ISSN 2522-9400 **European Modern Studies Journal** *Vol 8 No 2*
available at www.journal-ems.com

DOI: 10.59573/emsj.8(2).2024.27

Electronic Technologies for Quality Control in the Biscuit Manufacturing Process

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Abstract. By 2030, the biscuit industry may go global due to advancements in electronic tools like eNose, eTongue, and eVision. This shift is governed by precision, productiveness, and regulatory compliance. Ultimately, the automation increase is driven by this consequence. This article will critically look at the issues and benefits arising within the biscuit production field after the shift towards the use of electronic control systems. It analyses the present situation and figures out the ineffectiveness on the part of conventional tools in solving the problem as it currently exists and shows how electronic instruments can be better in aiding visual and sensory inspections. While there have been remarkable achievements, these are persisting, of course, and they include high investment costs, specific skills requirements, and less flexibility when adapting to different production conditions. Without thorough research and development, the challenges in the production of the electronic control systems will still stand and no technology will be created to resolve the problems of the system. This study further reaffirms the need for the invention of modern and improved quality control processes for biscuit manufacturing plants. Through identifying previous methods and approaches and, the advantageous features of each, as well as highlighting shortcomings of current quality control strategies, this paper serves as an effective driving force for the future evolution and further improvement of quality control practices during biscuit production. Comprehensive product evaluation is attended to by employed approaches that analyse future benefits and opportunities as well as drawbacks and risks of the application of electronic quality control systems in the biscuit industry.

Keywords: biscuit authentication, automatic detection, biscuit safety, sensor technology, data science, quality control, biscuit production

Introduction

Biscuits are popular and consumed in various parts of the world. They are consumed as snacks, desserts, or as accompaniments to tea and coffee. The global biscuits market size reached US$ 117.5 Billion in 2022. The global biscuit market is expected to reach USD 169.5 billion by 2028. Higher prices for the biscuits are only guaranteed if the manufacturing process is conducted with the highest quality. Details of quality parameters (colour, taste, moisture etc.) are recorded in the quality assessment process during the biscuit manufacturing process.

Biscuit manufacturing is a systematic process comprising ingredient preparation, mixing, forming, baking, cooling and packaging. It begins with combining ingredients like flour, sugar, fat, and leavening agents, followed by dough mixing (Misra & Tiwari, 2014). After the mixing process fermentation process is conducted. The fermentation process in biscuit manufacturing involves combining flour, water, milk solids, egg whites, sugar, shortenings, leaving agents, emulsifiers, starch salt etc. (Gunawardane & Dabare, 2015; Wick et al., 2003). This process releases carbon dioxide gas, causing the dough to rise and expand, resulting in a light, airy texture. The fermentation period varies but is crucial for biscuit flavour and volume. Fermentation is a crucial process in biscuit manufacturing, shaping the texture, flavour, digestibility, volume, and shelf life of biscuits. It involves the production of carbon dioxide gas

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by yeast, which raises the dough, resulting in a light, airy texture. Fermentation also enhances the taste of biscuits by producing various flavour compounds, partially breaking down complex carbohydrates, and increasing the dough's volume (Annuk, 1994), which collectively determines the overall quality of the final biscuit product currently used in the manual process of fermentation. After the dough has been mixed, yeast is added. The biscuit process does this while the dough is being prepared, while others wait until after the dough has been prepared. The fermentation process can take a long time at a specific temperature, allowing the dough to become light and airy. The dough is then shaped into biscuits, which are baked in controlled ovens. After baking, they cool to develop their desired texture.

Quality control ensures product consistency, and once approved, the biscuits are packaged for distribution. Automated machinery is often employed to ensure efficiency. Quality parameters in biscuit manufacturing are typically developed during the product development and process optimization stages. The development of quality parameters involves careful consideration of various factors to ensure that the final product meets the desired standards and specifications. Manufacturers proceed with product development by providing information on the characteristics of biscuits and specifying the tastes, texture, appearance, shelf-life, and nutritional values. Process design targets where next ingredients like flour, sugar, fats, leavening agents, and flavouring are defined in terms of quality standards that all selected suppliers must consistently meet. On the other hand, various quality parameters for each processing stage, including mixing, dough resting, sheeting, cutting, baking, cooling, and packing are chosen for process optimization. Rigorous monitoring of quality control testing is carried out during the whole production process, as in-process and finished product tests are done based on such measures as thickness, weight, colour, moisture content, texture, or taste. The consistency is attained through equipment calibration that has a lot of parameters and these must be adjusted regularly to include temperature of the oven, speed of the conveyor and dough thickness. The cross-correlation of the quality parameters and regulatory standards confirms that the biscuit is edible and complies with legal regulations. In addition, manufacturers constantly improve through monitoring and evaluating processes applying corrective actions aimed at improving the whole process for the sake of uniformity.

The conventional quality control process in biscuit production over the years has been viewed as a basic or impractical process because of some inherent limitations. Many drawbacks are associated with traditional methods such as manual inspections which are labor-intensive, time-consuming, and have a high probability of human errors. Such an approach may cause discrepancies in defining and combatting quality issues resulting in critical parameters such as thickness, weight, color and taste. With consumers' preferences changing quickly, the traditional quality control process may not cope with the market necessity of speeding up and simplifying production. Additionally, it might be not provided with the latest analytical features and round-the-clock monitoring typical of modern technologies. As the importance of accuracy, uniformity, and conformity to rigid environmental controls increases, it becomes more obvious that traditional quality control approaches are defective (Ahmad & Ahmed, 2014).

Alternatively, automated quality control processes enabled by technology continue to gain traction since they produce precise, quickly generated, and data-based findings where it is possible to ensure that products maintain a certain standard while improving the overall efficiency of the manufacturing system. The manufacturing industry, in particular biscuit production, has greatly changed especially over the recent past when large manual systems of quality checks have been replaced with automated systems, which are smarter and more effective.

The new advanced technologies eliminate the traditional manual ways of doing things and enable a more effective and precise process. Due to the automated inspection systems comprising sensors, cameras, and machine learning algorithms, ensure that several quality parameters are measured as well as assessed as part of any industrial production line. This system possesses far more improved and shorter evaluation features relating to the size, shape, colour, thickness and texture of biscuits (Ciosek et al., 2009). Integration of these technologies ensures that the final products are more than merely in conformity with specifications but also meet the relevant regulations. The adoption of automated quality control measures in the industry is a clear confirmation that the industry is ready to embrace such advanced technologies which would make it possible to offer perfect biscuits, not only today but also in the future, both per customer and consumer expectations and regulators' standards.

