Journal of Dairy Research

cambridge.org/dar

A review of factors influencing the quality and sensory evaluation techniques applied to Greek yogurt

Rabin Gyawali[1], Xi Feng[2], Yan Ping Chen[3], Jose M. Lorenzo[4,5] and Salam A. Ibrahim[1]

[1]Food Microbiology and Biotechnology Laboratory, Food and Nutritional Sciences Program, North Carolina Agricultural and Technical State University, Greensboro, NC 27411, USA; [2]Department of Nutrition, Food Science and Packaging, San Jose State University, San Jose, CA 95192, USA; [3]Department of Food Science and Technology, School of Agriculture and Biology, Shanghai Jiao Tong University, Shanghai 200240, China; [4]Centro Tecnológico de la Carne de Galicia, Avd. Galicia no 4, Parque Tecnológico de Galicia, San Cibrao das Viñas, 32900 Ourense, Spain and [5]Facultad de Ciencias de Ourense, Área de Tecnología de los Alimentos, Universidade de Vigo, 32004 Ourense, Spain

Invited Review

Cite this article: Gyawali R, Feng X, Chen YP, Lorenzo JM and Ibrahim SA (2022). A review of factors influencing the quality and sensory evaluation techniques applied to Greek yogurt. *Journal of Dairy Research* **89**, 213–219. https://doi.org/10.1017/S0022029922000346

Received: 27 September 2021
Revised: 24 January 2022
Accepted: 26 January 2022
First published online: 25 April 2022

Keywords:
Electronic nose and tongue; Greek yogurt; processing techniques; quality; sensory evaluation; starter culture

Author for correspondence:
Xi Feng, Email: xi.feng@sjsu.edu

Abstract

Greek yogurt is one of the fastest growing products in the dairy industry. It is also known as strained yogurt, which is obtained after draining the whey. As a result of the draining process, Greek yogurt has higher total solids and lower lactose than regular yogurt. Since it is a concentrated yogurt, its sensory characteristics are different from regular yogurt. However, there is little information about factors influencing the quality of Greek yogurt and sensory evaluation techniques applied to Greek yogurt. This review aims to describe the effects of ingredients, starter cultures, processing techniques and other parameters on quality characteristics and sensory properties of Greek yogurt. In addition, advantages and limitations of novel sensory evaluation techniques applied to Greek yogurt products are discussed. In particular, we take a look at advanced techniques such as the electronic nose and electronic tongue and the benefits of these techniques with regard to Greek yogurt. This review should help the Greek yogurt industry to improve its current products and develop innovative products based on appropriate food evaluation techniques.

In recent years, Greek yogurt, also known as Greek-style yogurt (GSY) or strained yogurt in Europe, has become very popular in North America (Gyawali and Ibrahim, 2016, 2018; Moineau-Jean *et al*., 2017). Greek yogurt is a yogurt that has been strained to remove the whey, resulting in a thicker consistency than unstrained yogurt while preserving the yogurt's distinctive, sour taste. The textural qualities of Greek yogurt also play a crucial role in sensory attributes. For example, the texture of yogurt is affected when there is weak body and whey separation. During the straining process, Greek yogurt is concentrated. As a result of the straining process it has higher total solids and lower lactose content than regular yogurt. In the USA no legal standard exists for Greek yogurts, however, Greek yogurt should contain increased protein content to a minimum of 5.6% when compared to 2.7% protein in regular yogurt (Desai *et al*., 2013). Moreover, Greek yogurt has a creamy white color, a soft and smooth body, good spreadability and is slightly acidic (Nsabimana *et al*., 2005). Since it is a concentrated yogurt, it possesses sensory attributes that are different from regular yogurt as well as superior nutritional properties (Nsabimana *et al*., 2005). However, as there is limited information in the literature regarding factors influencing the quality of Greek yogurt, more data relating to consumer perception and specific drivers of taste acceptability would be useful for Greek yogurt product developers. Therefore, in this review, our aim is to discuss the effect of ingredients, starter culture and processing conditions on the quality and sensory attributes of Greek yogurt. Moreover, the sensory properties of commercial Greek yogurts and the driving factors of acceptability through different sensory evaluation testing will be addressed.

Factors influencing the quality and sensory attributes of Greek yogurt

Ingredients

The ingredients added to Greek yogurt can directly affect its quality and sensory properties. As consumers have become increasingly health conscious, there is increasing demand for low-fat or nonfat Greek yogurt types. Thus, one of the primary challenges facing the Greek yogurt industry is to produce low fat yogurt that exhibits a rich textural quality (Wouters, 2012). Currently, the industry is developing low-fat yogurt products without changing the sensory and functional properties of semi-solid milk products. Initially, hydrocolloids and stabilizers were used to imitate fat perception and to enhance the stability of yogurt. An alternative is to utilize protein-based fat replacers. This could be done by fortifying the milk using ingredients such as whey protein concentrate (WPC). In the current industrial production of high protein yogurt, protein fortification and the heat treatment of milk are two of the most important processing parameters affecting yogurt texture. WPC is generally used to reduce whey separation and to increase the firmness of the yogurt. Consequently, Greek yogurt manufacturers have found that WPC (1–2%, *w/v*) helps to stabilize yogurt as the gels are firmer and have less tendency to develop syneresis. Adding WPC to yogurt milk is also a way to achieve higher total solids and higher protein content (Gyawali and Ibrahim, 2018).

