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Review

Ensuring Beverage Excellence: A Quality Control Guide

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Abstract: In the food industry, beverage is one of the important sectors that includes various alcoholic and non-alcoholic beverages. The quality of raw materials, equipment, and satisfaction of consumers are the important factors that determine the quality of the beverage manufacturing system. The nonfulfillment of any of the aforementioned factors can lead to the rejection of goods by consumers. This review paper provides a comprehensive examination of beverage quality control and addresses the various challenges faced by the beverage industry. The critical role of water quality in beverage production and the diverse quality attributes encompassing microbiological, physicochemical, and organoleptic characteristics are thoroughly discussed. The microbial contamination and poor product quality like off-flavor, unpleasant smell, and textural changes result in product recall. The quality of beverages can be ensured by sequential assessment of raw material quality, the process of production and packaging, microbial assessment, and sensorial attributes. The review also explores novel approaches such as biosensors, electronic tongues and noses, smart packaging, and the application of artificial intelligence and machine learning to address these issues. These developments provide novel solutions to ensure the quality and safety of products.

***Keywords*:** quality control, beverages, water quality, sensory analysis

1. Introduction

Beverages not only satisfy hydration needs but also weave a complex tapestry of human experience. They extend beyond mere pleasure to play a vital role in human nutrition, with milk providing essential nourishment for children and fermented products bolstering gut health. Beverages contain essential vitamins, minerals, and phytochemicals, which are beneficial to health. Both young children and the elderly can consume juices more conveniently than whole fruits. An additional benefit of juices over whole fruits and vegetables is their ease of manufacturing and shipping [1]. The beverage industry can be divided into two primary categories namely non-alcoholic and alcoholic as shown in Figure 1. Soft drinks, syrups, fruit juices, and fruit-based products are from non-alcoholic industries while alcoholic industries manufacture distilled and non-distilled beverages [2]. The incessant need for traditional foods and the growing interest in novel industrial beverages have drawn attention to the fermented beverage industry. Since the earliest days of human civilization, people have produced and consumed fermented foods, which are essential components of the human diet [3].

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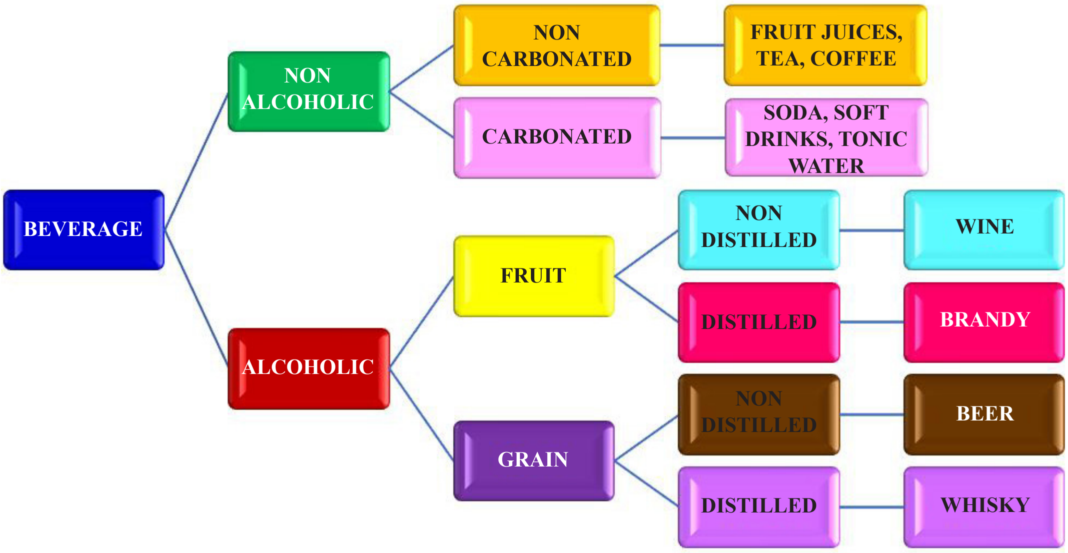