Increased production of quality control in the latest biscuit manufacturing has led to innovative electronic technologies that include eNose, eTongue, and eVision. The E-nose is a chemically functional system that mimics the human sensory organ, the nose. E-nose technology has been proven effective in the field of biscuit production, as researchers can detect specific odours linked to the quality attributes; however, they can state deviations from the expected smell of baked products. Act moreover, the eTongue approximates human taste perception through the array of sensors that analyze the chemical content of those biscuits. This technology allows accurate identification of the difference in taste, which means providing consistent taste profile delivery according to the specification. So far, researchers have identified eTongue as an efficient and beneficial tool in monitoring and controlling taste consistency in biscuit making. Apart from, eVision is an electronic vision system that is used to visually inspect biscuits during the production process, there are many other systems which can be used to monitor the maturity of products in storage. eVision technology can detect visual defects by applying cameras and high-end image processing algorithms, making it possible to maintain shaping standards for the biscuits. This kind of visual inspection process improves quality control through the detection of undesirable features that include shape irregularities, colour variances or any other visible surface defects.

The new era of electronic technologies for quality control in the biscuit manufacturing industry implies a change of paradigm, which allows to achieve higher precision, success rate and control. In addition to improving product quality, the synergy of methods of sensory and visual function through the integration of eNose, eTongue, and eVision enhances the functionality of both consumer satisfaction and industry demands. Today, eNose, eTongue, and eVision have proven to be highly effective tools that can significantly improve the quality control procedures in biscuit manufacturing. However, several limitations might impede their further implementation.

If we generally take a closer look at the facts, it will appear that first, the primary costs involved in such initiatives are enormous. Smaller manufacturers may have to cite the additional costs incurred in acquiring, installing, and maintaining high-tech sensor systems such as eNose and eTongue as a limitation. Second, the required specialized knowledge in running and maintaining these technologies can prove limiting. That is, precisely skilled staff are needed to understand the data, in the case of malfunctions of a technical nature, and to ensure the operation of the electronic systems. Other constraints include the degree of flexibility of such technologies to various biscuit recipes and manufacturing facilities. Specifically, changes in input ingredients, food preparation methods and process settings may necessitate further adjustment of the electronic systems to ensure the precision of test results. Besides, at present electronic technologies may not satisfy all the needs of quality control. Even though the basic technology is used to eNose and eTongue only on sensory aspects, there will be challenges in meeting other important quality parameters like texture or structural integrity. In addition, electronic technologies may face issues when trying to work with real-world complexities, including changes in the environmental conditions or some contaminants present that could bring about an error in the outcome. Finally, though eNose, eTongue, and eVision bring important perspectives to the practice of quality control in the biscuit-making enterprise, overcoming such current shortfalls is crucial if these solutions are to become widely adopted by the industry. Ongoing efforts are required in the research and development area to improve the robustness, adaptability, and cost-effectiveness of these technologies such that they can be easily available for a wide-ranging number of manufacturers.

Therefore, a comparison of current systems and identification of drawbacks are important in developing novel technologies. Therefore, this paper will focus on the comparison of methods developed for the analysis of biscuit quality during the biscuit manufacturing process under laboratory conditions and factory scale. In this paper, a brief discussion of chemical compounds detected and followed by conventional methods used for detection is also discussed. Then, existing e-technologies and statistical algorithms which were used in data analysis will be discussed.

Literature Review

Biscuit Quality Evaluation

Release of aroma and taste compounds during the biscuit manufacturing process

During the biscuit-making process, the aroma and taste compounds are combined in such an order that they turn even basic ingredients into enjoyable meals. The change starts with the painstaking selection and blending of ingredients of their kind such as flour, sugar, fats and flavours. This is the process when these ingredients are mixed and enzymes which are naturally occurring in the raw materials speed up the chemical reactions that bring out the compounds responsible for the desired aromas of the biscuits. Processes such as the Maillard browning, caramelization and lipid oxidation form a fascinating aroma for the dough in the meantime (Manley, 2000).

At elevated baking temperatures, a complex chemical reaction cascade takes place, providing a rich and complex aroma. Maillard reactions between reducing sugars and amino acids generate lots of savoury, nutty, and caramel-like aromas, while lipid oxidation leads to the formation of additional aromatic compounds, adding fatness to the flavour palette of the biscuits (Damodaran, 2007). While the dough is undergoing fermentation, a whole lot of biochemical reactions are going on, with the production of aroma compounds that determine the smell and taste of biscuits. The smell of biscuits is a highly important sensory attribute which influences consumer perception and experience. The addition of fruit bromelain to the dough of a biscuit provides a new path for the alteration of aroma chemicals, thus, changing the sensory perception of the baked goods. During fermentation, microorganisms such as yeast or lactic acid bacteria degrade the sugars present in the dough to produce different by-products including organic acids, alcohols, and esters. These volatile compounds evaporate from the dough and permeate the surrounding ambience thus providing a distinctive scent to the biscuits. The aroma profile generated during fermentation depends on many things such as the type of microorganisms, fermentation temperature and duration, and composition of the dough.

Temperature and fermentation period are other important factors that have a direct effect on the aroma. Longer fermentation times lead to more sophisticated biochemical changes as compared to shorter fermentation times; therefore, the longer fermentation times will result in a more complex aroma profile and faster fermentation times increase the production of aroma compounds as compared to fermentation at a higher temperature (Han et al., 2018).

Furthermore, the type and ratio of ingredients in the dough, including flour, sugar, fats, and flavourings, can guide its aroma formation during fermentation. For example, some sugars or amino acids existing in the dough may act as microbial substrates used during their cellular metabolism, resulting in the development of aromas. In general, the fermentation process employed in biscuit production is a very complex and unusual process that plays an important role in determining the aroma of the finished product. The flavor development during fermentation can be understood and thus, by optimal control of the fermentation process, manufacturers can produce biscuits with the desired sensory characteristics thus enhancing their quality. Some prominent compounds are present in a biscuit aroma and tastes are given in Table 1 and Table 2.