From a technological perspective, the interaction of denatured whey protein with casein micelles or with κ-casein in the serum phases is regarded as responsible for an acceptable yogurt structure. Therefore, it is practically possible to obtain a yogurt with desired textural properties by the addition of WPC (Mahomud *et al*., 2017). It is shown that yogurt with 4.5% protein and casein to whey protein ratio of 60/40 can be used for the development of low-fat yogurts (Krzeminski *et al*., 2011). It is clear that adding whey proteins to low-fat yogurts improves their firmness properties, making such properties comparable to those of full-fat yogurt. The fortification of yogurt with whey protein causes a decrease in the casein:whey protein ratio. As this ratio decreases, the gel network becomes finer and the network of cross-links becomes denser resulting in less whey drainage from the smaller pores (Puvanenthiran *et al*., 2002). In a recent study, Gyawali and Ibrahim (2018) demonstrated that supplementing nonfat GSY with yogurt WPC (1%, *w/v*) and pectin (0.05%, *w/v*) was an effective way to reduce acid whey generation during the GSY manufacturing process. The formation of aggregate by interaction with casein micelles created a more rigid gel structure in the yogurt.

Meletharayil *et al*. (2016) demonstrated that CO_2-treated milk protein concentrate (TMPC) as a protein source had an influence on the quality of GSY. When skim milk was fortified to 9% (*w/w*) with TMPC, authors found that TMPC can be used in GSY production as it could potentially help address higher acidity levels due to its lower buffering capacity. The results also showed that the use of CO_2-treated milk protein concentrate in conjunction with hydrodynamic cavitation could be used to control the increased viscosity, firmness and acidity that is encountered in the manufacture of GSY containing added milk protein ingredients. The fortification of TMPC in the milk base also exhibited higher WHC compared to yogurt with milk protein concentrate alone. Similarly, Bong and Moraru (2014) evaluated the effect of micellar casein concentrate (MCC) on the chemical and physical properties of GSY. These authors found that the consistency and viscosity of GSY was similar to those of GSY prepared with the conventional whey straining process, indicating that MCC could be a suitable dairy ingredient source. Other ingredients such as non-fat milk solids, skim milk powder and whey protein can also be used as additives in order to achieve a thickened texture without undergoing the physical concentration step normally applied in Greek yogurt production (Chandan and O'Rell, 2006).

An additional amount of fat in the yogurt base also increased the overall compactness of the gel yogurt microstructure and decelerated shear-induced disruption as the fat globules act as linking protein agents (Krzeminski *et al*., 2011). Megalemou *et al*. (2017) assessed the sensory properties of cow, goat and sheep milk derived Greek yogurts having lipid contents of 3.06, 3.75, and 6.76 (g/100 g yogurt) respectively, and found the sheep milk yogurt to be the most palatable. It scored higher for the taste attributes of fatty, rich and delicious in addition to higher scores for whey and grainy texture attributes. The differences in such organoleptic variations could be related to the differences in lipid content and fatty acids profile of the tested yogurt samples. Desai *et al*. (2013) evaluated the sensory properties of plain commercial Greek yogurts. Full fat yogurts were characterized by firmness and denseness, whereas low- and non-fat yogurts lacked firmness, denseness and cohesiveness. Additionally, Desai *et al*. (2013) found that Greek yogurts of different fat levels were primarily differentiated by texture attributes rather than by flavor attributes. Similarly, inulin delivers creaminess to dairy products and thus it is ideal for use in Greek style yogurt as this allows manufacturers to increase the fiber content of their products (Wouters, 2012).

Haddad *et al*. (2007) conducted a study to identify the contributions of sensory properties, fat levels and information related to the absence of preservatives to purchasing decisions regarding labneh, a strained product similar to Greek yogurt. It is produced by concentrating milk to approximately 23% total solids (*wt/vol*) by the traditional cloth bag method, ultrafiltration, reverse osmosis or direct reconstitution (Ozer *et al*., 1998). Analysis of the responses revealed that the likelihood of a decision to purchase was primarily related to the higher fat content and sensory properties of the labneh rather than the health claims and use of preservatives. Atamian *et al*. (2014) characterized the physicochemical and sensory properties of bovine, caprine, and ovine Greek yogurt with different fat levels. Results of this study showed that the types of milk fat significantly affected the chemical composition (moisture, fat, protein, ash, acidity, and magnesium) and sensory attributes (color, denseness, and melting rate). In addition, the authors suggested that the sensory characteristics of yogurt can be manipulated if production is carried out during specific lactation periods (milk obtained during the early, middle or late lactation period) of animals.

Serhan *et al*. (2016) conducted a study to characterize the physicochemical, microbiological and sensory parameters of labneh made from a mixture of goat's and cow's milk. The labneh produced from goat's milk was characterized by higher moisture, ash and fat content, but lower pH, total solids, protein and lactose content compared to that from cow's milk. Interestingly, the authors found that labneh prepared with 40% goats' milk plus 60% cow's milk was the one most preferred by the sensory panel. This could be due to the changes in fatty acid profiles with a reduction in short fatty and linoleic acids and a slight increase in palmitoleic acid which had a positive effect on the sensory acceptance. Similarly, Malek *et al*. (2001) produced labneh (26% total solids) from cow's, goat's and sheep's milk that was evaluated for sensory properties by a consumer panel. The sensory evaluation results demonstrated that the cow's milk labneh was more acceptable than that from goats and sheep which did not differ significantly in consumer acceptability ratings.

