assessments (3.7 ± 1.0 vs. 3.1 ± 1.0 for cheese, $p = 0.02$; 2.8 ± 0.5 vs. 2.1 ± 0.4 for UHT milk, $p < 0.001$). At dimensional level, health scores were significantly higher in the grazing period, whereas no difference by season in nutritional scores appeared in either assessment. Also, technological scores were higher in the grazing period in the UHT milk assessment model but no differences across seasons appeared for the cheese assessment model. Finally, sensory scores were higher in the grazing period in the cheese assessment (sensory score in the UHT milk assessment was assigned the same value for all the farms because of missing data, so no comparison could be made).

Discussion

Definition of intrinsic quality

Milk intrinsic quality has often been defined as the resultant of four dimensions: nutritional, sanitary/safety/hygiene, sensory, and technological (Coulon, 2008; García et al., 2014). In our assessment models, the sensory and technological dimensions have a meaning close to that usually taken in the literature, but the nutritional and health dimensions encompass a different meaning. Nutritional quality usually refers to the combination of ability to meet food requirements and positive/deleterious effects of milk on human health. For example, FA profile has often been related to the nutritional quality of milk, although the human nutritional needs for FAs can be strictly defined only for essential FAs: ALA and linoleic acid (LA), and not on the other FAs having beneficial or deleterious effect on health (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (ANSES), 2011). In this light, the experts decided to clearly separate nutritional aspects from effects on health in these assessment models. Only the ALA and the LA contents were therefore taken into account in the nutritional dimension (in the cheese assessment model). Finally, sanitary quality usually refers to the absence of hazardousness often evaluated as the absence of pathogens and/or of chemical pollutants in the milk (Coulon, 2008; García et al., 2014). Here, the definition was enlarged to cover all potential impacts on human health, positive and negative. As the appraised object was a bulk tank milk safe for human consumption, pathogens such as Listeria monocytogenes did not appear in our assessment models despite belonging to health aspects.

Assessment models according to the fate of milk

Considering the fate of the milk entailed differences between the two assessment models of the quality of the milk (for cheese and UHT milk).

Importance of dimensions according to the fate of milk

The experts opted to assign more weight to the sensory aspects for cheese assessment model, considering that the raw milk cheese is purchased by consumers for its gustative and olfactory experience and less for nutritional or health expectations. As the technological process is very complex and largely responsible, in interaction with the milk composition (Frétin et al., 2019), for the sensory characteristics of the final cheese, the technological dimension was also given a large weighting. On the contrary, UHT milk is an 'everyday' product that is mainly used as an ingredient among others, so that the sensory dimension in UHT milk assessment model is limited to its taste or rather the absence of defects in the taste, as milk is defined as having no special taste per se (Clark and Bodyfelt, 2009). As it is more frequently consumed, the expectations of its effects on nutrition and health were assumed to be high, justifying higher assigned weighting.

Criteria and indicators according to the fate of milk

At criteria and indicator levels, the differences between the two assessment models were still perceptive. The sensory dimension was based only on the absence of defects in the UHT milk assessment, while for the cheese, three aspects referring to the human senses were considered: appearance, texture, and flavour. The technological dimension of the UHT milk assessment model was based on the capacity of the milk to permit good conservation of the final product, linked to acidity and micellar stability (linked in turn to possible milk precipitation during storage; Gaucher et al., 2011). In comparison, the technological dimension in the cheese assessment model referred more to parameters that could affect the transformation process, such as acidification capacity, drainability and more generally cheese yield capacity.

The transformation process leading to the final product also meant differences between indicators. For example, no microbial aspects were considered in the UHT milk assessment model as the microbial constituents are destroyed by the process (heating at ultra-high temperature), except for the level of Pseudomonas, considered as a predictor of proteolysis that can occur both before and after the transformation process. This group of bacteria produces proteolytic enzymes able to stay active after a high temperature treatment and impair milk quality (Gaucher et al., 2011). Similarly, lactose and soluble protein contents were not relevant to the cheese assessment model as they are nearly completely released in the whey during the clotting and draining stages of the pressed uncooked non-standardized raw milk cheese process (Kindstedt, 2014). On the contrary, FA profile, minerals, and total β-carotenes appeared in both assessment models.