Figure 1. Classification of beverages

Fermentation is the process by which microorganisms and their enzymes modify food ingredients to produce desirable changes [4]. The byproducts of fermentation include hydrogen peroxide, bacteriocin, and organic acids that inhibit the growth of pathogens, and further provide a natural preservative property for the product [5]. Fermentation enhances organoleptic properties, nutritional bioavailability, shelf-life, and gut microbiome balance through an orchestrated acidic microenvironment, enzymatic enrichment, and targeted antimicrobial activity [4]. The beverage industries have grown from local to global markets since the turn of the 20th century [2]. The invention of glass, cans, and plastic bottles as well as high-speed packaging lines and changing packaging systems, technological advances have undoubtedly contributed to the rise in the intake of carbonated beverages [6]. There are three types of claims for fermented beverages: (a) drinks contain live, active cultures; (b) drinks contain probiotics but lack sufficient proof of their positive effects on human health; and (c) drinks contain microbes, for which there is sufficient proof of a positive impact and the product label may make specific claims [5]. Even though microorganisms that can be used as probiotics in beverage production change over time, they typically include lactic acid bacteria*, Bifidobacterium sp., Streptococcus sp., Leuconostoc sp., Enterococcus., Aspergillus sp.* And *Saccharomyces sp*. [7]. Dairy-based beverages like yogurt, Bulgarian butter milk, acidophilus milk, kefir, and cultured milk are obtained by lactic acid fermentation. Beverage industries will expand rapidly with the assistance of artificial intelligence [2]. The Food and Drug Administration (FDA) advocates for the implementation of best practices that require mandatory labeling for untreatable beverages and their products. These products fall short of achieving a 5-log reduction in pertinent microorganisms, signifying an elevated risk of harboring harmful pathogens. Good Manufacturing Practice (GMP) guidelines, cover the significance of plant management practices particularly emphasizing aspects like personal hygiene to guarantee product quality consistency. The outlined system safeguards against contamination by pathogens throughout processing which ensures a hygienic workspace, and mandates proper handwashing and responsible personal habits of employees. Additionally, construction and ground management for appropriate equipment storage, waste disposal, and pest control measures are needed. Specifications are provided for building controls (floors, walls, ceilings, ventilation, lighting, and pest detection), sanitary facilities (water, plumbing, sewage, and toilets), and handwashing practices (hot water, sanitary towels, and sanitizer usage signage). Importantly, all processing line elements which include lubricants, fuel, and water, must be devoid of contamination. Production and processing practices emphasize secure food packaging materials, clean raw materials, comprehensive sanitation, and Clean-in-Place (CIP) procedures for quality control. It is crucial to monitor processing stages like freezing, dehydration, heat treatment, acidification, and refrigeration, as these phases present potential contamination risks due to mechanical failures, delays, and temperature fluctuations. The implementation of these multifaceted GMP plant management practices can effectively secure product quality and consumer safety [8]. The challenges of the modern world have caused the food packaging industry to evolve rapidly [9]. The objective of the paper is to provide an extensive overview of beverage quality control, by addressing various challenges faced by the beverage industry such as microbiological contamination, undesirable chemical reactions, and sensory qualities associated with it, and to provide insights into advanced techniques for efficient quality control, such as biosensors, artificial intelligence and machine learning, e-noses and e-tongue. The novel information cited in the manuscript is about the emerging technologies in beverage quality control including smart packaging with integrated sensors, biosensors for microbial detection, electronic noses and tongues for beverage analysis, and flexible printed chemical sensors for real-time monitoring, AI and ML-based sensors for quality checking. These advancements offer innovative solutions for ensuring product safety and quality.

2. Different quality issues in the beverage industry

The section delves into the detrimental effects of light exposure and chemical reactions on beverage flavor, texture, and nutritional content. It highlights the necessity of employing reliable analytical methods and innovative approaches like smart packaging.

The contaminants present in the beverages can be of 4 different classifications namely, organic contaminants (urea, fat, formaldehyde), inorganic contaminants (lead, silica, copper), microorganism-based contaminants (yeasts, fungicides, bacteria), and nano-sized contaminants (silver nanoparticles) [10]. The various reactions involved in this quality deterioration are lipid oxidation, proteolysis, phase separation in emulsion, changes in organoleptic properties, and enzymatic and non-enzymatic browning [11]. Major chemical reactions responsible for deterioration are hydrolysis and lipid oxidation which in turn leads to changes in texture, denaturation of enzymes, and development of off-flavor [11]. Lipid oxidation is an important cause of quality degradation in beverages that contain high amounts of unsaturated fatty acids, for example, milk-based beverages. It can also lead to the generation of volatile and non-volatile compounds responsible for unpleasant flavor and smell. In addition to the changes in the sensorial attributes, it can also change texture and nutritional composition [11]. The oxidation reaction can damage the proteins due to the generation of free radicals on the side chain and backbone of protein molecules. Another quality concern is induced chemical reactions that generate singlet oxygen which causes oxidation of lipids and proteins. Furthermore, oxidation can generate volatile compounds responsible for off-flavor in beverages especially those rich in fats and vitamins [11]. The light absorption can cause degradation of chlorophyll and vitamins which leads to the formation of singlet oxygen. Photooxidation in alcoholic beverages can cause the development of off-flavor, and photoisomerization of vitamins and terpenes. The color of beverages rich in natural colorants like carotenoids and chlorophyll will undergo photoisomerization which results in color change [11]. The assessment of beverage quality consistently necessitates the development of more reliable, sensitive, and efficient analytical techniques to ensure traceability, safety, and quality to meet legal requirements and consumer preferences. The development of affordable methods for the quick and low-cost identification of analytes has drawn increased attention in recent years, with a focus on safety control and contamination analysis [12]. The rapid expansion of nanoscale materials in sensing and detection applications offers a substitute for conventional methods to identify chemical and biological contaminants in beverages. Significant advancements in nanoscience over the past few years resulted in the development of sensors and other systems that are increasingly being used for beverage analysis [13, 14]. Recently, beverage companies have used smart packaging for their finished goods and products. Smart packaging involves sensor technology to monitor the temperature, moisture, and gas composition (oxygen and carbon dioxide) of the beverages [15, 16]. Indicators present in packaging material provide a color change in response to changes in beverage composition [17]. The different indicators used in beverage industries include temperature indicators, oxygen indicators, microbial indicators, and freshness indicators [18]. The freshness sensor in packaging material monitors the freshness inside the container and provides information about the quality and safety of the beverage during storage, distribution, and transportation [19]. Moreover, the quality sensors will have the ability to convey information about the safety and quality of the beverages directly to the consumer through label devices or sensor films. The distribution control can be optimized along with a stock rotation management system, waste reduction, and sensors in packaging material function as active shelf-life labeling devices in combination with 'use-by-date' labeling [19].

3. Significance of water quality

The significance of water quality in beverage production highlights the need for efficient treatment through various filtration and disinfection procedures to eliminate contaminants, guarantee safety, and meet consumer expectations.

Water quality has a significant connection with the physiochemical, microbiological, and organoleptic characteristics of beverages. The removal of elements that degrade water quality guarantees both beverage safety and improves sensory qualities. The beverage industry is required to establish a water treatment facility before initiating other manufacturing processes associated with the production of beverages [11]. The elements that cause quality deterioration like suspended matter, algae, and pathogenic microorganisms must be removed from raw water to produce high-quality beverages [20]. The presence of inorganic substances, suspended organic materials like trihalomethane, and foreign physiochemical components such as dissolved minerals should be eliminated [21, 22]. The presence of lower concentrations of sulfates, iron, and chlorides can result in off taste of beverages. This also can affect the pH or alkalinity of the water, which would ultimately have negative sensory effects. The main objective of water treatment is to eradicate or reduce these factors within the permissible limit [23].