Starter culture

The type of starter culture can affect yogurt quality. For example, exopolysaccharide (EPS) producing starter cultures are becoming increasingly popular due to their high water holding and texture improving abilities. Thus, EPS producing cultures have been used to enhance the overall quality of yogurt including Greek/Greek-style/concentrated by increasing viscosity and improving sensory attributes including mouth-feel, taste perception and creaminess, as well as enhancing storage stability (London *et al.*, 2015). Different combinations of dairy starter cultures can also have a direct influence on the sensory properties of concentrated yogurt. It has been reported that fresh yogurt made with the addition of yogurt starter and *Bifidobacterium bifidum* had the highest organoleptic scores, followed by products made with yogurt starter and *Propionibacterium freudenreichii* ssp. Shermanii (Nsabimana *et al.*, 2005). Previous studies have shown that when non-EPS producing strains are used as the starter culture, the casein to serum protein (CN:SP) ratio of the yogurt milk base and total solid are important factors that influence the ability of the yogurt gel network to retain free water (Lee and Lucey, 2010). According to Puvanenthiran *et al.* (2002), decreasing the CN:SP ratio in the yogurt milk base increased the firmness of the yogurt. Maragkoudakis *et al.* (2006) evaluated two probiotic *Lactobacillus* strains (*L. plantarum* ACA-DC 146 and *L. paracasei* subsp. *tolerans* ACA-DC 4037) for their potential application in Greek set type yogurt production as starters or starter adjuncts. The yogurt was evaluated with respect to its microbiological, physicochemical and sensory properties. Yogurt produced with *L. paracasei* exhibited the best sensory properties with a rich, traditional smooth taste. In addition, yogurt prepared with the *L. paracasei* strain also showed good physicochemical and microbiological properties after two weeks of refrigerated storage with > 7.0 log cfu/g of probiotic and starter culture. However, when the authors used very high inoculums of encapsulated starter culture (10 log cfu/g) and *L. paracasei* (11 log cfu/g), the produced yogurt took a surprisingly long fermentation time to reach pH 4.6. That yogurt also exhibited poor sensory properties. These results indicate that the type and amount of starter cultures have a significant influence on the overall quality of yogurt.

Processing conditions

A number of methods are used in Greek yogurt production. The traditional process involves the straining of yogurt in cloth bags while commercial scale production involves concentrating heat treated skim-milk yogurt in a quarg separator and blending the yogurt with cream to the desired total solids and fat levels (Haddad *et al.*, 2007). The non-strained type of Greek-style yogurt can be thickened with hydrocolloids or supplemented with milk proteins. In the case of a non-strained type, hydrocolloids can be added at the beginning, together with all other dairy ingredients. However, with the strained type, it is preferable to add the hydrocolloids after the concentration process (Wouters, 2012; Gyawali and Ibrahim, 2016). The composition and rheological properties of yogurt are greatly influenced by the production process that is applied. For example, in yogurt preparation, heat treatment of the milk leads to the denaturation of the whey proteins, resulting in the formation of micelle-bound and soluble protein complexes (Lucey, 2002). The formation of these complexes can increase the gelation pH to ~ 5.3 and thereby influence the firmness, WHC and porosity of acid gels (Xu *et al.*, 2015). After the gel has set, yogurt can also undergo a concentration step to become what is known as strained or Greek-style yogurt. Traditionally, the finished product is strained through cheesecloth for an extended period. The whey is subsequently drained out, and the yogurt curd increases in total solids and percent milk fat (Gyawali and Ibrahim, 2016). These types of yogurts are known for their 'remarkably thick viscous body' (Chandan and O'Rell, 2006). New technologies, such as ultrafiltration or centrifugation, have overtaken this traditional process since such new technologies can improve both efficiency and microbiological quality (Chandan and O'Rell, 2006). With the growing popularity of Greek yogurt, there has also been an increase in acid whey production. To address this issue, several researchers are conducting studies on yogurt using different milk processing methods. Recently, Uduwerella *et al.* (2017), demonstrated that enhancing the initial milk total solid based on the protein concentration may produce Greek yogurt with less acid whey generation while maintaining desirable physical and chemical characteristics in the final product. Their results showed that an ultrafiltration method to concentrate the yogurt base prior to the fermentation step can produce yogurt with a hard gel structure, low syneresis, maximum viscosity, and a high protein and fat content. Similarly, Meletharayil *et al.* (2016) reported an alternate processing technology to avoid the dewheying process during GSY manufacturing. The results of their study showed that hydrodynamic cavitation can be used to control acid whey generation in GSY manufacturing. Such cavitated GSY had higher WHC due to the incorporation of moisture into the protein matrix which is not expelled during the yogurt straining. Since the production of GSY requires several additional processing steps the possibility of microbial contamination by pathogens or spoilage organisms also increases. The growth and survival of microbial contaminants (*Escherichia coli* and *Kluyveromyces marxianus*) in GSY during storage as a result of centrifugation or ultrafiltration was compared with that in regular stirred yogurt. The increased buffering capacity of GSY produced from ultra-filtered milk led to reduced viability of harmful as well as other pathogenic microorganisms during storage (Moineau-Jean *et al.*, 2017).

Traditional labneh processing also involves manual handling which results in increased opportunities for contamination by yeast and molds. To avoid this, producers have used several additives to manage the shelf-life of (Haddad *et al.*, 2007). The shelf-life of concentrated yogurt was evaluated by Al-Kadamany *et al.* (2003). The shelf life of yogurt that was produced by blending skim milk yogurt and cream stored at 5°C was considerably longer than that of yogurt produced with the traditional cloth bag straining method. The longer shelf-life of that yogurt was due to the elimination of vegetative forms of yeasts and molds through heat treatment during the skim milk yogurt phase, which prevented access to the finished product at later stages during processing. In contrast, yogurt produced with the cloth bag straining method appears to be subject to a higher risk of contamination due to the longer period required for the straining process. This longer straining process is thus relatively unhygienic and results in the proliferation of yeasts and molds which thereby reduces the shelf-life. Similarly, Dagher and Ali (1985) explored a yogurt processing method that prolonged the shelf-life of concentrated yogurt. The results of their study revealed that a mild heat treatment (70°C for 3 min) in the presence of hydrogen peroxide, potassium sorbate and thickeners greatly improved the quality and shelf-life of yogurt as confirmed by a sensory evaluation test. The authors also suggested that the yogurt prepared with the quick centrifugation method had favorable organoleptic characteristic as well as less chance of the bacterial and mold contamination that is frequently observed in cloth bag straining methods.

