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Innovative techniques applied to food quality control: A systematic review

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A B S T R A C T

Globalization has enabled the use of quality systems within organizations, it has undergone a process of constant changes that have been motivated by economic and social factors of global scope. And as a result, it has become one of the most worked on topics in the company based on international standards. The study refers to a systematic review of the literature based on the guiding question: What are the innovative solutions that have been developed to manage food quality control? The selection of scientific documents was made in April 2022, through a survey in the SciELO, Scopus and Web of Science databases, in which the keywords "quality management", "food quality control", "technological innovations", "quality management", "food quality control" and "technology innovations" were used for the last twenty years. As one of the results, we can highlight the use of neural networks to characterize different types of milk as a very viable option, with a rate of 95% of correctly classified samples. Thus, the importance of developing effective and low-cost methods to ensure the quality and safety of food products for human consumption was perceived. Quality management is a very important tool within the agri-food industry, as it is directly related to the health and satisfaction of customers, which also leads to greater profitability and competitiveness of enterprises

R E S U M O

A globalização possibilitou o emprego de sistemas de qualidade dentro das organizações passou por um processo de constantes mudanças que foram motivadas por fatores econômicos e sociais de abrangência mundial. E em função disso, tornou-se um dos temas mais trabalhados na empresa com base nos padrões internacionais. O estudo se refere a uma revisão sistemática da literatura baseada na pergunta norteadora: Quais as soluções inovadoras que vêm sendo desenvolvidas para gerenciar o controle da qualidade dos alimentos? A seleção dos documentos científicos foi feita em abril de 2022, por meio do levantamento nas bases de dados *Scielo, Scopus e Web of Science*, no qual utilizou-se as palavras-chaves "gestão de qualidade", "controle de qualidade de alimentos", "inovações tecnológicas", "*quality management*", "*food quality control*" e "*technology innovations*" referente aos últimos vinte anos. Como um dos resultados, podemos destacar a utilização das redes neurais para caracterização de diferentes tipos de leite como uma opção bastante viável, apresentando índice de 95% de amostras classificadas corretamente. Assim, percebeu-se a importância do desenvolvimento de métodos eficazes e de baixo custo para garantir a qualidade e segurança dos produtos alimentícios para o consumo humano. A gestão da qualidade é uma ferramenta muito importante dentro da indústria agroalimentar, pois está diretamente relacionada à saúde e satisfação dos clientes, o que remete também a uma maior rentabilidade e competitividade dos empreendimentos.

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Introduction

The use of quality systems within organizations has undergone a process of constant changes that have been motivated by economic and social factors of worldwide scope. Highlighting the intensification of competition, the change in business success criteria, in addition to the pressures for the adoption of appropriate quality management techniques. This process of technological changes and innovations has altered the desires and needs of consumers, forcing organizations to adopt new practices to meet the requirements and expectations of customers regarding products (Gobis & Campanatti, 2012).

In recent times, quality has become one of the most worked topics by organizations and, due to globalization, it has begun, within industries, to be evaluated based on international standards, requiring from production structures, standardization, records, and especially the use of tools. Thus, companies need to acquire certifications to be competitive in both the national and international markets, as quality is not just another competitive differential, but a condition to remain in the market (Vanzella & Santos, 2015).

However, tools are only the vehicle for quality improvement, so they alone are not capable of leading the company to a process of continuous improvement, customer satisfaction and consolidation of market position without the proper guidance of senior management and employees, in addition to the support of suppliers. Thus, quality improvement is induced much more by the adoption by top management of a culture of quality and less by technical methods (Barbosa *et al.*, 2017).

The absence of quality control, both in managerial processes and in the realization and product processes, leads to financial consequences, unnecessary costs, rework, losses, waste and inconvenience to customers, which can generate great operational inconveniences and financial losses, even for customers (Paula *et al.*, 2017).

The concept of quality is associated with products and services, considering factors such as customer satisfaction, process control, standardization, continuous improvement, partnerships or support processes, in order to obtain joint advantages and rationalize time and inputs. In this way, quality management develops the organization, providing a competitive advantage for companies (Thomé *et al.*, 2021).