The organoleptic qualities of mineral water make it an appealing option rather than normal tap water [24]. In the beverage industry microorganisms in drinks are effectively inactivated by UV disinfection treatment [25].

Table 1. Requirements of water quality for beverages by the FDA

Physical Quality	Maximum permissible level
Turbidity	5 NTU
Color	15 Color Units (CU)
Odor	Odor. No. 3
Chemical Quality	*Concentration in milligrams per liter*
Chloride	250.0
Iron	0.3
Manganese	0.05
Total Dissolved Solids	0001
Zinc	5.0
Chemical Contaminants (Inorganic substances)	*Concentration in milligrams per liter (or as specified)*
Arsenic	0.010
Antimony	0.006
Barium	2
Beryllium	0.004
Cadmium	0.005
Chromium	0.1
Copper	1.0
Cyanide	0.2
Lead	0.005
Mercury	0.002
Nickel	0.1
Nitrate	10 (as nitrogen)
Nitrite	1 (as nitrogen)
Total nitrate and nitrite	10 (as nitrogen)

Table 1. (cont.)

Chemical Contaminants (Inorganic substances)	Concentration in milligrams per liter (or as specified)
Selenium	0.05
thallium	0.002
Allowable levels for volatile organic chemicals (VOC's)	
Contaminant (CAS Reg. No.)	*Concentration (mg/L)*
Benzene (71-43-2)	0.005
Carbon tetrachloride (56-23-5)	0.005
o-Dichlorobenzene (95-50-1)	0.6
p-Dichlorobenzene (106-46-7)	0.075
1,2-Dichloroethane (107-06-2)	0.005
1,1-Dichloroethylene (75-35-4)	0.007
cis-1,2-Dichloroethylene (156-59-2)	0.07
trans-1,2-Dichloroethylene (156-60-5)	0.1
Dichloromethane (75-09-2)	0.005
1,2-Dichloropropane (78-87-5)	0.005
Ethylbenzene (100-41-4)	0.7
Monochlorobenzene (108-90-7)	0.1
Styrene (100-42-5)	0.1
Tetrachloroethylene (127-18-4)	0.005
Toluene (108-88-3)	1
1,2,4-Trichlorobenzene (120-82-1)	0.07
1,1,1-Trichloroethane (71-55-6)	0.2
1,1,2-Trichloroethane (79-00-5)	0.005
Trichloroethylene (79-01-6)	0.005
Vinyl chloride (75-01-4)	0.002
Xylenes (1330-20-7)	10
Allowable levels for pesticides and other synthetic organic chemicals (SOC'S)	
Contaminant (CAS Reg. No.)	*Concentration (mg/L)*
Alachlor (15972-60-8)	0.002
Atrazine (1912-24-9)	0.003
Benzo(a)pyrene (50-32-8)	0.0002
Carbofuran (1563-66-2)	0.04
Chlordane (57-74-9)	0.002
Dalapon (75-99-0)	0.2
1,2-Dibromo-3-chloropropane (96-12-8)	0.0002
2,4-D (94-75-7)	0.07
Di(2-ethylhexyl) adipate (103-23-1)	0.4
Di(2-ethylhexyl) phthalate (117-81-7)	0.006
Dinoseb (88-85-7)	0.007

Table 1. (cont.)

Allowable levels for pesticides and other synthetic organic chemicals (SOC'S)	
Contaminant (CAS Reg. No.)	Concentration (mg/L)
Diquat (85-00-7)	0.02
Endothall (145-73-3)	0.1
Endrin (72-20-8)	0.002
Ethylene dibromide (106-93-4)	0.00005
Glyphosate (1071-53-6)	0.7
Heptachlor (76-44-8)	0.0004
Heptachlor epoxide (1024-57-3)	0.0002
Hexachlorobenzene (118-74-4)	0.001
Hexachlorocyclopentadiene (77-47-4)	0.05
Lindane (58-89-9)	0.0002
Methoxychlor (72-43-5)	0.04
Oxamyl (23135-22-0)	0.2
Pentachlorophenol (87-86-5)	0.001
PCBs (as decachlorobiphenyl) (1336-36-3)	0.0005
Picloram (1918-02-1)	0.5
Simazine (122-34-9)	0.004
2,3,7,8-TCDD (Dioxin) (1746-01-6)	3×10^{-8}
Toxaphene (8001-35-2)	0.003
2,4,5-TP (Silvex) (93-72-1)	0.05
Disinfection byproducts	*Concentration (mg/L)*
Bromate	0.10
Chlorite	1.0
Haloacetic acids (five) (HAA5)	0.060
Total Trihalomethanes (TTHM)	0.080
Residual disinfectants	
Chloramine	4.0 (as Cl_2)
Chlorine	4.0 (as Cl_2)
Chlorine dioxide	0.8 (as Cl_2)

Source: (FDA, 21 CFR Part 165 Subpart B)

Simple filtration techniques that use activated carbon and polish filters can remove the suspended matter based on the size and shape while advanced filtration systems such as reverse osmosis, nanofiltration, and ultrafiltration can remove unwanted microorganisms from water [11]. The filtered water will undergo alkalinity reduction by using hydrated lime treatment in which soluble bicarbonates are converted into insoluble bicarbonates and removed as sludge. The final step is disinfection of water which can be achieved by chlorination for complete eradication of microorganisms or to reduce it to an acceptable limit. Ultraviolet irradiation is an alternate method for chlorine-based disinfection due to the drawback of the generation of trihalomethanes [11]. Recently, ozone has been gaining popularity for water treatment but the higher cost and health concern associated with the inhalation of ozone limits their application. The application of Hazard Analysis and Critical Control Points (HACCP) and GMP in a bottling plant can limit microbial contamination leading to the production of superior-quality bottled water [26]. The advent of IoT contributed to an advancement in the food and beverage sector, improving productivity and quality assurance [27]. In a study, a microcontroller (ESP32) based Internet of Things (IoT) liquid quality tester system with several sensors for temperature, turbidity, gas, and pH measurements has been used to analyze the normal water, Pepsi, and 7 up. The results with water indicated the absence of gas. It gave a graphical result for temperature, turbidity, and pH measurements for all the 3 samples [27].