Sensory evaluation techniques applied to Greek yogurt

Traditional yogurt evaluation

Among college students, teams and individuals in the USA, the Collegiate Dairy Products Evaluation Contest (CDPED) is an annual contest to judge the quality and market grade of dairy products. It is supported by a Director, Board and dairy industry partners and is coordinated by USDA personnel (96th Annual Collegiate Dairy Products Evaluation Contest, 2018). In 1916, the first National CDPED was held in Springfield, MA. Butter was the only product evaluated in that contest with milk and cheddar cheese being added at the 1917 competition. Vanilla ice cream, cottage cheese and strawberry yogurt were added in 1926, 1962 and 1977, respectively (Clark and Costello, 2009). Until now, six dairy categories are evaluated, including 2% fluid milk, butter, cheddar cheese, vanilla ice cream, cottage cheese and strawberry-flavored Swiss-style yogurt. Participated students receive training from college professors who are experts in dairy product evaluation. Meanwhile, a group of industry experts select six products from the above six categories and they evaluate products and the score and attributes are reviewed by assigned coach judges and used as official score cards (Collegiate Dairy Products Evaluation Contest, 2022).

The official judges of Swiss style/blended yogurt (including Greek style) with natural and alternative sweeteners provide three replicates of each sample in their original 8 oz. commercial containers. A foil or a blank carton is used to cover replicates #2 and #3. Replicate #1 is inverted onto a plate for observation in the first 10 min of the 35 min judging period. The contestants evaluate the appearance of the samples without disturbing the display sample on the plate. The contestants are provided with a spoon to remove the samples from replicate #2 in order to evaluate the flavor and texture profiles. Replicate #3 is used to judge the attributes 'free whey' and/or 'shrunken'. For replicates #2 and #3, these samples must also be judged within the 10 min. allotted time period (2018 Collegiate Dairy Products Evaluation Contest).

The contestant's score on the scorecard is expressed as the difference between their score and the official score. The purpose of this competition is to assess the contestants' ability to independently recognize the merits and defects of the samples as pointed out by the official judges. However, as a fermented semi-solid product derived from yogurt through draining away water and water-soluble components, Greek yogurt has usually received the lowest score in these contests, which suggests a need for a dedicated sensory evaluation test for Greek yogurt (Desai *et al*., 2013).

Descriptive test for Greek yogurt

A descriptive test has been employed to evaluate the sensory characteristics of Greek yogurt and Greek-style yogurt. Muir and Hunter (1992) developed a sensory vocabulary to exam the sensory properties of fermented milk, including Greek yogurt and Greek-style yogurt. Using descriptive analysis, the bacterial strain, temperature, pH and storage time were found to be major factors influencing yogurt flavor and texture properties (Coggins *et al*., 2008). In relation to fat content, Desai *et al*. (2013) found that different fat levels determined texture profiles rather than flavor characteristics. Suh and Kim (2020) studied microbial communities related to sensory characteristics of commercial drinkable yogurt products in Korea. Nguyen *et al*. (2017) investigated different hydrocolloids on texture, rheology, tribology and sensory perception of low-fat pot-set yoghurt. Coggins *et al*. (2008) developed a sensory lexicon for conventional milk yogurt in the United States. In their study, 62 characteristics including flavor, aroma, texture, basic taste, feeling factors and appearance were used to validate the sensory lexicon. However, the yogurt could not be categorized by fat percentage or source of milk (organic or conventional) by the developed sensory lexicon. Until now, there is still no set standard for identifying Greek yogurt in the United States, and Greek yogurt is made using a variety of methods.

Affective test for Greek yogurt: Acceptability/preference test

Today's continually changing marketplace offers consumers a variety of niche products, but consumer preferences are becoming increasingly more difficult to predict. This challenge has resulted in more emphasis on the importance of collecting data related to consumers' opinions (Meilgaard *et al*., 2007). One way to collect and assess data from consumers is *via* an affective test that can be used to evaluate the personal response of current or potential customers to a product, a product idea, or specific product characteristics.

Desai *et al*. (2013) studied the sensory properties and drives affecting acceptability for Greek yogurts. Their results indicated that consumer preferences for Greek yogurt increased in accordance with firmness, dense texture, moderate sweet aromatic, milkfat and dairy sour flavors and moderately sour taste. However, consumers were unable to differentiate between strained and fortified Greek yogurts as both strained Greek and fortified Greek style yogurts received the highest overall acceptability scores in blind testing situations. As a result, the addition of dried dairy ingredients and/or the use of traditional straining and centrifugation are both suitable for a successfully manufactured Greek yogurt. Consumer acceptance of newly developed Greek yogurts has been determined using preference ranking tests and acceptability tests. For example, Dida and Obsioma (2014) used goat milk to develop mango-flavored Greek yogurt. Acceptability/preference test also are applied in new application of Greek yogurt. Jaramillo *et al*. (2022) and Phadungath (2015) investigated the acceptability of Greek yogurt as a healthier alternative for cream cheese in cheesecake.