Table 1. Some prominent compounds are present in a biscuit aroma

References	Compound	Aroma	Biosynthetic pathway
(Cho & Peterson, 2010)	2-acetyl-1-pyrroline	Cracker-like odor properties (warm, toasty, slightly sweet)	2-acetyl-1-pyrroline is suggested to be a key odorant of the crust in bread. It is primarily generated during thermal processing, specifically through Maillard reactions between reducing sugars and amino acids.
(Cho & Peterson, 2010)	(E)-2-nonenal, 3-methylbutanal, (Z)-2-nonenal, (E,Z)-2,6-nonadienal, (E,E)-2,4-decadienal, 1-octen-3-ol, (E,E)-2,4-nonadienal	Fatty/green/cucumber, Strong/pungent/ malty/ and slightly fruity, Fatty/ waxy/metallic, Green/grassy/slightly floral, Earthy mushroom like aroma, Strong/green/grassy, and somewhat fatty odor	During baking through thermal reactions, particularly caramelization and Maillard reactions. During caramelization, sugar molecules undergo thermal decomposition, leading to the formation of various aromatic compounds contributing to the flavor and aroma of bread.
(Cho & Peterson, 2010)	Methional	Sulfurous, cooked cabbage-like, or onion	Methional is generated during baking through thermal reactions, particularly the Maillard reaction.
(Manley, 2000)	Maillard reaction products	Savory, nutty, caramel	The Maillard reaction occurs between reducing sugars (such as glucose) and amino acids under elevated temperatures, resulting in a complex cascade of chemical reactions that produce a wide range of aroma compounds.
(Damodaran, 2007)	Lipid oxidation products	Rancid, metallic, fishy, or cardboard	Lipid oxidation occurs when fats in the dough undergo reactions with oxygen under elevated temperatures. This process leads to the generation of various volatile compounds, including aldehydes, ketones, and hydrocarbons, which contribute to the overall aroma and flavor complexity of biscuits.

(Han et al., 2018)	Organic acids, alcohols, and esters	Various sweety /buttery/ floral/pungent aroma	During fermentation, microorganisms such as yeast or lactic acid bacteria metabolize sugars present in the dough, producing organic acids, alcohols, and esters as by-products. Organic acids are formed through various metabolic pathways, while alcohols and esters are synthesized through yeast fermentation and subsequent enzymatic reactions. The specific aroma profile developed during fermentation depends on factors such as the type of microorganism used, fermentation temperature, and the composition of the dough.

Table 2. Some prominent compounds are present in a biscuit taste

References	Compound	Taste	Biosynthetic pathway
(Nursten, 2000)	Maillard Reaction Products	Sweet, savory, nutty, roasty	Interactions between reducing sugars and amino acids during baking
(Schieberle, 1995)	Volatile Organic Compounds (VOCs)	Fruity, floral, buttery, nutty	Formed through various pathways involving lipid degradation, Maillard reactions, and thermal decomposition
(Reineccius, 1999)	Esters	Fruity, floral, sweet	Formed through the reaction of alcohols and organic acids
(Shahidi et al., 2005)	Aldehydes	Fruity, floral, green, nutty	Formed through various pathways including lipid oxidation and Maillard reactions
(Nawar, 1980)	Maillard Reaction Products	Sweet, savory, nutty, roasty	Interactions between reducing sugars and amino acids during baking

Detection of visual aspects and imperfections during the biscuit manufacturing process

While producing biscuits, the fermentation stage is done keeping in mind the visual aspects and imperfections thus ensuring the great quality and consistency of the product. From the point of view of colour development, fermentation is another stage put under the microscope. The appearance of the dough is uniform in colour is, therefore, an indication that the fermentation and enzymatic activity are optimum whereas inconsistent colourations denote issues such as inequalities in fermentation and/ or uneven dough composition. Visual inspection makes it possible to detect any visual variations of colour in products and hence allows the operators to make the right adjustments to the quality of the product.

Another important aspect to consider is the dough expansion and dough rise during the process of fermentation. Correct fermentation makes the dough rise and expand because of the gases, for example, carbon dioxide. Yet, dough over-fermentation or under-fermentation leads to abnormalities in dough volume or texture. Visual inspection is an effective way to determine the extent of dough expansion and notice any abnormalities which can lead to imperfections in the final cookie texture and appearance (Bamforth & Ward, 2014).

Furthermore, also, the outer texture of the dough fermenting is carefully observed to be uniform and the same. The smooth and uniform texture of the dough may suggest that it has been well-fermented. The development of lumps or unevenness would also mean that the mix has not been properly done or the fermentation condition has not been suitable. Manual inspection enables the operator to test the dough feel and make changes, if needed, to achieve the desired shortbread or biscuit texture (Sanaeifar et al., 2016).

In addition, visual examination using observation is used to detect any foreign substances or contaminants within the fermented dough. Impurities like foreign materials or any addition can be the cause of these products' safety and performance being affected, meaning that they can be removed and rectified. Visual inspection is a very effective tool for contamination prevention, and it, therefore, avoids replication of the fermented dough and ensures the integrity of the manufacturing process (Zhou, et al., 2014). The visual aspects to be considered during the biscuit manufacturing process are given in Table 3.

Table 3. Some visual aspects are to be considered during the biscuit manufacturing process

Visual aspects	References
Shape and size	(Dayakar Rao & Bhargavi, 2017)
Surface texture	(Gunawardane & Dabare, 2015)
Color	(Misra & Tiwari, 2014)
Surface finish	(Misra & Tiwari, 2014)
Rise and Crack Pattern	(Ghosh et al., 2015)
Clearance	(Zorić, Matić, & Hocenski, 2022)

Conventional methods for analyzing biscuit aroma and taste

By now, most standard ways are taken into consideration to assess the aroma and taste of biscuits, which are based on findings of many research and proven methods. Sensory evaluation of expert panels is a primary method of evaluation, providing subjective judgment on the color of biscuits, the degree of intensity of the aroma, flavour profile, texture, and overall acceptability. Numerous studies have provided evidence of the viability of sensory evaluation in describing the sensory factors of the biscuits, which are invaluable propositions for the determination of consumer preferences and the optimization of future products. A thorough sensory assessment of biscuit samples was conducted at CITA-CTIC La Rioja by using a standardized procedure aimed to measure different biscuit characteristics, to have valid and consistent outcomes. The trained panellists with filtered pass results of basic taste and odour, tests found non-structured, continuous graphic scales an effective way of evaluating the intensity of sensory attributes. Such scales allowed for consistent and comparable assessments across samples because they evaluated a particular set of attributes objectively with the standard as a point of reference, and a deviation from which identified sensory faults like rancidity or oxidative processes (San José et al., 2017).