Sensors are used in an Internet of Things-based beverage quality check to assess temperature, turbidity, pH, and gas presence. A cloud platform receives the data for analysis and real-time monitoring. If quality requirements are not achieved, alerts are generated. Data visualizations in real time are offered via a web portal. Accurate and efficient beverage quality control is ensured by this approach.

The liquid quality analyzer offers immediate data on the quality of the liquid and it is a vital device for practical applications as the analysis is revolutionized through on-site and real-time monitoring in remote or field situations made feasible by its compactness and portability [27]. Requirements of water quality for beverages by the FDA [28] are shown in Table 1.

4. Quality control in the beverage industry

Quality control guarantees both customer satisfaction and safety. To prevent microbial contamination, assess sensory qualities, and maintain product quality requirements, beverage quality control uses sophisticated tools including sensory analysis and biosensors, a thorough examination of raw ingredients, and hygienic manufacturing practices.

Table 2. Permissible levels of preservatives and additives in beverages according to FSSAI are listed below

S.No	Preservatives/Additives	Ready-to-serve (tea/coffee)	Carbonated fruit beverages/fruit drinks	Carbonated water, soft drink conc. (liquid/ powder)	Fruit-based beverage mix/ powdered fruit based fruit-based beverages
A.	*Acidifying agents (singly or in combination)*				
1.	Citric acid	-	GMP	GMP	GMP
2.	Fumaric acid	-	-	GMP	GMP
3.	Lactic acid	-	-	GMP	GMP
4.	L-tartaric acid	-	GMP	GMP	GMP
5.	Malic acid	-	GMP	GMP	GMP
6.	Phosphoric acid	-	-	GMP in cola beverages only	GMP
B.	*Anti-caking agents (singly or in combination)*				
1.	Carbonates of calcium and magnesium	-	-	-	2% maximum in powders only
C.	*Antioxidants*				
1.	Ascorbic acid	-	GMP	GMP	GMP
D.	*Colors (can be used singly or in combination within the specified limits)*				
	(a) Natural				
1.	Chlorophyll	-	100 ppm maximum	100 ppm maximum	200 ppm maximum
	(b) Synthetic				
1.	Ponceau 4R	-	100 ppm maximum	100 ppm maximum	200 ppm maximum

Table 2. (cont.)

S.No	Preservatives/Additives	Ready-to-serve (tea/coffee)	Carbonated fruit beverages/fruit drinks	Carbonated water, soft drink conc. (liquid/ powder)	Fruit-based beverage mix/ powdered fruit based fruit-based beverages
E.	*Flavors*				
1.	Natural flavoring and natural flavoring substances/ natural identical flavoring substances/artificial flavoring substances	-	GMP	GMP	GMP
F.	*Preservatives (singly or in combination)*				
1.	Benzoic acid and its sodium, potassium salt, or both (calculated as benzoic acid)	-	120 ppm maximum	120 ppm maximum	-
2.	Sulphur di-oxide	-	70 ppm maximum	70 ppm maximum	120 ppm maximum
3.	Sorbic acid and its sodium, potassium, and calcium salts (calculated as sorbic acid)	300 ppm	300 ppm	-	-
G.	*Thickening agents/ stabilizing/ emulsifying agents*				
A.	Vegetable gums (singly or in combination)				
1.	Gum arabic	-	GMP	GMP	GMP
B.	Alginates (singly or in combination)				
1.	Calcium alginates	-	-	GMP	-
2.	Potassium alginates	-	GMP	-	-
3.	Sodium alginates	-	-	-	-
C.	Pectinases	-	GMP	GMP	GMP
D.	Ester gum	-	100 ppm maximum	100 ppm maximum	100 ppm maximum
E.	Xanthan gum	-	-	0.5% maximum	0.5% maximum
F.	Alginic acid	-	GMP	GMP	GMP
G.	Quinine (as sulphate)	-	-	100 ppm maximum	100 ppm maximum
H.	*Phosphorus penta oxide*				
1.	Sodium hexa meta phosphate	-	1,000 ppm maximum	1,000 ppm maximum in carbonated water only	-

Source: (Food Safety Standards Authority of India, 2011)

The quality of food products is determined by different attributes accompanied during the manufacturing process [29]. These characteristics of food quality can be broken down into aspects related to microbiology, biochemistry, and organoleptic properties. Food quality attributes encompass the appearance, accessibility, and nutritional value of food. Sensorial attributes are determined in terms of appearance, flavor, consistency, odor, and structure. The important objective of quality management is to improve knowledge and understandability for method development to assess the product quality according to the specifications provided by international standards and prepare and maintain the records. The best quality management system should maintain a fail-safe system in which all the possible defects can be identified during the manufacturing process. The raw ingredients affect the overall quality of beverages while water used for manufacturing soft drinks should be free from odor, taste, and color. It should be free from sedimentation, turbidity (<

1 mg/L), and organic matter (< 1 mg/L). Soft drinks can be prepared from crystalline sugar which is a cheap source or from sugar syrups such as fructose corn syrup and artificial sweeteners. Granulated sugar should be free from abnormal color and taste with ash and arsenic content less than 0.02 and 1%, respectively. Fructose corn syrup should contain 72° Brix and be free from the contamination of foreign matter. The carbon dioxide should be free from oil contamination which can be produced through dry ice and can be stored in cylinders either in liquid or gas form. The sanitizing treatment of equipment involved in the manufacturing of beverages and the other items that are in direct contact with the products has to undergo suitable sterilization treatment. Permissible levels of preservatives and additives in beverages according to FSSAI [30] (Food Safety Standards Authority of India, 2011) are shown in Table 2.