Affective test for Greek yogurt: Just-about-right test

Just-about-right (JAR) tests are used to determine the optimum level of sensory attributes of products. In the consumer tests, the consumers are often asked whether a sensory characteristic of a product (sweetness, bitterness, etc.) is too high or too low or just about right. Such information can assist the researchers in understanding the reason why consumers like or dislike a product and thus provide valuable information to help guide the development of new products (Lawless and Heymann, 1998).

Narayanan *et al*. (2014) used JAR scales and penalty analysis to determine appropriate concentrations of stevia sweeteners for vanilla yogurt. They found that the addition of stevia or aspartame was not accepted by consumers, and the yogurt sweetened with sucrose likewise did not have a positive effect on consumer preferences. The study emphasized the importance of careful selection of stevia type and concentration as well as optimizing yogurt cultures and fermentation conditions prior to product launch. Another interesting study was conducted by Li *et al*. (2014) indicated that JAR and ideal scaling provide similar insights into the influence of sensory attributes on likeability. In their study, sweetness and coffee flavor in dairy beverage were evaluated by JAR and scaling. A well-balanced sweetness and coffee flavor dairy beverage is needed to maximize consumer sensory perceptions. However, they also found that JAR scaling is more efficient as it requires fewer panelists and less data analysis work. Since little research has been done on Greek and Greek style yogurt with JAR test, the driving factors of consumer preferences towards Greek and Greek style yogurt is still unknown.

Other affective tests

Quicker and more easily set-up sensory evaluation methods with untrained panelists or consumers have garnered particular interest in recent years. Recruited participants can complete the sensory test immediately, thus drastically reducing the time and cost of running sensory experiments. Popular methods include projective mapping (or Napping, a modified projective mapping restricted to a rectangular framework or tasting sheet), Check-All-That-Apply (CATA), Pivot© profile, and others.

Projective mapping requires assessors to position samples on a sheet of paper according to sensory similarity. The paper could be either square or rectangular shape. To conduct projective mapping, similar samples are positioned close together, and different samples are positioned far apart on the sheet for data collection. The experiment could be conducted either by 9 to 15 trained assessors or 15 to 50 untrained assessors. By locating seven Greek yogurts (five traditional samples and two labeled as light samples) on an A4 sheet of paper, Esmerino *et al.* (2017) found that the two types of Greek yogurt were different in appearance (bright, yellow, white), taste (sour, bitter), milk flavor, and mouth feeling (greasy, astringent, and gritty).

CATA is another fast sensory evaluation method requiring 50 to 100 untrained consumers. The method required consumers to select descriptors from a list of previously developed words or phrases to profile products (Jaeger *et al.*, 2013). CATA results found that a particular traditional Greek yogurt was positively correlated with yellow, greasy and milk flavor, but negatively correlated with gritty and sour. A second traditional one presented a highly positive correlation with cheese aroma, salty, greasy and cheese flavor, and a negative correlation with sweet aroma and vanilla aroma. By contrast, a light Greek yogurt was positively correlated with white, firm, astringent and bitter aftertaste, and negatively correlated with bright, homogeneous appearance, sweet aftertaste, and creamy, and a second light Greek yogurt was negatively correlated with cheese flavor, salty, greasy and cheese aroma (Esmerino *et al.*, 2017).

The Pivot© profile (PP), a method that compares samples to a reference (pivot), could provide an estimation of the intensity of attributes in the samples relative to the pivot. Recruited panelists are required to list those attributes that they perceive to be less or more intense in the sample than in the pivot, respectively. Correspondence analysis (CA) and multidimensional alignment (MDA) were commonly used to measure the data obtained (Esmerino *et al.*, 2017). CA results indicated that sweet taste could be used to characterize samples and the pivot along the first dimension, and sour was negatively correlated with cheese flavor and bright. The MDA further revealed that traditional Greek yogurt varied differently in aroma and flavor such as bitter, sour, sweet aroma, and milk aroma. Light Greek yogurt exhibited very similar sensory characteristics, with positive correlations for consistent, sour, and astringent but negative correlations for yellow, creamy, fermented aroma, vanilla flavor, and cheese flavor.

The three methods (projective mapping, CATA and PP) provide similar sensory information to describe the difference among traditional and light Greek yogurt, but each has limitations. Hence, the most appropriate one should be selected to determine the sensory profile of the particular Greek yogurt. In addition, other consumer-based profile methods, such as sorting and ultra-fast profile could be used to characterize product profiles as well as to modify yogurt formulae.

Advanced techniques for sensory evaluation of Greek yogurt

Historically, yogurt producers have used human sensory panels to assess newly developed yogurt products in order to determine optimized ingredient combinations. However, humans cannot evaluate countless ingredient combinations quickly and accurately. Consequently, this provides an opportunity for electronic tongues and noses that can mimic the chemical reactions of human taste buds and nostrils (Watson, 2017). Flavor release profiles throughout the fermentation and aging processes of food materials can be measured using electronic noses and electronic tongues. These electronic devices are comprised of an array of sensors with nonspecific responses that have pattern recognition ability using multivariate data analysis. The information from the sensors is collected through pattern recognition techniques such as principal component analysis (PCA) or artificial neural networks (ANN). These methodologies, which are promising approaches for real-time, in-line, *in situ* determinations and non-destructive sensing, are potentially extremely useful for the dairy industry.

Electronic tongues (E-tongues)

The E-tongue is a robotic system with an array of sensors. It has good reproducibility, low detection limits and high sensitivity for screening the taste attributes of food (Woertz *et al.*, 2010). The logic of the application of a low-selectivity sensor is based on an analogy to biological functionalities of the taste sensory system in mammals. For example, with mammals, the millions of taste receptors on the tongue respond to various substances in liquid or solid form. The electronic signals are then transmitted to the brain where the taste neurons process the signals (Vlasov *et al.*, 2005). The purpose of E-tongues is thus qualitative analysis such as recognition, classification or identification of samples based on standard taste parameters as being sweet, acid, bitter, salty and umami (Dias *et al.*, 2009). It is composed of an auto-sampler, array of chemical sensors with different selectivity and a software with appropriate algorithms to process the signal and get the results (Peris and Escuder-Gilabert, 2013).