Moreover, the quantitative description of aroma and taste attributes is offered by descriptive analysis that provides a structured approach to the sensory evaluation, allowing the use of standard scales for highly trained panellists. Studies on this subject point out the value of descriptive analysis in evaluating the sensory complexity of biscuits and in detecting minor differences among the different variants (Lawless & Heymann, 2013). Concurrently, modern instrumental analysis techniques such as gas chromatography-mass spectrometry (GC-MS) and high-performance liquid chromatography (HPLC) have been presented as suitable methods for characterizing aroma, these techniques enable the identification and quantification of aromatic and non-aromatic compounds present in biscuits and give an insight into the chemical composition of the substances that contribute to sensory perception. Research works have demonstrated the efficacy of instrumental analysis to assess the role of processing conditions and ingredient compositions on the aroma and taste of biscuits.

Conventional methods for analyzing the visual aspects

The standard to examine the visual aspects of the biscuit production processes is used to maintain quality and consistency in the products. Side by side, they include different visual inspection methods that enable the evaluation of multiple visual properties indispensable for product analysis and improvement.

One widely disseminated process usually includes visual inspection by human operators trained or knowledgeable in visual perception of defects or irregularities. This commission carries out its work through its expert knowledge of how to determine anomalies like cracks, discolorations, uneven shapes, and surface imperfections that may affect the aesthetic appearance and the quality of the final product. Colorimetric analysis is a traditional practice used to evaluate colour parameters of biscuits. Colorimeters or spectrophotometers are used to read out the parameters such as lightness, hue, and chromaticity for colour uniformity providing an objective calculation method for the consistency of biscuit batches. Furthermore, visual inspection systems, powered with machine vision technology, are becoming common in the biscuit industry as a replacement for labour-intensive tasks that need human intervention for quality control. These systems are made with cameras and image recognition algorithms to see the product faults as they happen and immediately detect the bad biscuits and reject them. Strong traditional approaches often employed in the visual aspects of making biscuits are of high importance, since such approaches provide the required quality, consistency and the consumer satisfaction needed. With the collaboration of human wisdom and technological strides, manufacturers can have adequate control and monitoring of the whole visual production process, hence enriching the quality and marketing of their biscuits.

Electronic Technologies

Electronic Tongue, Nose, and Vision

Electronic tongues rely on sensor arrays and a unique measuring technique used to analyze and quantify tastes in much the same way as human sensation does. Taste sensors or the so-called electronic tongues are advanced arrays of sensors, each exhibiting specific selectivity or sensitivity to certain taste-related compounds ranging from sourness, saltiness, sweetness, bitterness, and savoury taste. The system operates by giving the sample, often a liquid or solution, to a sensor array that, in turn, makes the sensors interact which causes the sensors to produce changes in their electrical responses. The manifestations of such changes may take the form of various alterations in conductivity, potential or impedance. Identification of this pattern in the electric signals or any other physical variable by the electronic tongue is important. Furthermore, the sensor array responses are presented as acquired data which are afterwards processed by methods of pattern recognition such as PCA or ANNs (Chen, Zhao, & Vittayapa, 2008; Ghosh et al., 2015). Processed data is aimed at discerning the differences between the tastes and counting the taste intensities or corresponding compositions in the sample. Calibration models are the most popular models that are applied to examine the correlation between the sensor responses and the known concentrations or intensities of the taste compounds.

An electronic nose is, in effect, a device that mimics the human nose to detect odours and volatile compounds. It contains a system of sensors, a sampling system, a data acquisition system, and a data processing algorithm. The sensor array comprises different chemical sensors responding to chemicals of different natures uniquely. The sensor arrays and data acquisition system are influenced by odour effects in the sampling system, and they read the response signals. Data processing algorithms are designed to uncover odour patterns by processing these signals that are used to detect the presence of different smells and help in the diagnosis of diseases. The ability of electronic noses to find use in food quality control, environmental monitoring, medical diagnostics, and industrial processes is what spurs their development. They have fast, untargeted odor sensing capabilities which makes them valuable in a broad range of applications and disciplines.

Electronic noses (e-noses) and electronic tongues (e-tongues) which are innovative solutions utilizing artificial olfaction and artificial taste, respectively, simulate the human olfactory and gustatory systems. These systems use either the e-nose (i.e. arrays of gas sensors or chemical sensors) or e-tongue (i.e. taste compounds) for volatile and non-volatile compounds, respectively, the latter as food samples. The area being reviewed here revolves around the use of e-nose and e-tongue technologies for the quality-related parameters assessment of food. These features such as fragrance, taste, freshness, genuineness, and quality in general may be part of them. Through the utilization of pattern recognition algorithms such as artificial neural networks (ANN), convolutional neural networks (CNN), partial least square regression (PLS), support vector machine (SVM), and principal component analysis (PCA), e-nose, and e-tongue systems can identify and decode complex information as well as provide the characteristics of food quality (Tan & Xu, 2004).

Electronic vision is a name of computer vision that has branched into artificial intelligence and computer science with the function of helping computers interpret and process visual information from digital images or videos. The objective is to replicate and improve the visual performances of human vision through computational methods and techniques. Some of the important aspects of this technology are image acquisition, processing, feature extraction, object detection and recognition, scene understanding, as well as machine learning. Electronic vision encompasses a broad field of research that spans a multitude of disciplines, ranging from autonomous vehicles, surveillance, medical imaging, industrial automation, and augmented reality. From assessing robotic vision to parsing out visual data, electronic vision is critical for machines, used in many fields, such is the case in biscuit production where electronic vision systems have great advantages for quality control and optimization. These systems involve the usage of high-resolution cameras and advanced algorithms to do cookie inspection for defects, color, and texture consistency, measure sizes and shape parameters, and automate sorting and packaging. The electronic vision provides in-process quality assurance through fault detection in production equipment and visual documentation which helps in traceability. It also contributes to maintenance efficiency. Moreover, the research on biscuit pictures helps in process optimization by detecting the sources of inefficiencies and finding where improvement is necessary (Sanaeifar et al., 2016; Tan & Xu, 2004).