4.1 *Microbiological quality control of beverages*

Beverages are rich sources of nutrients which makes them a suitable medium for the growth of various microorganisms. Yeast and mold are the major spoilage microorganisms in beverages which are rich in sugar and acids. It is essential to maintain the quality by optimizing nutritional efficiency that can better shield consumers from disease. In fact, among the different sectors, the beverage industry has stringent regulations to protect the health and safety of consumers [12]. Alcoholic beverages are made up of various compounds, each with unique qualities that give them their flavor, aroma, and other characteristics [31]. In the case of microbial contamination, non-spore-forming bacteria have been associated with the deterioration of alcoholic beverages. On the other hand, spore-forming bacteria (*Clostridium sp*.) can target the raw materials such as grains and malt in alcoholic beverages. These microorganisms can be eliminated by pasteurization or through sterile filtration. Temperature and time are two extremely important variables because they can alter the final quality in terms of textural haziness and flavor degradation. Additional variables include ropiness or inadequate fermentation, changes in acidity may impart physical haze in beer, wine, and other beverages [11]. Some beverages are less likely to become contaminated by microorganisms because they contain high levels of acidity, salt, sugar, or alcohol, which act as barriers against bacterial survival. However, some pathogenic microorganisms are strictly regulated and controlled in fruit juices and milk-derived beverages, including *Salmonella, Listeria monocytogenes*, and *Escherichia coli* [32]. Together with biosensors based on acoustic transduction, which are primarily meant to be used for detecting microbiological contaminants, optical-based biosensor systems have also been widely developed as an alternative to the electrochemical transduction method. Targeting the presence of food-contaminating microorganisms like *Salmonella typhimurium, E. coli 0157:H7, Staphylococcal enterotoxins,* and *Salmonella* has been done using these techniques [33, 34].

Table 3. Microbiological limits for ready-to-serve, carbonated, and fruit beverages according to FSSAI are listed below

Product	Parameters	Limits
Carbonated beverages, ready-to-serve beverages, fruit beverages	a) Total plate count	Not more than 50 cfu/ml
	b) Yeast and mold count	Not more than 2.0 cfu/ml
	c) Coli form count	Absent in 100 ml

Source: (Food Safety Standards Authority of India, 2011)

The conventional enumeration methods are time-consuming and labor-intensive due to these drawbacks, most of the food industries started to adopt rapid methods like spectroscopic techniques combined with chemometric methods, biosensors, and mass spectroscopy. The microbial contamination of beverages can be prevented by identifying the sources and provision for the contamination throughout the production chain. This can be done by adapting the suitable GMP, HACCP, standard operating procedures (SOPs), and sanitation standard operating procedures (SSOPs) [11]. Microbial control by maintaining a suitable temperature is the widely used approach in beverage industries by chilling (< 8 °C) or freezing (-18 °C) [11]. It involves proper temperature management during the product handling and production chain. The number of microorganisms can be controlled by the application of thermal, non-thermal processing methods, packaging techniques, and incorporation of antimicrobial agents and preservatives [11]. Microbiological limits for ready-to-serve, carbonated, and fruit beverages according to FSSAI [30] (Food Safety Standards Authority of India, 2011) are shown in Table 3.

4.2 *Sensory analysis for beverage quality control*

Food analyte quantification has been made quick and clear with the use of sensors [35]. The organoleptic properties of any food product can be measured using two different forms of sensory analysis namely subjective and objective which use human senses and instruments, respectively. The beverage quality is mainly determined by their sensorial attributes such as taste, aroma, color, texture, and flavor which are analyzed by the sensory choices of consumers [36]. The sensory scales are designed to differentiate the preferred products in terms of the magnitude of aroma, color, and other organoleptic properties. The overall product quality of alcoholic beverages is dependent on the color and bitterness. Beverages can be divided into opaque, translucent, and transparent for evaluation of color by analytical instruments [11]. Instruments used to analyze beverages based on color are shown in Table 4. Opaque beverages contain higher solids which include tomato juice, orange juice, and milk [11]. Translucent beverages have a moderate range of solids, for example, apple juice, soft drinks, and alcoholic beverages [11]. The reflectance or transmittance of light by opaque beverages can be measured by analytical instruments [11]. Transparent beverages contain lower amounts of soluble solids and the color can be analyzed by transmission instruments (Table 1).

Table 4. Instruments used to analyze beverages based on color

Types of beverages	Instrument for analysis	Example
Opaque beverage	Diffuse reflectance instrument	Tomato juice, orange juice, milk, smoothies, soy milk,protein drinks
Translucent beverage	Transmittance or reflectance measuring instrument	Apple juice, lemonade, soft drinks, coffee, tea, alcoholic beverages, andenergy drinks
Transparent juice	Transmission instrument	Filtered apple, cranberry and grape juice

Source: (Aadil RM, 2019b)