Indicator units and thresholds according to the fate of milk and the dimension

FA contents were measured as concentrations (g/L of milk) in the cheese assessment model, as the milk used in the process was non-standardized for milk fat. Conversely, in the UHT milk process, the milk was fat-standardized, milks were not differentiated by FA concentrations, but instead by FA relative proportions (% of total FAs).

For a given indicator used in different dimensions and in both assessment models, thresholds can differ from one dimension to another and between models. For example, in the cheese assessment model, fat-to-protein ratio was used as an indicator for the cheese yield in the technological dimension and for the cheese texture in the sensory dimension, with different interpretations according to the dimension. The main drivers of the cheese yield are proteins (more specifically caseins) and fat content in milk, with a higher weighting for the protein part (Banks, 2007). However, a certain balance between fat and protein is required to guarantee the ability of the protein matrix to retain fat globules during cutting and early stages of stirring and limit fat loss in whey (Guinee et al., 2007). The 'technological' score of the fat-to-protein ratio was therefore higher for a lower ratio (10/10 for ratio ≤1.10 and 0/10 for a ratio ≥1.40; Table S3). The process is different for the effect of the fat-to-protein ratio on the cheese texture. Cheese firmness is closely related to fat in dry matter, which is linked to the fat-to-protein ratio of the milk. An increase in the fat-to-protein ratio will thus give a softer, smoother cheese (Coulon et al., 2004). Cheesemaking targets an intermediate fat-to-protein ratio, so that the cheese texture corresponds to the standards for the cheese variety. Hence the distribution of 'sensory' scores was bell-shaped, with an optimal score for a ratio of 1.15, and then degressive scores for larger or smaller ratios (0/10 for ratio ≤1.05 and ≥1.35). To conclude, of the 37 and the 21 different indicators in the cheese and the milk assessment models, respectively, 7 indicators are common (same unit, same interpretation) between the two models.

Assessment models shaped from participative approach

The building process, using a participative approach, produced the first overall intrinsic milk quality assessment model, to our knowledge. It made it possible to reconcile the points of view of the different actors involved in the development of the models. Scientists from the dairy field and professionals from the dairy industry, ensured the scientific and technical validity of the information and thus the credibility of the assessment models. Perhaps the actors missing from this panel who could confer a stronger legitimacy are the breeders. Besides, the number of meetings required was high but could perhaps be reduced with experience. However, reducing this number could negatively impact the participatory approach and reduce credibility of the tool (e.g. through lack of consensus). The models were salient since the information given by the assessment was relevant for the decision makers (farm level) and appropriate to the context (suitable for use in the field and adapted to two products). According to Cash et al. (2002), salience, credibility and legitimacy are the three properties that an assessment must possess to be functional as a decision support tool and be accepted by the stakeholders.

Assessment models shaped from the scope

Experts chose the indicators associated with each dimension and prioritized them considering the constraints of the specifications identified for the tool at the beginning of the project. Some relevant indicators were withdrawn because they were too costly to analyse. Some other indicators were not directly measured, but estimated, either by others with less costly analyses, or by mid-infrared spectrometry or flow cytometry methods when reliable prediction equations existed (Table S2). The health dimension was particularly impacted by these specifications by ignoring some pathogens, trace metals and organic pollutants, for which there are threshold values not to be exceeded to allow the commercialization of the product.

Some other indicators were kept in the assessment models even if they could only be analysed with reference analysis methods (so they could not be analysed on all laboratories and had a quite high cost) because experts considered that in the near future routine analysis methods will be developed. This induced a gap between the initial specifications and the developed assessment models on these points (that affected the test on 30 farms). This will have to be updated in the future according to scientific and technical advances in analytical methods.

Beyond of the choice of the relevant indicators, the scope of the assessment also impacted the developed models in their structure in order to maintain the information available and transparent at all levels, from indicators to the overall assessment. This allows the models to be used to advise the farmers (by self-assessment or with the help of farm advisor) by identifying the main advantages (to be maintained) and drawbacks (to be improved) in terms of milk quality. An example of such an application on a real farm is given in Figure S3. However, this is only a diagnostic tool, to find the best remedial solutions the farmer or his advisor would have to think about new practices that can solve drawbacks without negatively impacting the good points observed in terms of quality.