Such vision systems apply to food product cameras, image processing algorithms, and machine learning to analyze the visual attributes of the product. The hyperspectral imaging systems can analyze parameters, which include color, size, shape, texture, and surface defects giving quick and objective quality control in biscuit manufacturing. The NIRS technology to perform the food quality testing tasks. By contradiction, electronic vision technologies let manufacturers detect visual imperfections, achieve product uniformity, and develop product aesthetics (Tahara & Toko, 2013).

Smelling, tasting, and viewing process

In the biscuit manufacturing process, electronic technologies do away with the conventional evaluation of the product by the human senses of smell, taste, and sight with the help of simulated electronic systems. The electronic systems include e-nose, e-tongue, and computer vision systems, each performing independently and thus ensuring product quality and consistency.

The process of the electronic nose mimics the smelling process by using the arrays of gas sensors to detect the VOCs which are emitted during several stages of biscuit production. The aroma can be very accurately determined by the e-nose system which analyzes the unique volatile patterns arising during mixing, baking, and cooling. Real-time monitoring helps manufacturers fix the parameters of the processing chain on time to achieve consistency in product quality (Delgado-Rodríguez et al., 2012). These receptors (MOS and conducting polymer receptors) build a complex system that mimics the human olfactory system. The uniqueness of the electronic nose (E-nose) resides in that its sensors can differentiate odour profiles and consequently give a complete mapping of the odours surrounding the process of fermentation. MOS sensors chosen for their high electrical conductivity as well as their broad-spectrum characteristics are the preferred sensors as they can detect the by-products released during fermentation without being affected by other substances allowing the sensor array to get unique insights (Sanaeifar et al., 2016). The typical electronic nose process is given in Figure 1 as a block diagram.

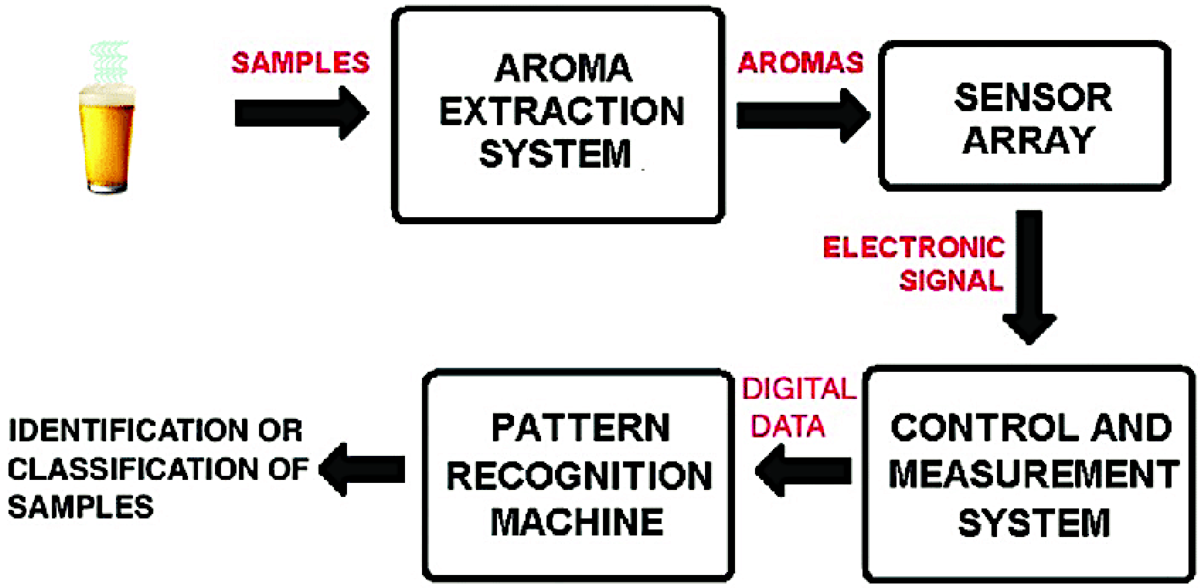

Figure 1. Typical electronic nose process block diagram (San José et al., 2017)

The e-nose works like a human nose, which uses an ensemble of sensors to identify VOCs (volatile organic compounds) present in an odour. The process includes sample pick-up and conditioning, then delivery to the e-nose with a sampling system. The sensor array reacts with the VOCs allowing the generation of the signals which are conditioned, preprocessed and converted to the features. These algorithms detect these characteristics by comparing them with a database of known odour profiles and, eventually, this process may generate a qualitative or quantitative result. Further add-ons such as a reference gas line, data processing system, and user interface make the system functional. E-noses are relevant both in industry and medicine, being used for odour discrimination, quality control and medical diagnosis.

The e-tongue instead of tasting the biscuit samples employs arrays of chemical sensors that resemble the taste profile. These sensors perceive flavouring compounds like sweetness, bitterness, saltiness, and umami giving a complete flavour taste assessment. E-tongue systems are used for sensory evaluation and taste attributes assessment to assure the quality and consistency of the product and detect the negative taste variations caused by ingredient or processing changes (Chen, Zhao, & Vittayapa, 2008; Peris & Escuder-Gilabert, 2013). A typical electronic tongue process is given in Figure 2 as a block diagram.