The textural attributes include viscosity, fizzy, fibrous, foamy, grainy, sticky, and soft nature of beverages that determine the taste quality [11]. The complex rheology of beverages depends on the ingredients and processing conditions [11]. The electronic nose along with the electronic tongue for the evaluation of different beverages. Sensory evaluation of alcoholic beverages includes certain fundamental issues such as the reduction of alcohol content [37]. The assessment of beverages with a high alcohol content can be challenging because alcohol distorts taste perception and hides both undesired off-tastes, and delicate, and subtle flavors (Figure 2). The dilution of alcoholic beverages with de-ionized water to a moderate range between 15-25% alcohol can preserve delicate flavors while improving the detection of off-tastes like geosmin [37]. Aged products require special attention to prevent the loss of their subtle qualities. The accurate and pertinent sensory evaluations of high-alcohol beverages can be attained by maintaining consistent dilution across evaluations [37]. Biofilm formations can be dodged with periodic sanitization of the processing plant and contact premises. Food processing monitoring is made easy with the use of e-nose and e-tongue, which are robust, cost-effective, and highly accurate analytical instruments for both in-line and offline measurements as well as end-product quality detection [38]. The E-tongue is a crucial tool in the food sector, particularly for quality control and assurance of food and beverages, since it can sense any taste like a human olfactory system [39]. E-tongue has been used to measure the bitterness of drinks or dissolving chemicals, as well as to determine the aging of flavor in beverages [40, 41].

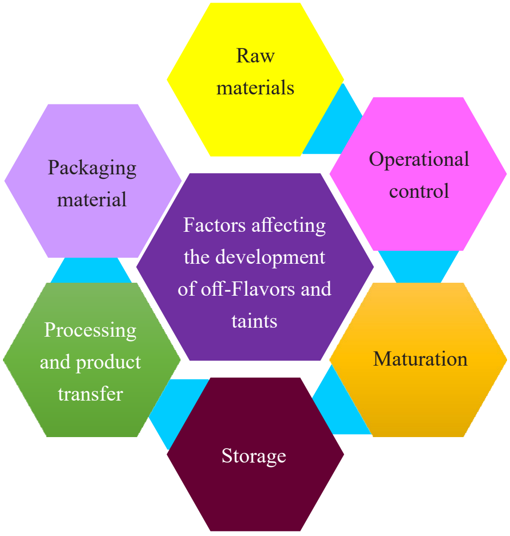
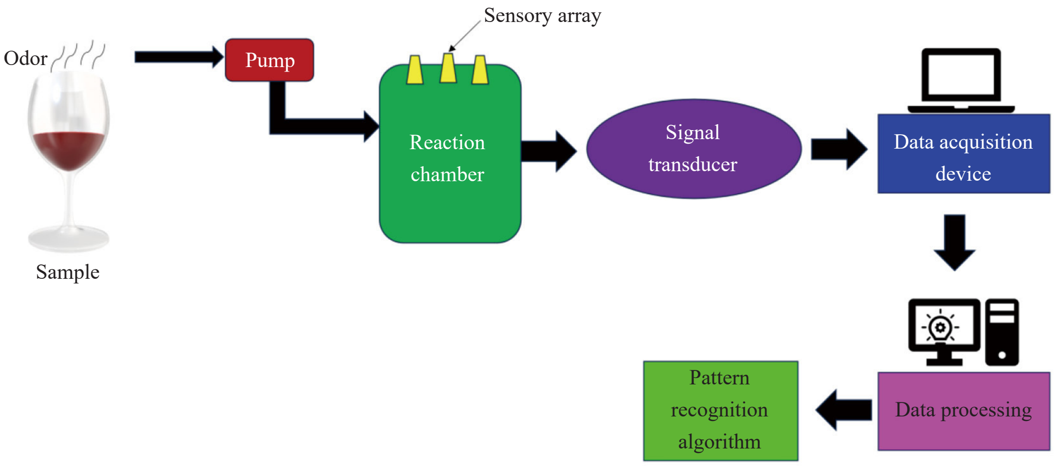


Figure 2. Factors affecting the development of off-flavors and taints in alcoholic beverages

To analyze complex fluid media, such as food and beverages, a taste sensor system called the electronic tongue or electrochemical sensor is connected to a model recognition device. Among the methods employed in electrochemical techniques were cyclic voltage monitoring [42-44] and potentiometry [45]. The type and brand of orange beverage and Chinese vinegar may be distinguished using commercial e-tongue by employing pattern classifiers such as random forest, artificial neural network, and support vector machines [46]. It can also be used to identify the sensory characteristics of alcoholic beverages using pattern recognition algorithms such as principal component analysis, and fuzzy evaluation [47]. Voltametric sensors are employed to monitor the quality and duration of storage for unsealed pasteurized milk using classifiers such as Principal Component analysis, support vector machines, and partial least squares regression [48]. The signals gathered by an electronic nose system, in conjunction with pattern recognition algorithms, and various machine learning classifiers, facilitate the identification of distinct sample types by grouping comparable emissions into clusters that reflect substances derived from related food volatiles.

The ability of the latest generation of electronic noses (e-noses) to get around the drawbacks of conventional methods makes them promising for beverage analysis [49]. A schematic representation of the E-nose system is shown in Figure 3.

Various kinds of sensors used in the development of E-noses are as follows, Metal Oxide Semiconductor (MOS) Sensors, Conducting Polymer (CP) Sensors, Surface Acoustic Wave (SAW) Sensors, Metal Oxide Semiconductor Field Effect Transistors (MOSFETs), Electrochemical (EC) Sensors, Optical Sensors, Colorimetric Sensors, and fluorescence sensors [50]. Various types of e-nose sensors, mechanisms of action, and detection are given in Table 5. E-noses are unaffected by the presence of ethanol, in contrast to mass spectrometry (MS), which frequently experiences saturation problems with it. They can therefore perform a wide range of analytical techniques on beverages and are extremely versatile. Additionally, the e-nose and e-tongue are used to measure the amount of alcohol in drinks made from various source materials, classify beverages based on flavor types [51], distinguish beverages based on botanical sources [52], and measure the quantity of alcohol in a variety of commercially sold alcoholic beverage types: whiskey, grappa, beer, and wine [49]. A sampling device, a detector unit with ten metal oxide sensors, and pattern recognition software equipped in the portable electronic nose (PEN 3) are used to analyze the flavors in Chinese spirits. Then the spirits were let into the sensors, the Win Muster program was used to record and examine the spirits' reactions [51]. Moreover, conducting polymers and other biosensors can be employed to identify the gases emitted during microbial metabolism [53, 54]. Flexible printed chemical sensors integrated into food packaging have a bright future, even though the majority of these advancements remain unexplored [55].