Assessment models shaped from current technical and scientific knowledge and its interpretation by the focus groups

Experts chose the indicators with their current knowledge on their relevance and the possibility of defining thresholds to evaluate them (according to the knowledge and the references available at a given time). As knowledge and references evolve continuously, the assessments had to be upgradeable. For the health and nutritional dimensions of quality, the panel of experts agreed on the choice of the indicators and on their rough interpretation (such as, for example, the higher the ALA content, the better the health evaluation of the milk, in accordance with the literature (Haug et al., 2007; ANSES, 2011), but they did not succeed in giving threshold values for most of the indicators, although they successfully defined them for sensory and technological dimensions. Hence it was more difficult to determine a threshold value above which the quality was impaired in the health and nutritional dimensions because of a lack of consensus among the experts due to insufficient knowledge. Levels of nutrients from milk that could affect health and nutrition positively or negatively are very difficult to determine as their interpretation depends on the composition of the rest of the consumer's diet and on many other aspects (physical activity, genetics, environment, etc.). Quantitative recommendations are set only on the overall consumption of the constituents (minerals, FAs, etc.) (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (ANSES), 2011), and not on the consumption of dairy products and even less on the nutrient content in the dairy product itself (Martin et al., 2019). These dimensions of milk quality are also more sensitive issues, for which the positioning of the experts was more difficult. A database was therefore used to define these thresholds values. This means that they do not have a direct nutritional or health meaning (no thresholds for which the indicator would become dangerous), even if the general orientation of the interpretation is known. It will be possible to review this point in step with the future evolution of scientific knowledge on the contribution of dairy products to dietary recommendations and requirements (Martin et al., 2019). In addition, the indicators used to assess nutritional quality were selected among those providing at least 5% of needs by the products concerned (UHT milk and cheese) thus depending on the current, geographically targeted (France) consumption of these products. As this consumption can vary according to place and time, it had to be possible to modulate and update the assessment.

The participatory approach also allowed stimulating discussion among the experts in the collective focus group times and produced unexpected ways to measure some milk quality criteria. For example, the protein level was evaluated by both protein content and the level of Pseudomonas, which can induce proteolysis before milk transformation that would lead to denaturation of the proteins, impairing coagulation. The alcohol and Ramsdell tests are rarely used as indicators in the literature, but are commonly used in the dairy industry to test the stability of the colloidal suspension of caseins and thus the stability of milk (Gaucher, 2007).

Validation of the assessments

Pseudomonas, an influent indicator

In both assessment models, the level of Pseudomonas appear to be most influential input (Table 1). As previously explained this indicator is considered as a proxy of proteolysis that will occur between the measurement in the tank and the milk delivery to the transformation plant. Whenever an indicator related to the proteins content in milk (total proteins, caseins, soluble proteins) was used, the experts associated it with the Pseudomonas indicator to consider a potential level of proteolysis. As a consequence, this indicator is used several times for both assessments. Its great influence on the results is thus not surprising but may be questioned: protein degradability is obviously relevant in respect with the milk quality, but does it deserve to have such an important overall weight? Deeper investigations should be performed to answer that question and it would be possible to revise the models accordingly.

A low but real discriminating power

The assessment was performed on 30 farms. Overall quality scores on the 30 farms presented a narrow dispersion, which could question the power of the assessment to discriminate the bulk tank milks of the different farms in terms of intrinsic quality. However, some indicators could not be measured (alcohol test, Dornic acidity, levels of Pseudomonas and E. coli) and the corresponding missing values were replaced by the same mean value extracted from databases or literature (Table S2) for all the farms, independently of the season, which could explain this narrow dispersion. Despite this limitation, the assessment was able to discriminate the different milks in terms of intrinsic quality at the seasonal level as it showed significant differences between indoor and grazing period quality scores of the cheese and UHT milk assessments. Quality scores were better in grazing than in indoor periods, resulting from significant seasonal differences in health and sensory scores, mainly in the cheese assessment, and in health and technological scores in the UHT milk assessment. This supports the choice of the experts to plan two periods of assessment to take this seasonal variability into account in the final score. Milk components and properties related to nutritional, technological or organoleptic aspects are known to vary widely during the year, notably from changes in the feeding system (Verdier-Metz et al., 2005; Ferlay et al., 2006; Hurtaud et al., 2014).