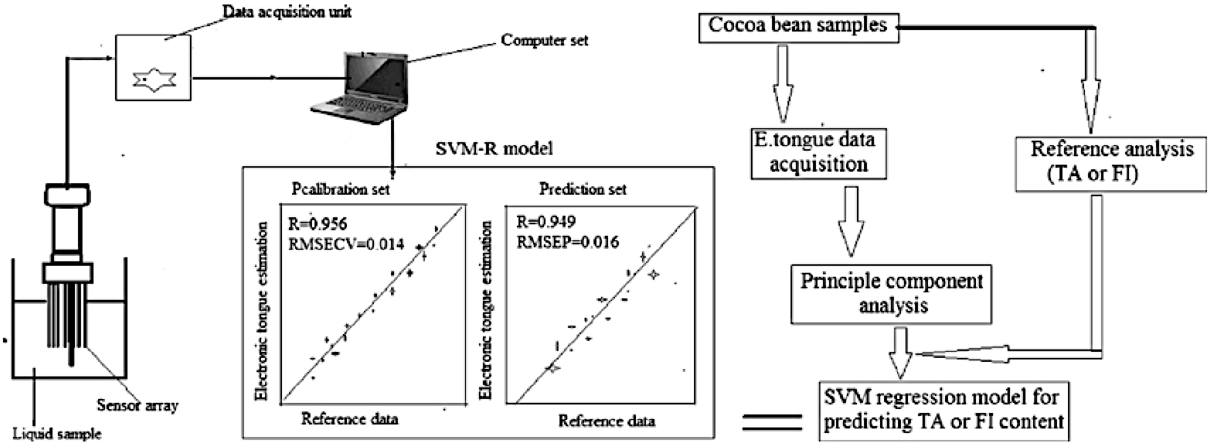

Figure 2. Typical electronic tongue process block diagram (Huang et al., 2014)

A similar instance is the e-tongue (electronic tongue) which refers to an array of sensors that function like the taste receptors of human beings and hence can differentiate the taste stimuli and has already been commercialized. The array of detectors and the compounds samples are represented while the device interacts with taste compounds and electrical signals which aggregate in proportionate to the different tastes. The improved signal quality leads to non-stationary data and hence becomes non-linear, feature extraction uses their proxies of the taste response to extract their information. The feature-matching algorithms make a comparison of a set of features to the repository of the recognized taste profiles, and they give a classification or identification of flavour as a result. The outputs may be flavour type, concentration or similarity to reference samples and might be used in taste control, food analysis, and beverage characterization. With the Arrival of the data acquisition system, reference electrode, and user interface, system functionality will tend to increase.

Computer vision systems emulate the visual process by using cameras and image perception algorithms for irregularity inspection of the biscuits in the production line. These systems analyze visual features e.g. colour, shape, size, texture, surface defects, and imperfections. Automating quality control tasks, computer vision technology augments manual inspection and saves manpower besides decreasing errors and increasing manufacturing efficiency (Deshpande & Sathe, 2017) of NIRS for food quality detection. Machine vision systems employ cameras, lighting, and image-processing algorithms in the process of obtaining and analyzing images of their biscuit samples. That’s what these systems can do, i.e. detect defects such as cracks, chips, or irregularities in shape or size. Colour inspection systems, which are used in the analysis of the colour of biscuits, are meant to check the consistency and compliance with quality standards. These systems can identify colour variations caused by uneven baking, ingredient variability and others (Patel et al., 2012). Atypical electronic vision process is given in Figure 3 as a block diagram.

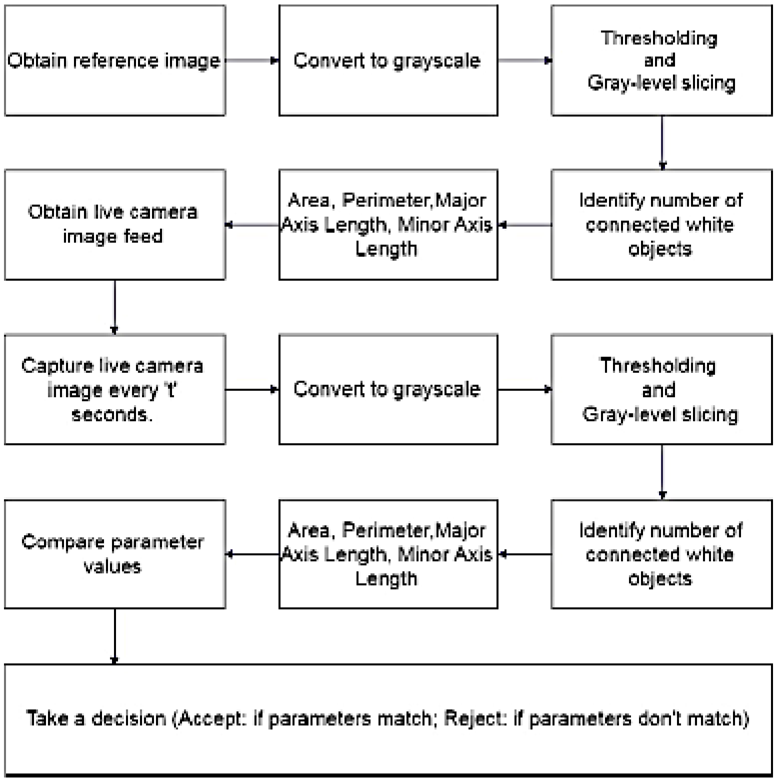

Figure 3. Typical electronic vision process block diagram (Deshpande & Sathe, 2017)

The standard electrical vision process consists of several steps, thereof, each step is shown in the block diagram (Figure 3). In the first stage, image acquisition converts a spatial scene into a digital format by an optical sensor. Preprocessing leads to refining the images and retrieving the relevant features like reduction of noise and adjustment of contrast. Segmentation splits images into semantic blocks, with background and foreground as well as individual objects as elements. Feature extraction provides quotients which can be used to characterize regions in terms of shape and colour. Classification or recognition categorizes key features that are used in object identification by machine learning algorithms that include neural networks. Post-processing, as the name suggests, is a final aspect of operations that focuses on cleaning the results of outliers and generating final outputs such as labelled objects or control signals. Other features thereof might be the communication with external devices and user interfaces for interaction and visualization.

Validation of electronic technologies response for biscuit process monitoring

One method that can be applied is the standardization of the electronic sensors by using reference standards with specific properties to draw a correlation between the sensor responses and certain biscuits' attributes like aroma, taste, and texture. Electronic measurements will be verified by comparing sensor readings with pre-defined standards hence accuracy and consistency will be obtained. However, in the case of the performance of E-technologies, the performance may be compared with conventional analytical methods commonly used to check biscuit quality. Such analytic comparison helps authenticate the performance and trustworthiness of the electronic sensors concerning important properties. Sensory evaluation is the other important validation step of this work using sensory panels which are trained to evaluate the sensory features of the biscuit obtained by E-technologies. Blind taste or olfactory tests can be conducted to compare the experimental findings of electronic sensors and human perception, thereby establishing the accuracy of electronic measurements.