Schematic representation of the E-nose system

Figure 3. Schematic representation of the E-nose system

Table 5. Various types of e-nose sensors, mechanism of action, and detection

E-nose sensors	Mechanism	Detection
Metal oxide semiconductor sensors	Gas sensors react to various gases which are of two types: n-type and p-type. P-type sensors detect oxidizing substances, whereas N-type sensors respond to reducing compounds. Both types of sensors operate by through oxidation-reduction reactions with chemisorbed oxygen on the surface of the sensor material.	Detects the distinct volatile gas molecules.
Conducting polymer sensors	Their mechanism of operation is based on the variations in electrical resistance caused by the adsorption of volatile gases on the sensor surface.	Detects a variety of volatile organic compounds (VOCs) including aldehydes, acetates, alcohols from drinks, and ammonia.
Surface acoustic wave sensors	These sensors operate by utilizing mechanical waves, or acoustic waves, to detect the presence of volatile molecules on the detecting surface. thereby changing the amplitude.	Used for the rapid identification of food deterioration and pathogens.
Metal oxide semiconductor field effect transistors	The sensor comprises three layers: silicon semiconductor, silicon oxide insulator, and catalytic metal, which generates an electric field when voltage is applied. The transistor modifies and records the electric field in response to interactions between polar chemicals and metal.	Detects various gas mixtures.
Electrochemical sensors	The sensors work based on the interaction between the volatile gaseous molecules and the sensing materials that produce the electrical signals.	Detects and measures the electrochemically active gases.
Optical sensors	Optical sensors function through light modulation measurements	Detects changes in wavelength, color, and fluorescent light emissions upon exposure to analytes.
Colorimetric sensors	These sensors use color change and absorbance as the basis for their detection when volatile gaseous molecules interact with chromogenic materials.	Detects the spoilage of meat.
Fluorescence sensors	These sensors work by detecting lower wavelength fluorescent light emissions from the target gaseous molecules.	Detects the food contaminants.

Source: (Kaushal, 2022)

Artificial intelligence (AI), is well-known for its simplicity, precision, and cost-saving features, and has established a substantial impact on the food sector through modeling, prediction, sensory evaluation, quality control, and complicated problem-solving ability [56]. The Sensomics-Based Expert System (SEBES) was designed to forecast important aroma compounds without the use of human olfactory systems for sensory evaluation and quality control of red wine and rum. This resulted in a good agreement in the main odorants for the food aroma distillate [57]. Samples of rum and wine were distilled, specific aroma compounds were identified and quantified using GC-MS analysis, and vital components were predicted using SEBES application based on concentrations and odor activity values. In a study, three machine learning systems (Support Vector Machines, Radio Frequency, and Multi-Layer Perception) were evaluated to assess wine quality. The Radio Frequency approach was superior to others, by achieving the best results with an average precision of 81.96%. This implies that the RF algorithm is capable of assessing wine quality [58].

5. Conclusion

The beverage industry plays a vital role in human health and well-being, but ensuring the highest quality beverages demands a multifaceted approach that prioritizes consumer health, maximizes nutritional value, and adheres to regulations. This review article examined various aspects of beverage quality control, and the various challenges faced by the industry like undesirable chemical reactions, microbiological contamination, and sensory quality variations. Upholding Good Manufacturing Practices (GMP) is crucial for consistent product safety and quality. Fortunately, technological developments provide potential solutions to these challenges. Innovative analytical techniques such as Electronic-tongues and noses, biosensors, and smart packaging with built-in sensors provide quicker and more effective quality control processes. The Internet of Things (IoT), helps in monitoring a wide range of characteristics in real-time both during manufacturing and storage and this can further improve the quality assurance in the beverage industry. However, the ever-changing market demands further innovation.

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Author contributions

The authors confirm their contribution to the paper as follows: writing and data collection: Swetha V; conceptualization and review: Jeevitha G C. All authors reviewed the manuscript and approved the final version of the manuscript.

Data availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no competing financial interest.

References

[1] Rivankar SN, Walke GA, Patil AN, Nigalye A. Beverage industry in India and scope for medium scale juice extraction units in Goa. *IOSR Journal of Engineering*. 2019; 43-46. Available from: https://www.researchgate.net/