Hruškar *et al.* (2009) used the E-tongue to evaluate milk and dairy products on the Croatian market. They found that a commercial E-tongue (α-ASTREE, Alpha M.O.S) could differentiate among five different brands of milk, five yogurts and various dairy products. Dias *et al.* (2009) also reported the identification of goat milk adulteration with bovine milk by E-tongue taste evaluation. However, most of the applications of E-tongues are in liquid samples during fermentation monitoring, and include wine (Buratti *et al.*, 2011), beer (Kutyła-Olesiuk *et al.*, 2012) and whey (Buczkowska *et al.*, 2010; Witkowska *et al.*, 2010). E-tongue technologies are of limited value for semi-solid products such as Greek yogurt, although Wei *et al.* (2017) did use a self-developed voltametric electronic tongue to monitor the fermentation, post-ripeness and storage properties of yogurt by as affected by pH and viscosity. The pH and viscosity of each process could be accurately predicted. However, as other chemical and physical parameters (protein and sugar contents) could be changed during processing and storage, this newly developed sensor should be further validated under different conditions.

Electronic noses (E-noses)

The electronic nose (E-nose) was introduced in order to analyze the volatile profile and quality control of yogurt. E-nose instruments can visualize the aroma profile of the samples by combining chemometric techniques with artificial neural networks (Cimander *et al*., 2002). Such instruments usually apply an array of chemical sensors, such as conductive polymers and metal oxides. The primary advantage of the E-nose is that once the instrument is calibrated, the sensor can conduct the odor assessment on a continuous basis much faster and at a lower cost than would be the case with an actual sensory panel. Marilley *et al*. (2004) used mass spectrometry based E-nose data with further principal component analysis to investigate 7 different genotype strains of *Lactobacillus casei* isolated from Gruyère cheeses, which provided clear discrimination results. The results could be used to screen for new aroma producing strains. However, the drawback of the E-nose is that this equipment only responds to relatively high amounts of volatile compounds in the food, which makes it less sensitive than GC-MS and the human olfactory system. Because of these disadvantages, an E-nose cannot provide as much detailed information as the GC-MS (Cheng, 2010).

Limitations

Traditional sensory evaluation (descriptive tests and affective tests) of Greek yogurt has its own limitation as the evaluation grades for Greek yogurt were lower than those for other types of yogurts. As a consequence of this, the merits of Greek yogurt are incompletely understood. As discussed above, recent innovative sensory evaluation methods such as the Pivot Profile revealed a more accurate correlation between attributes and samples, however, further research is needed to test the repeatability. Moreover, there have been very few studies of Greek yogurt employing E-tongue and E-nose technologies. This might be due to the fact that the aroma of Greek yogurt is weak and its viscosity is high, which makes it an inappropriate candidate for this type of evaluation. However, when the E-tongue or E-nose is coupled with other instruments, such as near-infrared spectrometry, it could also be applied in an online monitoring system (Navratil *et al*., 2004).

Conclusions

Greek yogurt is currently one of the fastest growing products in the dairy industry. Thus, a greater knowledge of enhanced manufacturing procedures and consumer preferences would be very useful information for helping the Greek yogurt industry to improve its current products as well as develop innovative products for the future. An appropriate sensory evaluation method could identify more information from consumers without over expenses. Coupling E-nose or E-tongue with other analytical instruments, the acquired data could provide practical strategies in quality control and research and development.

Acknowledgments. This publication was made possible by Grant or project Number NC.X308-5-18-170-1 from the National Institute of Food and Agriculture (NIFA). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIFA. Author (XF) would like to acknowledge the support of the Department of Nutrition, Food Science and Packaging at San Jose State University (San Jose, CA 95192, USA). Author (SAI) would also like to acknowledge the support of the Department of Family and Consumer Sciences and the Agricultural Research Station at North Carolina Agricultural and Technical State University (Greensboro, NC, 27411 USA).

References

96th Annual Collegiate Dairy Products Evaluation Contest (2018) Available at https://www.dairyproductscontest.org/pdf/2018_Contest_Information/2018_cdpec_rules_updated.pdf (Accessed 22 September 2021).

Al-Kadamany E, Khattar M, Haddad T and Toufeili I (2003) Estimation of shelf-life of concentrated yogurt by monitoring selected microbiological and physicochemical changes during storage. *LWT-Food Science and Technology* **36**, 407–414.

Atamian S, Olabi A, Kebbe Baghdadi O and Toufeili I (2014) The characterization of the physicochemical and sensory properties of full-fat, reduced-fat and low-fat bovine, caprine, and ovine Greek yogurt (Labneh). *Food Science & Nutrition* **2**, 164–173.

Bong D and Moraru C (2014) Use of micellar casein concentrate for Greek-style yogurt manufacturing: effects on processing and product properties. *Journal of Dairy Science* **97**, 1259–1269.

Buczkowska A, Witkowska E, Górskia Ł, Zamojska A, Szewczyk KW, Wróblewski W and Ciosek P (2010) The monitoring of methane fermentation in sequencing batch bioreactor with flow-through array of miniaturized solid state electrodes. *Talanta* **81**, 1387–1392.

Buratti S, Ballabio D, Giovanelli G, Zuluanga Domínguez CM, Moles A, Benedetti S and Sinelli N (2011) Monitoring of alcoholic fermentation using near infrared and mid infrared spectroscopies combined with electronic nose and electronic tongue. *Analytica Chimica Acta* **697**, 67–74.