Customer satisfaction is related to the perceived quality of the product, in which the consumer, when purchasing it, evaluates his initial expectation in the purchase with the final perception when consuming it. This same perception can lead to dissatisfaction, which is a determining factor for choosing another product. Thus, the identification of weaknesses and compensation with another, with superior performance, is the most valued by the client, being fundamental for excellence in the provision of services (Lima & Seleme, 2020).

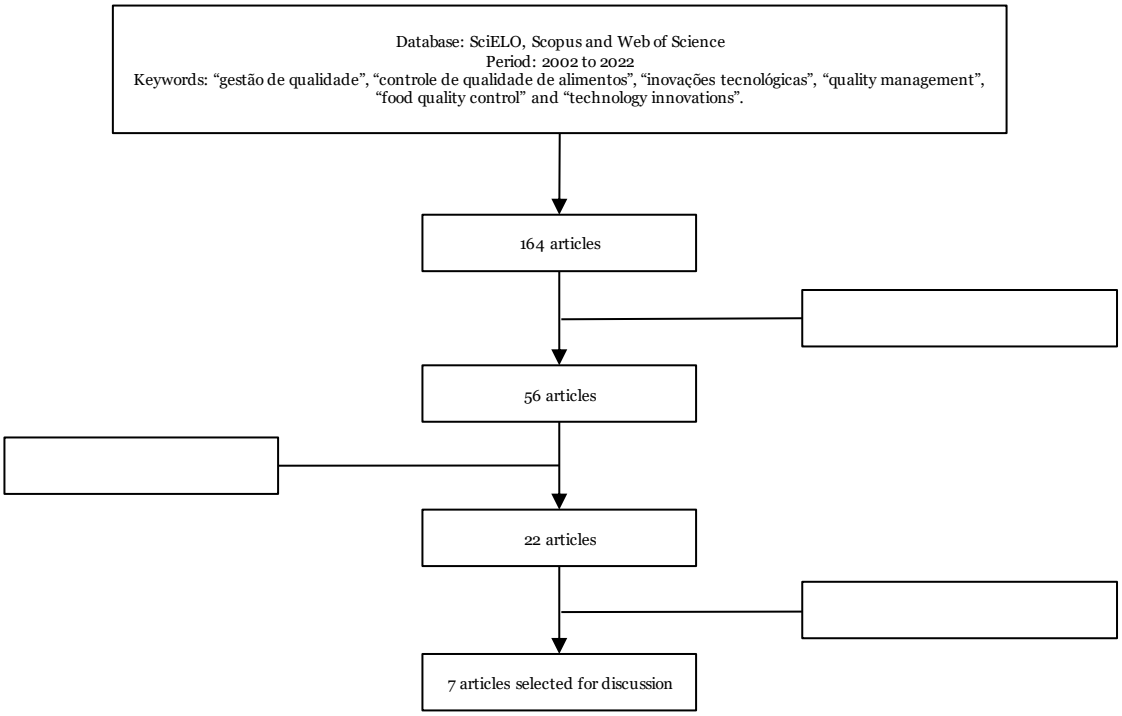
Generally, the quality control of food products is conducted through the use of classical analytical techniques, such as volumetric and gravimetric tests. These methods are characterized by being methods that have a high analysis time, require sample preparation and subsequent steps, requiring greater knowledge and training of professionals, as well as requiring large volumes of toxic solvents, causing a negative impact on the environment (Galuszka *et al.*, 2013). In view of the importance of quality management in the functioning of organizations, the work aims to survey the context of technological innovations that have been developed in this area aiming at applications in food productss.

Methodological procedures

The study refers to a systematic review of the literature following the steps exemplified by Sampaio and Mancini (2007), based on the guiding question: What are the innovative solutions that have been developed to manage food quality control? The selection of scientific documents was made in April 2022, through a survey in the databases: SciELO, Scopus and Web of Science, in which the keywords “quality management”, “food quality control”, “technological innovations”, “quality management”, “food quality control” and “technology innovations” were used for the last twenty years, and this period was chosen to have a better perspective of the evolution of quality control technologies in food. The terms used were connected using the Boolean operator “AND” and were applied to the search fields referring to the title and abstract of the articles.