A severe assessment tool

The choice to limit compensation between scores led to low overall scores. To obtain a good score at each aggregation level, the milk of a farm must have good scores in all sublevel parts. This severity was accentuated by the construction of the assessments. Some indicators such as *Pseudomonas* level or casein concentrations served several times in the assessment to evaluate different criteria and principles, resulting in a high influence of these indicators on the assessments (Table 1). Thus, if a bulk tank milk has a bad score on this indicator, it will be penalised several times.

Conclusion and perspectives

An innovative method for developing milk quality assessment has been built and led to an evaluation of the intrinsic quality of milk taking into account its different dimensions (nutritional, health, technological and sensory dimensions) as well as the fate of the milk (semi-skimmed standardized UHT milk or pressed uncooked non-standardized raw milk cheese). These two assessment models have the same four dimensions but differ greatly on principles (mainly on sensory and technological ones), criteria and indicators as well as on weights given to the inputs. They were based on the decisions of experts, according to their own knowledge and opinions. The models built are intended to be evolutive and the different elements can be revised: addition or deletion of indicators, definition of thresholds, weights assigned to inputs, compensation rules, in order to provide improvement at each level of the evaluation process.

Moreover, this method can be adapted to other products (particularly dairy products) according to their specificities and constraints in use (costs, application time and users). The assessment models are transparent. They allow the assessor to start from the overall score and access all the intermediate scores up to the indicators measured in the milk. It is therefore possible to identify, at each level, what can be maintained and what has to be improved. Combined with a thorough knowledge of the relationships among the inputs and the breeding practices that influence them, these models can be used to instigate changes in farming practices to improve milk quality.

Ethics approval

No animal were used.

Data and model availability statement

None of the data were deposited in an official repository. The rights of access to the data, or models will be made available by the respective author upon a confidential request.

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Declaration of interest

None to declare.

Acknowledgements

The authors would like to thank the experts who participated in the focus groups for the development of the assessments, interviewers and samplers who went to the farms to collect milk and information, as well as the French farmers who collaborated in the samplings and surveys. Authors would also like to acknowledge the help they received when drafting this article from the UMRH Scientific Writing Workshop chaired by Isabelle Veissier and Isabelle Ortigues-Marty. The authors also thank MetaForm Langues (Clermont-Ferrand, France) for checking and amending the English text.

Financial support statement

This research was supported by the Ministry of Agriculture in the framework of the CasDAR Qualenvic project (N°1251).

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Table 1

Sensitivity analysis of the UHT milk and cheese assessments of bovine bulk tank milk[1]

Indicators	Overall score μ	Overall score σ	Nutritional dimension score μ	Nutritional dimension score σ	Health dimension score μ	Health dimension score σ	Technological dimension score μ	Technological dimension score σ	Sensory dimension score μ	Sensory dimension score σ
UHT milk assessment										
Pseudomonas level	1.46	4.02	0.42	0.74	0.76	2.55	1.86	5.67	5.88	10.71
$pH_{initial}$	1.41	2.19					6.90	10.79		
Calcium concentration	0.74	0.66	2.20	1.67						
Total β-carotenes concentration	0.73	0.49			2.22	1.19				
Vitamin B2 concentration	0.67	0.32	1.88	0.47						
Lactose concentration	0.62	0.50			1.81	1.24				
Cheese assessment										
Pseudomonas level	1.55	2.82	1.08	2.15	0.52	1.00	0.88	1.79	2.54	5.22
Total caseins concentration	0.94	0.62	2.23	1.60	0.92	0.87	2.10	1.20		
Total bacteria count	0.82	1.48							1.89	3.17
ALA concentration	0.71	0.41	2.24	1.24	0.76	0.33				
Urea concentration	0.68	0.76					1.66	1.79	0.67	0.77
Calcium concentration	0.64	0.44	1.56	0.74			0.83	0.77		
Coliforms level	0.58	1.72							1.05	3.09

Abbreviations: UHT = Ultra-high temperature; ALA = α-linolenic acid (C18:3 n-3)