Chandan RC and O'Rell KR (2006) Principles of yogurt processing. In Chandan RC, White CH, Kilara A and Hui YH (eds), *Manufacturing Yogurt and Fermented Milks*. Ames: Blackwell Publishing, pp. 195–209.

Cheng H (2010) Volatile flavor compounds in yogurt: a review. *Critical Reviews in Food Science and Nutrition* **50**, 938–950.

Cimander C, Carlsson M and Mandenius CF (2002) Sensor fusion for on-line monitoring of yoghurt fermentation. *Journal of Biotechnology* **99**, 237–248.

Clark S and Costello M (2009) Dairy products evaluation competitions. In Clark S, Costello M, Drake M and Bodyfelt F (eds), *The Sensory Evaluation of Dairy Products*, 2nd Edn. New York, NY: Springer, pp. 43–72.

Coggins PC, Schilling MW, Kumari S and Gerrard PD (2008) Development of a sensory lexicon for conventional milk yogurt in the United States. *Journal of Sensory Studies* **23**, 671–687.

Collegiate Dairy Products Evaluation Contest (2022) Available at https://www.dairyproductscontest.org/ (Accessed 14 January 2022).

Dagher S and Ali A (1985) Effect of pasteurization, centrifugation and additives on quality of concentrated yogurt (labneh). *Journal of Food Protection* **48**, 300–302.

Desai NT, Shepard L and Drake MA (2013) Sensory properties and drivers of liking for Greek yogurts. *Journal of Dairy Science* **96**, 7454–7466.

Dias LA, Peres AM, Veloso ACA, Reis FS, Vilas-Boas M and Machado AASC (2009) An electronic tongue taste evaluation: identification of goat milk adulteration with bovine milk. *Sensors and Actuators B: Chemical* **136**, 209–217.

Dida K and Obsioma V (2014) Development of Greek yogurt from goat's milk. *Philippine Journal of Veterinary and Animal Sciences* **40**, 121–132.

Esmerino EA, Tavares Filho ER, Thomas Carr B, Ferraz JP, Silva HLA, Pinto LPF, Freitas MQ, Cruz AG and Bolini HMA (2017) Consumer-based product characterization using pivot profile, projective mapping and check-all-that-apply (CATA): a comparative case with Greek yogurt samples. *Food Research International* **99**, 375–384.

Gyawali R and Ibrahim SA (2016) Effects of hydrocolloids and processing conditions on acid whey production with reference to Greek yogurt. *Trends in Food Science & Technology* **56**, 61–76.

Gyawali R and Ibrahim SA (2018) Addition of pectin and whey protein concentrate minimizes the generation of acid whey in Greek-style yogurt. *Journal of Dairy Research* **85**, 238–242.

Haddad Y, Haddad J, Olabi A, Shuayto N, Haddad T and Toufeili I (2007) Mapping determinants of purchase intent of concentrated yogurt (Labneh) by conjoint analysis. *Food Quality and Preference* **18**, 795–802.

Hruškar M, Major N, Krpan M, Krbavčić IP, Šarić G, Marković K and Vahčić N (2009) Evaluation of milk and dairy products by electronic tongue. *Mljekarstvo* **59**, 193–200.

Jaeger SR, Chheang SL, Jin D, Bava CM, Gimenez A and Vidal L (2013) Check-all-that-apply (CATA) responses elicited by consumers: within-assessor reproducibility and stability of sensory product characterizations. *Food Quality and Preference* **30**, 56–67.

Jaramillo S, Kobayashi-Wagner R and Beaulaurier D (2022) Acceptability of Greek yogurt as a healthier alternative for cream cheese in cheesecake. Available at https://www.cwu.edu/diet/acceptability-greek-yogurt-healthier-alternative-cream-cheese-cheesecake (Accessed 18 January 2022).

Krzeminski A, Großhable K and Hinrichs J (2011) Structural properties of stirred yoghurt as influenced by whey proteins. *LWT-Food Science and Technology* **44**, 2134–2140.

Kutyła-Olesiuk A, Zaborowski M, Prokaryn P and Ciosek P (2012) Monitoring of beer fermentation based on hybrid electronic tongue. *Bioelectrochemistry (Amsterdam, Netherlands)* **87**, 104–113.

Lawless HT and Heymann H (1998) *Sensory Evaluation of Food: Principles and Practices*. Gaithersburg, Maryland: Aspen Publishers, Inc.

Lee W and Lucey J (2010) Formation and physical properties of yogurt. Asian-Australasian. *Journal of Animal Sciences* **23**, 1127–1136.

Li B, Hayes J and Ziegler G (2014) Just-about-right and ideal scaling provide similar insights into the influence of sensory attributes on liking. *Food Quality and Preference* **37**, 71–78.

London LE, Chaurin V, Auty MA, Fenelon MA, Fitzgerald GF, Ross RP and Stanton C (2015) Use of *Lactobacillus mucosae* DPC 6426, an exopolysaccharide-producing strain, positively influences the techno-functional properties of yoghurt. *International Dairy Journal* **40**, 33–38.

Lucey J (2002) Formation and physical properties of milk protein gels. *Journal of Dairy Science* **85**, 281–294.

Mahomud MS, Katsuno N and Nishizu T (2017) Formation of soluble protein complexes and yogurt properties influenced by the addition of whey protein concentrate. *Innovative Food Science & Emerging Technologies* **44**, 173–180.

Malek A, Shadarevian S and Toufeili I (2001) Sensory properties and consumer acceptance of concentrated yogurt made from cow's, goat's and sheep's milk. *Milchwissenschaft* **56**, 687–689.