After searching the databases, a total of 164 documents were found. A total of 108 documents were excluded because they did not have free access for reading, leaving a total of 56 articles. Based on the identification of articles with original results, 34 documents were discarded, classified as abstracts, conference papers, reviews, and those that did not understand the type of document required to carry out the study, leaving 22 articles. Subsequently, the articles were read to verify the documents that fit the objective of the study, applying quality control techniques to food, and thus, a selection of 7 articles was made to discuss the work (Figure 1).

Figure 1. Procedures used for the selection of articles for discussion in the study.



Source: Research data (2022).

Results and discussion

Quality control to ensure food safety is a topic of great importance, making it necessary to adopt fast and safe measures to maintain and guarantee the proper quality of food products offered to the population (Nogueira & Damasceno, 2016). Table 1 presents some studies published in the last 20 years related to different techniques that can be applied to ensure food safety.

Chart 1. Main methods developed to perform food quality control.

Methods	Place	Main results	Authors/Year
Use of ultrasound and artificial neural networks for	São Paulo State University (*Universidade Estadual Paulista*) in	- It has a low cost; - Advantages of being a non-destructive technique that can replace several pieces	Nazário *et al.* (2009)

characterization of bovine milk.	Franca - São Paulo (Brazil).	of equipment with just one.	
Use of UV-VIS spectrophotometry coupled with mathematical methodologies to quantify dyes in food.	State University of Ponta Grossa (*Universidade Estadual de Ponta Grossa*), Paraná (Brazil).	- The combination of techniques allows an adequate determination of multicomponents in food matrices; - Can be used in the quality control of dyes of interest in food products.	Santos *et al.* (2010)
Use of smartphone for detection of biomarkers in milk.	Eindhoven University of Technology (Holanda).	- Low cost and high sensitivity; - Smartphone based detection allows you to monitor multiple biomarkers simultaneously at low levels in milk.	Ludwig *et al.* (2015)
Development of a sensor for the identification of aflatoxin.	Chinese Academy of Agricultural Sciences (China).	- The developed sensor exhibited high selectivity for aflatoxin (AFM1) over other mycotoxins; - The proposed method was successfully applied in the quantitative determination of AFM1 in infant rice cereal and infant milk powder.	Guo *et al.* (2016)
Smartphone associated biosensor for detection of *E. coli* in egg and yogurt.	School of Mechanical and Materials Engineering- Washington State University (Estados Unidos).	- Portable and cost-effective optical accessory created with manufacturing has been integrated into the existing smartphone camera; - The mobile imaging unit achieves high resolution; - This device provides simple, fast and sensitive detection of *E. coli* bacteria.	Zeinhom *et al.* (2018)
PCR technique to identify adulteration in duck meat.	Biotechnology Research Institute, Chinese Academy of Agricultural Sciences (China).	- It was possible to develop and validate duck genomic DNA through the detection of the duck interleukin gene digital PCR for identification of duck meat in food products;	Chen *et al.* (2021)

		- The PCR technique can serve as an essential tool for method validation and proficiency tests in the analysis of duck content in meat products.	
Use of the smartphone to detect adulteration in meat.	Faculty of Sciences and Techniques - Hassan II University of Casablanca (Marrocos).	- The detection of adulteration in meat from smartphones shows promise, since the process can be carried out in conditions outside the laboratory without relying on the cold chain; - It has advantages such as high sensitivity, portability, speed and affordability.	Seddaoui & Amine (2021)

Source: Research data (2022).

Artificial neural networks are an excellent alternative for solving classification problems, since the processing is structurally parallel and presents several functionalities, such as adaptability, fault tolerance and abstraction, combining them with response speed, among others. This method is made up of parallel and distributed systems, made up of simple processing units, called neurons, that calculate certain mathematical functions. The neural network is trained, i.e., a set of selected input data with its respective output is presented to the network, which is responsible for acquiring a pattern among these data. It is this acquired pattern that is later used to generate responses in a simulation (Dias *et al.*, 2016).