[1] Presentation of the seven most influential indicators of the overall score of each assessment. For the full sensitivity analysis, see Tables S3 and S4

Table 2

Mean year and season milk quality scores on 10 at global and dimensions level obtained on 30 dairy cow farms

	UHT milk assessment			Raw milk cheese assessment		
Scores[1]	Grazing	Indoor	Season effect[2]	Grazing	Indoor	Season effect[2]
Year overall quality	2.6 ± 0.5 (1.5-3.6)			3.5 ± 0.7 (2.1-4.8)		
Season overall quality	2.8 ± 0.5 (1.6-3.8)	2.1 ± 0.4 (1.3-2.9)	***	3.7 ± 1.0 (1.9-5.8)	3.1 ± 1.0 (1.1-5.1)	*
Dimensions of milk quality						
Sensory	7.2 ± 0.0	7.2 ± 0.0	-	4.2 ± 1.0 (2.2-5.8)	3.4 ± 0.8 (2.0-5.3)	**
Technological	4.3 ± 1.5 (1.2-6.5)	3.0 ± 1.5 (1.0-6.5)	***	4.4 ± 1.2 (2.5-7.4)	4.5 ± 1.5 (1.5-7.6)	ns
Health	2.8 ± 1.0 (1.2-5.6)	2.0 ± 0.9 (0.8-4.7)	**	6.7 ± 0.9 (4.6-8.1)	4.5 ± 1.3 (0.8-6.6)	***
Nutritional	3.0 ± 1.1 (1.3-5.2)	2.9 ± 1.3 (0.7-5.8)	ns	3.2 ± 1.3 (1.5-6.1)	3.4 ± 1.3 (1.1-6.1)	ns

Abbreviations: UHT = Ultra-high temperature; ns = not significant.

[1] Mean ± SD (Minimum-Maximum)

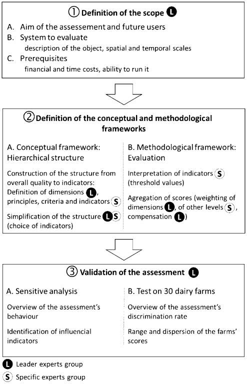
[2] Symbols indicate a difference between grazing and indoor period's scores at $P \leq 0.05$ (*), $P \leq 0.01$ (**) and $P \leq 0.001$ (***) on the considered dimension and product [results from the Student's test or Wilcoxon test when data could not meet the normality assumption (sensory and health scores in cheese assessment and technological and health scores in milk assessment)].

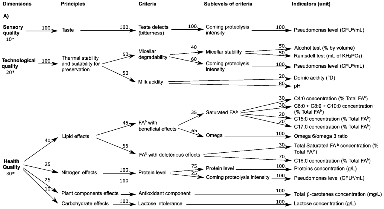
Figure captions

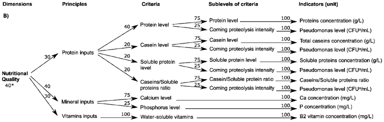
Fig. 1. Construction process of the multicriteria assessment model from the participative approach

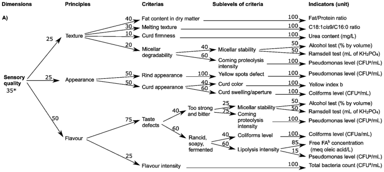
Fig. 2. Structure of the multicriteria assessment of the bovine intrinsic milk quality for ultra-high temperature (UHT) milk production per dimension: A) sensory, technological, health and B) nutritional quality. * Ponderation of the dimension to the global quality score; $\xrightarrow{100}$ Ponderation of the observation (indicators, subcriteria, criteria or principles) to the higher scale one (subcriteria, criteria, principles and dimensions , respectively); [a] CFU: Colony-forming unit; [b] FA: Fatty acids.

Fig. 3. Structure of the multicriteria assessment of the bovine intrinsic milk quality for cheese production per dimension: A) sensory, B) technological, C) health and nutritional quality. * Ponderation of the dimension to the global quality score; $\xrightarrow{100}$ Ponderation of the observation (indicators, subcriteria, criteria or principles) to the higher scale one (subcriteria, criteria, principles and dimensions , respectively); [a] CFU: Colony-forming unit; [b] FA: Fatty acids; [c] ALA: α-linolenic acid (C18:3 n-3); [d] LA: linoleic acid (C18:2 n-6).