Maragkoudakis PA, Miaris C, Rojez P, Manalis N, Magkanari F and Kalantzopoulos G (2006) Production of traditional Greek yoghurt using *Lactobacillus* strains with probiotic potential as starter adjuncts. *International Dairy Journal* **16**, 52–60.

Marilley L, Ampuero S, Zesiger T and Casey MG (2004) Screening of aroma-producing lactic acid bacteria with an electronic nose. *International Dairy Journal* **14**, 849–856.

Megalemou K, Sioriki E, Lordan R, Dermiki M, Nasopoulou C and Zabetakis I (2017) Evaluation of sensory and in vitro anti-thrombotic properties of traditional Greek yogurts derived from different types of milk. *Heliyon* **3**, e00227.

Meilgaard M, Civille G and Carr B (2007) *Sensory Evaluation Techniques*, 4th Edn. Boca Raton: CRC Press.

Meletharayil G, Metzger L and Patel HA (2016) Influence of hydrodynamic cavitation on the rheological properties and microstructure of formulated Greek-style yogurts. *Journal of Dairy Science* **99**, 8537–8548.

Moineau-Jean A, Guévremont E, Champagne CP, Roy D, Raymond Y and Lapointe G (2017) Fate of *Escherichia coli* and *Kluyveromyces marxianus* contaminants during storage of Greek-style yogurt produced by centrifugation or ultrafiltration. *International Dairy Journal* **72**, 36–43.

Muir DD and Hunter EA (1992) Sensory evaluation of fermented milks: vocabulary development and the relations between sensory properties and composition and between acceptability and sensory properties. *International Journal of Dairy Technology* **45**, 73–80.

Narayanan P, Chinnasamy B, Jin L and Clark S (2014) Use of just-about-right scales and penalty analysis to determine appropriate concentrations of stevia sweeteners for vanilla yogurt. *Journal of Dairy Science* **97**, 3262–3272.

Navratil M, Cimander C and Mandenius CF (2004) On-line multisensor monitoring of yogurt and filmjölk fermentations on production scale. *Journal of Agriculture and Food Chemistry* **52**, 415–420.

Nguyen P, Kravchuk O, Bhandari B and Prakash S (2017) Effect of different hydrocolloids on texture, rheology, tribology and sensory perception of texture and mouthfeel of low-fat pot-set yoghurt. *Food Hydrocolloids* **72**, 90–104.

Nsabimana C, Jiang BO and Kossah R (2005) Manufacturing, properties and shelf life of labneh: a review. *International Journal of Dairy Technology* **58**, 129–137.

Ozer BH, Bell AE, Grandison AS and Robinson RK (1998) Rheological properties of concentrated yoghurt (labneh). *Journal of Texture Studies* **29**, 67–79.

Peris M and Escuder-Gilabert L (2013) On-line monitoring of food fermentation processes using electronic noses and electronic tongues: a review. *Analytica Chimica Acta* **804**, 29–36.

Phadungath C (2015) Greek-style yogurt and its application in cheesecake. *International Journal of Food Engineering* **1**, 13–17.

Puvanenthiran A, Williams R and Augustin M (2002) Structure and visco-elastic properties of set yogurt with altered casein to whey protein ratios. *International Dairy Journal* **12**, 383–391.

Serhan M, Mattar J and Debs L (2016) Concentrated yogurt (Labneh) made of a mixture of goats' and cows' milk: physicochemical, microbiological and sensory analysis. *Small Ruminant Research* **138**, 46–52.

Suh S and Kim M (2020) Microbial communities related to sensory characteristics of commercial drinkable yogurt products in Korea. *Innovative Food Science & Emerging Technologies* **67**, 102565.

Uduwerella G, Chandrapala J and Vasiljevic T (2017) Minimising generation of acid whey during Greek yoghurt manufacturing. *Journal of Dairy Research* **84**, 346–354.

Vlasov YG, Legin AV, Rudnitskaya AM, Di Natale C and D'Amico A (2005) Nonspecific sensor arrays ("electronic tongue") for chemical analysis of liquids (IUPAC Technical Report). *Pure and Applied Chemistry* **77**, 1965–1983.

Watson E (2017) Sweet green field deploys 'intelligent tongue' in quest for steviol glycoside combinations with the most sugar-like taste. Available at https://www.foodnavigator-usa.com/Article/2017/11/01/Stevia-specialist-Sweet-Green-Fields-deploys-intelligent-tongue (Accessed by 07 May 2018).

Wei Z, Zhang W, Wang Y and Wang J (2017) Monitoring the fermentation, post-ripeness and storage processes of set yogurt using voltammetric electronic tongue. *Journal of Food Engineering* **203**, 41–52.

Witkowska E, Buczkowska A, Zamojska A, Szewczyk KW and Ciosek P (2010) Monitoring of periodic anaerobic digestion with flow-through array of miniaturized ion-selective electrodes. *Bioelectrochemistry (Amsterdam, Netherlands)* **80**, 87–93.

Woertz K, Tissen C, Kleinebudde P and Breitkreutz J (2010) Performance qualification of an electronic tongue based on ICH guideline Q2. *Journal of Pharmaceutical and Biomedical Analysis* **51**, 497–506.

Wouters R (2012) Low fat yet rich in texture, Greek yoghurt proves irresistible to consumers. *Wellness Foods Europe* **3**, 4–8.

Xu W, He S, Ma Y, Zhang Y and Wang R (2015) Effect of the heat-induced whey proteins/κ-casein complex on the acid gelation of yak milk. *RSC Advances* **5**, 8952–8956.