Statistical analysis tools like regression analysis, correlation analysis and principal component analysis (PCA) can be employed to assess the reliability and stability of E-technology responses in case of biscuits being manufactured differently and in different batches. These analyses provide useful information for the discovery of the trends or patterns in the sensor data and the assessment of the accuracy of electronic measurements (Tan & Xu, 2004). PLSR can facilitate in reducing biscuit recipe clutter and improving their production procedures to fulfil quality requirements using mappings. Winquist and Lundström blurred the technologies by creating a hybrid electronic tongue where different types of metallic electrodes were taken for the measurements of voltammetry. Principal component analysis (PCA) is widely used with data to discriminate food items by which they can be classified. The superiority of ion-selective electrodes based on the solid phase of crystalline material on an electronic nose for taste and odors analysis as well as the quality controls of drinks and food including wine and mineral water was discovered by Login and associates. The data analysis is done by using neural networks and PCA algorithms. The system S-5000Z contains a special chip that identifies chemicals in food, and that chips react to molecules of glucose, malic acid, sodium, bitter and amino acids. Their objective is like that of the human tongue while performing the task of taste discrimination.

In addition to this, E-technologies assist in maintaining ongoing monitoring of the performance of the production process and the quality of products in real-time. Validation is the process of verifying the sensor's capability to sense in real-time the variations and deviations detection, to allow to apply of timely corrective actions that maintain the product quality standards. Similarly, exposure tests of long-term stability are also required to measure the efficiency of electronic technologies that run over long periods. The monitoring approach is a method to ensure the stability and validity of the sensors' responding data during the lifespan of the electronic sensors. Underpinning, the final electronic technologies will be fully tested to ensure quality control and process optimization in durable biscuit manufacturing, should be undertaking comprehensive tests and evaluations using the combination of calibration and comparison with traditional methods, sensory evaluation, statistical analysis, real-time monitoring, and long-term stability tests (El Barbri et al., 2011; Ciosek & Wróblewski, 2008).

Sensitivity Evaluation of Electronic Sensors

Sensitivity evaluation of electronic sensors such as electronic tongues, principal component analysis (PCA), partial least squares regression (PLSR), artificial neural networks (ANN), electronic nose, and vision technology is needed to determine their success in the recognition of the subtle changes in quality attributes of the biscuits during the manufacturing processes. A summary of a few different sensors used in the electronic systems is given in Table 4.

Table 4. Summary of a few different sensors used in the electronic systems

Sensor ID	Main compounds	References
FOX3000, FOX4000 MOS Sensor	Gas sensor	(Peris & Escuder-Gilabert, 2013)
NIR light detector	Glucose level	(Daarani & Kavithamani, 2017)
thermocouple	Temperature (IPTS-68)	(Bentley, 1984)
pH-meter	pH measure	(Svendsen, Skov, & van den Berg, 2014)
TS-5000Z	Teats sensing system	(Tahara & Toko, 2013)

PCA (Principal Component Analysis) is employed quite often to analyze the sensitivity of electronic sensors by determining the variation in sensor responses and detecting the most significant principal components that contribute the most to the variation in data. The component loadings of each dimension clarify the groups of sensors more responsive to biscuit quality aspects like aroma, flavour, and texture, being the principal variables. Another statistical technique commonly used to assess the sensitivity of electronic sensors is Partial Least Squares Regression (PLSR), which mainly aims at establishing or determining the relationship between the sensor responses and the reference measurements of biscuit quality characteristics. PLSR can predict the quality characteristics of biscuits with the use of sensory data, this allows for quantitative measurement of the detection ability and accuracy of sensors. Artificial Neural Networks (ANN) are computer models that imitate the structure and behaviour of the human brain and can detect and learn complex patterns and correlations in the data from sensors. The ANN-based (artificial neural network) models can determine the quality of the sensors by training on large datasets of sensors' responses and quality attributes of biscuits. The ANN models which are used in biscuit quality prediction reveal the significance of the sensor's sensibility and reliability.

The electronic nose technique makes use of gas sensor arrays to detect volatile compounds discharged from the biscuits that form their aroma and taste. The sensitivity approach in the evaluation of electronic nose systems is to check their potential to tell the difference between different biscuit samples using their noses as indicators. Linear discriminant analysis (LDA) and Support Vector Machines (SVM) are the most used techniques to analyze the sensibility of electronic noses in detecting small changes in the sniff of biscuits. Vision technology, image processing and machine vision algorithms are the key elements that are used for the evaluation of visual parameters of biscuits like colour, shape, and surface texture. Sensitivity evaluation of vision systems can be performed in case of their capability to distinguish visual defects or variations in the appearance of a biscuit (Abdoulaye Diallo et al., 2023). Machine learning techniques e.g., convolutional neural networks (CNN) or deep learning methods are used during the training of vision systems to acquire the ability to analyze visual patterns such as biscuit images.

Altogether, sensitivity evaluation of electronic sensors, such as electronic tongue, PCA, PLSR, ANN, electronic nose, and vision technology, hold useful information on detecting and quantifying the minute variations in the sensory attributes of biscuits during the production process.

E-Nose, Tongue, and Vision Data Analysis

In the field of biscuit manufacturing, the application of E-Nose, E-Tongue or Vision technologies not only supplies us with great means to process and analyze sensory and visual data but also gives us advanced methods to interpret and process data.

The algorithms required for E-Nose systems, which are intricate and include principal component analysis (PCA), artificial neural networks (ANN), and support vector machines (SVM), are programmed to reveal complex scent profiles breaking down into fine variations and key odorant components (Keshri, 2019). These techniques allow the selection of essential features from the sensor responses, which is greatly advantageous for the interpretation of aromatic aspects and the relationships between them and the quality attributes. Analogously, the taste information collected through E-Tongue is heavily analysed employing multivariate approaches such as PCA and PLSR for approaches, which usually are used to explore convoluted taste patterns. With the aid of signal processing algorithms, the E-Tongue sensors elicited electrical signals are statistically analysed to describe taste profiles and distinguish such as biscuit formulations or processing conditions (Rodríguez-Méndez, 2006).