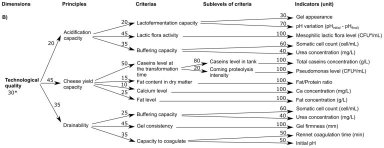

① Definition of the scope L
A. Aim of the assessement and future users
B. System to evaluate
description of the object, spatial and temporal scales
C. Prerequisites
financial and time costs, ability to run it
② Definition of the conceptual and methodological frameworks
A. Conceptual framework: Hierarchical structure
Construction of the structure from overall quality to indicators:
Definition of dimensions L, principles, criteria and indicators S
Simplification of the structure L S (choice of indicators)
B. Methodological framework: Evaluation
Interpretation of indicators S (threshold values)
Agregation of scores (weighting of dimensions L, of other levels S, compensation L)
③ Validation of the assessment L
A. Sensitive analysis
Overview of the assessment's behaviour
Identification of influencial indicators
B. Test on 30 dairy farms
Overview of the assessment's discrimination rate
Range and dispersion of the farms' scores
L Leader experts group
S Specific experts group

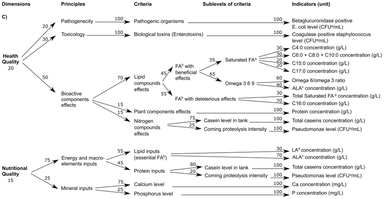

Dimensions
Principles
Criteria
Sublevels of criteria
Indicators (unit)
A)
Sensory quality 10*
Taste
Teste defects (bitterness)
Coming proteolysis intensity
Pseudomonas level (CFU[a]/mL)
Technological quality 20*
Thermal stability and suitability for preservation
Micellar degradability
Micellar stability
Alcohol test (% by volume)
Ramsdell test (mL of KH_2PO_4)
Coming proteolysis intensity
Pseudomonas level (CFU[a]/mL)
Milk acidity
Dornic acidity (°D)
pH
Health Quality 30*
Lipid effects
FA[b] with beneficial effects
Saturated FA[b]
C4:0 concentration (% Total FA[b])
C6:0 + C8:0 + C10:0 concentration (% Total FA[b])
C15:0 concentration (% Total FA[b])
C17:0 concentration (% Total FA[b])
Omega
Omega 6/omega 3 ratio
FA[b] with deleterious effects
Total Saturated FA[b] concentration (% Total FA[b])
C16:0 concentration (% Total FA[b])
Nitrogen effects
Protein level
Protein level
Proteins concentration (g/L)
Coming proteolysis intensity
Pseudomonas level (CFU[a]/mL)
Plant components effects
Antioxidant component
Total β-carotenes concentration (mg/L)
Carbohydrate effects
Lactose intolerance
Lactose concentration (g/L)
100
100
100
100
100
50
50
40
50
60
100
50
20
80
40
45
35
30
30
20
20
65
100
55
30
70
25
100
75
100
25
100
25
10
100
100
100
100


Dimensions
Principles
Criteria
Sublevels of criteria
Indicators (unit)
B)
Nutritional Quality
40*
30
40
30
Protein inputs
Mineral inputs
Vitamins inputs
40
20
20
20
Protein level
Casein level
Soluble protein level
Caseins/Soluble proteins ratio
75
25
Calcium level
Phosphorus level
100
Water-soluble vitamins
Protein level
Coming proteolysis intensity
Casein level
Coming proteolysis intensity
Soluble protein level
Coming proteolysis intensity
Casein/Soluble protein ratio
Coming proteolysis intensity
100
Proteins concentration (g/L)
Pseudomonas level (CFU⁸/mL)
Total caseins concentration (g/L)
Pseudomonas level (CFU⁸/mL)
Soluble proteins concentration (g/L)
Pseudomonas level (CFU⁸/mL)
Caseins/Soluble proteins ratio
Pseudomonas level (CFU⁸/mL)
Ca concentration (mg/L)
P concentration (mg/L)
B2 vitamin concentration (mg/L)