The research carried out by Nazário *et al.* (2009) used a cell for measuring the properties of liquids by ultrasound to obtain data on density, propagation velocity and attenuation coefficient, which were related to the concentrations of fat and water added in bovine milk samples, obtained with conventional methods used in dairy products, for the purpose of calibrating the samples. This data was used to design artificial neural networks, which provide the output of the fat content and the amount of water added to the milk, based on the parameters measured by the measuring cell. As a result, the neural networks developed resulted in more than 95% of samples being correctly classified, being a very viable option for characterizing the different types of milk.

In addition to problems related to adulteration, there is a great concern regarding the presence of contaminants in milk, such as residues of veterinary drugs. And so, there is a need

for more advanced techniques that allow more complex analyses to be carried out to verify if there is an abuse of the use of drugs in animals.

The use of smartphones has been the target of scientific research as promising alternatives in several areas of study. This is due to the characteristics of these devices, which are versatile equipment, easy to move and capable of being moved and adapted in various circumstances (Perino *et al.*, 2013).

The method proposed by Ludwig *et al.* (2015) proposed a smartphone based protein detection approach clearly demonstrates that it is, in principle, possible to monitor multiple biomarkers simultaneously at low levels in complex sample matrices such as milk extracts. This technique has broad applicability, in which various contaminants and/or biomarkers can be analyzed in a similar way for other food quality and safety, environmental monitoring, and health issues.

Food security continues to be a notable concern around the world. *Escherichia coli* O157H7 is a serotype of *E. coli* and comprises one of the Shiga toxin producers that are normally present in the gastrointestinal tract of humans and animals. The presence of risk of E. coli levels in food poses a serious threat to the security of the food supply and human well-being due to its ability to cause serious illness that can lead to death (Zeinhon *et al.*, 2018). Thus, there is a need to develop precise and efficient techniques that can be used to detect microorganisms in food to ensure their safety.

The proposal of Zeinhom et al. (2018) was to develop a compact and lightweight optical fluorescence biosensor to be attached to the existing camera module of a smartphone for detection of *E. coli* O157:H7. In summary, through image processing, the fluorescence image could be converted into fluorescence intensity that allows quantitative measurements of *E. coli*. The results proved that the proposed platform has good sensitivity and selectivity detection capability for detection of *E. coli* O157:H7 fluorescence compared to the standard fluorescence platform. Even though it has some drawbacks, such as the need for further image processing like other smartphone based devices, it still shows great potential to be applied in other areas of fluorescence and biosensor imaging.

Meat and meat products are rich in nutrients with a high protein content and many essential amino acids, which can boost human immunity. Thus, the composition and quality of meat has always been a cause for concern. Adulteration in these products is a serious problem worldwide.

This practice involves everything from replacing expensive meat with cheaper meat, to deliberately labeling one species of meat as another species. Not only do these malicious practices lead to health implications, but they also cause economic losses and serious violations of consumers' religious beliefs.

Recent research indicates highly sensitive techniques for food traceability, identifying meat species methods still face challenges, mainly due to tissue damage and protein degradation by the food process. To date, several meat species detection identification methods have been developed, which include physical, chemical, biochemical, chromatographic, anatomical, histological, spectrophotometric, electrophoretic, immunological, and immunoelectrophoretic techniques (Balakrishna *et al.*, 2019).

Therefore, a simple, fast, inexpensive, and portable quantitative method is essential to deal with the spread of meat fraud. Thus, a portable and sensitive smartphone based colorimetric immunoassay was developed by Seddaoui *et al.* (2021) for the quantification of pork. The proposed immunoassay was successfully applied to quantify pork in enriched buffer and binary meat mixtures (beef/pork). Thanks to the immunological test developed, a low detection limit was achieved (0.01%) in 30 minutes and with excellent selectivity. Based on smartphone detection, the competitive immunoassay developed shows great promise for the detection of possible meat adulteration, and can be handled in conditions outside the laboratory without depending on the cold chain proven by stability tests performed at 37°C and 50°C. Due to its sensitivity, portability, speed, and affordability, this technique can be easily extended to other food control applications.