In the same way, technology Vision uses complex visual processing algorithms to inspect the shape, texture, and colour of the cookie. These methods include edge detection as well as convolutional neural networks (CNN), and they form the basis of image analysis by bisecting the images, extracting visual features, and distinguishing the defects/irregularities. Statistical analysis acts to sieve out received image characteristics, providing information on biscuit quality, and consistency across production batches. Together, the approaches to data processing for E-Nose, E-Tongue, and Vision technologies provide a tremendous resource for the discernment and characterization of the sensory attributes and visual characteristics of biscuit manufacturers. With the help of today's advanced algorithms and statistical methods, it is possible to make in-formed decision-making, quality control and process optimization, making the quality and consistency of biscuit-making better (Loutfi, 2019).

Data processing

E-Nose, E-Tongue, and Vision technologies in biscuit manufacture greatly depend on data handling which is one of the most important areas. Such electronic sensor systems are producing numerous records that need some complex analysis to get an accurate picture and take useful actions.

Pattern recognition algorithms such as ANN, PCA, SVM, and PLS are the primary options for data processing of E-Nose. These algorithms scrutinize these patterns in the vent of data captured by the electronic nose sensors to detect specific aroma profiles, contaminants, and in general, the quality of the biscuits.

Additionally, E-Tongue data processing is like E-Nose data processing which involves analysis of multivariate data obtained from sensors that imitate human taste perception. Sophisticated statistical methods such as PCA, PLS, and ANNs are used to resolve the problem of interpreting complex taste profiles as well as differentiate between the biscuit formulations and detect deviations from the desired taste attributes.

In the event of image processing of visual data, image processing techniques are used to process images that are photos or sensors' capture. Visual defects, size measurement, and surface quality evaluation can be performed by employing these techniques, such as image segmentation, feature extraction, and classification algorithms.

Methodologies used in finding the optimum Quality

The optimum quality by the combination of various E-Nose, E-Tongue, and Vision Technologies is a multifaceted technique that must be tailored to every specific biscuit production and quality control requirement. While the ANN, SVM, PCA, and PLS algorithms are used for E-Nose to identify the distinct odor profiles obtained by the sensor array. These algorithms are important in determining the specific scent patterns that are unique to every single biscuit quality. Calibration and validation procedures are essential in securing the accuracy and reliability of the forecast models developed from the sensor data.

In another chip-based approach (E-Tongue systems) multivariate statistical analysis methods (PCA, PLS, Discriminant Analysis) are used to resolve the complex taste profiles measured by the array of chemical sensors. Taste profiles are decoded by the electronic tongue, which operates as a discriminator of various biscuit formulations based on their taste properties. An optimal sensor array configuration provides high sensitivity to the specified taste components to make the discrimination capability of the system higher.

Vision technologies leverage image processing techniques which are in the front line. The algorithms for image segmentation, feature extraction, and classification are employed for life cycle assessment. These methods of study include their ability to determine visual defects, determine dimension, and assess surface quality. Machine learning models, including Convolutional Neural Networks (CNNs) and Support Vector Machines (SVMs), are used to mark images, detect defects, and rank quality features. Colour analysis techniques help quantify colour characteristics such as hue, saturation, and brightness and result in important qualitative and consistent data.

Split testing methodologies to reach the maximum quality of the biscuit encompass statistical analysis, sensor optimization, and machine learning algorithms. Based on the special sensory features and quality traits of the biscuits, these approaches can help producers to achieve consistency in the product and make some improvements which meet the demands of consumers effectively.

Conclusion

From this point, it has become clear that the sophistication of quality control systems in biscuit production is moving towards more automation and advanced technology. Despite being successful up to a point, the old methods suffer from their inability to meet the standards of accuracy, speed, and flexibility regarding production requirements nowadays. Automation that comes through eNose, eTongue, and eVision represents a milestone in product consistency, compliance with regulatory standards, consumer demand satisfaction, and product quality maintenance.

Nevertheless, this technology is a powerful tool and is effective, but still, some challenges have to be addressed for it to be utilised widely. They involve the high start-up expenses, the requirement of dedicated personnel, and the limited abilities to cover all the quality attributes and real-world complexities. Continuous research and development projects are an important factor that increases the robustness, adaptability and affordability of these technologies, thus allowing them to be easily accessible by numerous other manufacturers. The technological development in the biscuit industry has led to a transformation in the manner we test and attain optimum quality. While the old methods still exist and, in certain instances, have been even enhanced, electronic technologies like eNose, eTongue, and Vision systems have, by and large, been added to and sometimes replaced them. Such technologies are advanced in terms of sensing and provide in-depth information about the aroma, taste and visual aspects of biscuits which is crucial for product quality assessment and consistency control. eNose and eTongue devices are specimen mimics that permit analysis of volatile properties and taste profiles in biscuits. This type of system relies on pattern recognition algorithms such as Principal Component Analysis (PCA) and Artificial Neural Networks (ANN) to make sense of large and complex data patterns and to detect issues concerning product quality.

Unlike vision systems however, that use image processing algorithms and machine learning techniques to look at the visual characteristics of biscuits such as colour, shape, and texture, vision systems only consider surface defects. These systems, can automate the process of quality inspection, improve the efficiency of manufacturing processes, and ensure production quality.

Validation of electronic systems entails thorough testing and evaluation which include calibration, comparison with conventional systems, sensorial evaluation, statistical analysis, real-time monitoring and long–term stability testing. Therefore, it has been proved through those methods that the efficiency of electronic sensors used for the detection of small changes in the quality attributes of biscuits is real and true.

In terms of maximum quality, a comprehensive strategy is adopted that involves the utilization of top-notch data manipulation methods, sensor tuning, and machine learning technology. Through these techniques, biscuit manufacturers can guarantee produced products' consistency, meet the consumers' expectations, and take advantage of the created optimal manufacturing environment. Overall, it can be said that while the integration of electronic technologies in biscuit production signifies a great leap in quality control and process optimization the path for enhanced product quality and consumer satisfaction is now being paved.

Acknowledgement

We hereby acknowledge the input of every member of this team for their tireless efforts during this work.

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