Dimensions
Principles
Criterias
Sublevels of criteria
Indicators (unit)
A)
Sensory quality
35*
25
Texture
40
Fat content in dry matter
100
Fat/Protein ratio
30
Melting texture
100
C18:1cis9/C16:0 ratio
10
Curd firmness
100
Urea content (mg/L)
20
Micellar degradability
40
Micellar stability
50
Alcohol test (% by volume)
50
Ramsdell test (mL of KH2PO4)
60
Coming proteolysis intensity
100
Pseudomonas level (CFUa/mL)
25
Appearance
50
Rind appearance
100
Yellow spots defect
100
Pseudomonas level (CFUa/mL)
50
Curd appearance
40
Curd color
100
Yellow index b
60
Curd swelling/aperture
100
Coliforms level (CFUa/mL)
50
Flavour
75
Taste defects
40
Too strong and bitter
25
Micellar stability
50
Alcohol test (% by volume)
50
Ramsdell test (mL of KH2PO4)
75
Coming proteolysis intensity
100
Pseudomonas level (CFUa/mL)
60
Rancid, soapy, fermented
40
Coliforms level
100
Coliforms level (CFUa/mL)
60
Lipolysis intensity
85
Free FAb concentration (meq oleic acid/L)
15
Pseudomonas level (CFUa/mL)
25
Flavour intensity
100
Total bacteria count (CFUa/mL)


Dimensions
Principles
Criterias
Sublevels of criteria
Indicators (unit)
B)
Technological quality
30*
20
45
35
Acidification capacity
Cheese yield capacity
Drainability
20
45
35
Lactofermentation capacity
Lactic flora activity
Buffering capacity
50
15
10
25
Caseins level at the transformation time
Fat content in dry matter
Calcium level
Fat level
80
20
Caseins level in tank
Coming proteolysis intensity
25
45
35
Buffering capacity
Gel consistency
Capacity to coagulate
30
70
100
60
40
100
100
100
100
100
60
40
100
50
50
Gel appearance
pH variation (pH initial - pH final)
Mesophilic lactic flora level (CFU*/mL)
Somatic cell count (cell/mL)
Urea concentration (mg/L)
Total caseins concentration (g/L)
Pseudomonas level (CFU*/mL)
Fat/Protein ratio
Ca concentration (mg/L)
Fat concentration (g/L)
Somatic cell count (cell/mL)
Urea concentration (mg/L)
Gel firmness (mm)
Rennet coagulation time (min)
Initial pH


Dimensions
Principles
Criteria
Sublevels of criteria
Indicators (unit)
C)
Health Quality 20
20
Pathogenecity
100
Pathogenic organisms
100
Betaglucuronidase positive E. coli level (CFU[a]/mL)
30
Toxicology
100
Biological toxins (Enterotoxins)
100
Coagulase positive staphylococcus level (CFU[a]/mL)
50
Bioactive components effects
70
Lipid compounds effects
45
FA[b] with beneficial effects
35
Saturated FA[b]
30
C4:0 concentration (g/L)
30
C6:0 + C8:0 + C10:0 concentration (g/L)
20
C15:0 concentration (g/L)
20
C17:0 concentration (g/L)
65
Omega 3 6 9
60
Omega 6/omega 3 ratio
40
ALA[c] concentration (g/L)
55
FA[b] with deleterious effects
30
Total Saturated FA[b] concentration (g/L)
70
C16:0 concentration (g/L)
15
Plant components effects
100
Protein concentration (g/L)
15
Nitrogen compounds effects
75
Casein level in tank
100
Total caseins concentration (g/L)
25
Coming proteolysis intensity
100
Pseudomonas level (CFU[a]/mL)
Nutritional Quality 15
75
Energy and macro-elements inputs
55
Lipid inputs (essential FA[b])
30
LA[d] concentration (g/L)
70
ALA[c] concentration (g/L)
45
Protein inputs
80
Casein level in tank
100
Total caseins concentration (g/L)
20
Coming proteolysis intensity
100
Pseudomonas level (CFU[a]/mL)
25
Mineral inputs
75
Calcium level
100
Ca concentration (mg/L)
25
Phosphorus level
100
P concentration (mg/L)