The Polymerase Chain Reaction (PCR) technique can also be used to identify fraud, in addition to being a fast, economical and easy-to-perform technique. DNA has been extensively used in the identification of species in different products, due to the ease of extraction of many biological matrices even after physical treatments such as cooking and the ability to provide sequences of genetic material through PCR assays (DALSSECO *et al.*, 2018).

Duck meat has a low added cost and is often used to adulterate more expensive foods such as lamb or beef in many countries. However, the lack of DNA based reference materials has limited quality control and adulterant detection. Therefore, Chen *et al.* (2021) carried out the development and validation of duck genomic DNA certified reference materials (CRMs) through the detection of the duck gene by digital PCR (dPCR) for the identification of duck meat in food products. CRMs were also used to determine the limit of detection (LOD) for six commercial test kits, which confirmed that these kits meet or exceed their claimed sensitivity and are reliable for duck detection.

Associated with the increase in the population's concern with the quality of food, there is a growth in the development of biosensors and these occupy an increasing space in the market, mainly due to their low cost and high efficiency. In food quality analyses, biosensors have been applied mainly in the detection of chemical and biological compounds, which allows the quantification of these components that are found naturally and those that are added for their enrichment, such as some vitamins and minerals (Arora *et al.*, 2011).

Biosensors are devices formed from a transducer and a biological element. The biological element has the property of selectively recognizing and interacting with the analyte, and can be used on the surface of the sensor, microorganisms, antibodies, nucleic acids, proteins, enzymes, among others. The interaction results in the alteration of one or more physicochemical properties that are detected and measured by the transducer. The main purpose of this tool is to produce an electronic signal proportional to the concentration of a particular analyte or group of analytes that interact with the biological component (Oliveira & Pereira, 2016).

In the study conducted by Guo *et al.* (2016), the authors proposed to develop a sensor for the identification of aflatoxin (AFM1). This substance is one of the most toxic contaminants present in dairy products, being a metabolite produced by dairy cows as a result of being fed contaminated feed. Once present in dairy products, AFM1 poses a danger to humans (especially infants) who consume them. The sensor produced was efficient in the determination of AFM1, being a method that can be applied to the detection of AFM1 in samples of rice cereals and milk powder for children, presenting a highly potential application for biologically small molecules and thus ensuring the food safety of consumers.

Another methodology that has been used is spectrophotometry in the UV-VIS region. This technique has low sensitivity but is often preferred due to its low cost, easy instrument operation, and quick determination. The limited selectivity resulting from spectral interferences results in widely overlapping absorption ranges. This factor can be circumvented by using multivariate calibration methods to obtain a mathematical model that describes the relationship between the responses (absorbances) and the concentrations of the sample components, minimizing the cost and time of the analysis (Santos *et al.*, 2010; Altunay, 2018).

Synthetic dyes are widely used in the formulations of industrialized foods in order to confer and restore the color, obtaining the desired aesthetic quality. Due to these aspects and the toxicological potential that some dyes may present, the quality control of these compounds is of fundamental importance. Thus, Santos *et al.* (2010) developed a study that aimed to evaluate the potential of derivative spectrophotometry and multivariate technique methodologies in the simultaneous determination of two food colorants: twilight yellow and tartrazine yellow, extracted with natural wool. The results obtained were very promising and it was found that the analysis of dyes using UV-VIS spectrophotometry coupled to mathematical methodologies allows an adequate determination of multicomponents in food matrices.

Thus, in view of the studies and results presented, the importance of developing fast, simple and low-cost techniques for application in food is notorious, as a way to verify possible

adulterations, detection of substances and pathogens, as a way to ensure quality and provide safety to food products available to consumers.

Final considerations

Quality management is very important within the agri-food industry, since food quality is directly related to customer health and satisfaction, which also leads to greater profitability and thus greater competitiveness. From the studies addressed in the work, it is observed that the techniques are easy to apply, fast, high sensitivity and the results were very promising to prevent possible fraud, adulteration and thus verify if the food is in compliance with the specific current legislation.

Thus, it is necessary to develop effective and low-cost methods to ensure the quality of food products and that they are safe for consumption. Thus, it is important to encourage research aimed at developing these techniques for food quality control, as these tools can be essential to reduce the potential risks associated with the food that is made available to consumers.

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