publication/332547413.
[2] Kumar S, Chand K. *Market trend in beverage industry*. 2021. Available from: https://www.researchgate.net/publication/351707747_Market_Trend_in_Beverage_Industry [Accessed 18th January 2024].
[3] Marco ML, Heeney D, Binda S, Cifelli CJ, Cotter PD, Foligne B, et al. Health benefits of fermented foods: microbiota and beyond. *Current Opinion in Biotechnology*. 2017; 44: 94-102.
[4] Admassie M. A review on food fermentation and the biotechnology of lactic acid bacteria. *World Journal of Food Science and Technology*. 2018; 2(1): 19-24.
[5] Marrero SC, Martinez-Rodriguez A, Perez SM, Moya SP. New trends and applications in fermented beverages. *Fermented Beverages*. 2019; 5: 31-66. Available from: https://doi.org/10.1016/B978-0-12-815271-3.00002-6.
[6] Ghose P, Nair P. Packaging of carbonated beverages. *International Journal of Agriculture and Food Science Technology*. 2013; 4(5): 421-430.
[7] Kandylis P, Pissaridi K, Bekatorou A, Kanellaki M, Koutinas AA. Dairy and non-dairy probiotic beverages. *Current Opinion in Food Science*. 2016; 7: 58-63.
[8] Aadil RM, Madni GM, Qazalbash RU, Rahman UU, Zeng XA. Quality control in beverage production: An overview. *Quality Control in the Beverage Industry*. 2019; 17: 1-38.
[9] Realini CE, Marcos B. Active and intelligent packaging systems for a modern society. *Meat Science*. 2014; 98(3): 404-419.
[10] Patra S, Choudhary R, Madhuri R, Sharma PK. Quality control of beverages for health safety: Starting from laboratory to the point-of-care detection techniques. In: *Quality Control in the Beverage Industry*. Academic Press; 2019. p.39-83.
[11] Aadil RM, Madni GM, Roobab U, Rahman UU, Zeng XA. Quality control in beverage production: An overview. *Quality Control in the Beverage Industry*. 2019; 17: 1-38.
[12] Llaver M, Martinis EM, Sotolongo CA, Wuilloud RG. Modern analytical nanotechnologies for beverages quality control. *Nanoengineering in the Beverage Industry*. 2019; 20: 71-103.
[13] Huang Q. *Nanotechnology in the food, beverage and nutraceutical industries*. Elsevier; 2012.
[14] Velmourougane K, Gopinandhan TN, Bhat R. Practical food safety: Contemporary issues and future directions. In: Bhat R, Gómez-López VM. (eds.) *Practical Food Safety: Contemporary Issues and Future Directions*. John Wiley & Sons; 2014. p.577-595.
[15] Adley CC. Past, present and future of sensors in food production. *Foods*. 2014; 3(3): 491-510.
[16] Kuswandi B. Environmental friendly food nano-packaging. *Environmental Chemistry Letters*. 2017; 15(2): 205-221.
[17] Arvanitoyannis IS, Stratakos AC. Application of modified atmosphere packaging and active/smart technologies to red meat and poultry: A review. *Food and Bioprocess Technology*. 2012; 5(5): 1423-1446.
[18] Kuswandi B, Mehran M. Sensors for beverages. *Trends in Beverage Packaging*. 2019; 16: 279-302. Available from: https://doi.org/10.1016/B978-0-12-816683-3.00010-4.
[19] Kuswandi B, Wicaksono Y, Jayus J, Abdullah A, Heng LY, Ahmad M. Smart packaging: sensors for monitoring of food quality and safety. *Sensing and Instrumentation for Food Quality and Safety*. 2011; 5(3): 137-146.
[20] Ashurst PR, Robert H. *Soft drink and fruit juice problems solved*. Woodhead Publishing; 2009.
[21] Ribera LF, Cotta JC, Gutierrez GA, Villanueva CM. Trihalomethane concentrations in tap water as determinant of bottled water use in the city of Barcelona. *Journal of Environmental Sciences*. 2017; 58: 77-82.
[22] Rahman IMM, Barua S, Barua R, Mutsuddi R, Alamgir MD, Islam F, et al. Quality assessment of the non-carbonated bottled drinking water marketed in Bangladesh and comparison with tap water. *Food Control*. 2017; 73: 1149-1158.
[23] Cantor AF. *Water distribution system monitoring: a practical approach for evaluating drinking water quality*. CRC Press; 2009. p.232.
[24] Garfí M, Cadena E, Sanchez-Ramos D, Ferrer I. Life cycle assessment of drinking water: comparing conventional water treatment, reverse osmosis and mineral water in glass and plastic bottles. *Journal of Cleaner Production*. 2016; 137: 997-1003.
[25] Shachman M. *The soft drinks companion: a technical handbook for the beverage industry*. 1st ed. CRC Press; 2004.
[26] Kokkinakis EN. Heterotrophic bacteria in bottled water. In: *Encyclopedia of Environmental Health*. Elsevier, Burlington; 2011.
[27] Sribhavisha KB, Manasa D, Prakash DR, Narayanan SA, Mohanty A, Sumathi G. A novel on quality check of beverages using IoT. In: *3rd International Conference on Artificial Intelligence for Internet of Things (AIIoT)*. IEEE; 2024. p.1-5.

[28] FDA SB. *Requirements for specific standardized beverages.* US Food and Drug Administration, Code of Federal Regulations; 2020. Available from: https://www.ecfr.gov/current/title-21/part-165/subpart-B.
[29] Błaszczyk I. The management of food safety in beverage industry. *Safety Issues in Beverage Production*. 2019; 18: 1-38.
[30] Wikipedia contributors. *Food Safety Standards Authority of India*. Wikipedia, The Free Encyclopedia; 2014. Available from: https://en.wikipedia.org/w/index.php?title=Food_Safety_and_Standards_Authority_of_India&oldid=1248961223.
[31] Pontes MJC, Santos SRB, Araujo MCU, Almeida LF, Lima RAC, Gaiao EN, et al. Classification of distilled alcoholic beverages and verification of adulteration by near infrared spectrometry. *Food Research International*. 2006; 39(2): 182-189.
[32] Wareing PW, Davenport RR. Microbiology of soft drinks and fruit juices. In: *Chemistry and Technology of Soft Drinks and Fruit Juices*. John Wiley & Sons, Ltd.; 2016. p.290-309. Available from: https://doi.org/10.1002/9781118634943.
[33] Rani DN, Abraham TE. Kinetic study of a purified anionic peroxidase isolated from *Eupatorium odoratum* and its novel application as time temperature indicator for food materials. *Journal of Food Engineering*. 2006; 77(3): 594-600.
[34] Volpe G, Palleschi G, Turner APF. New biosensors for microbiological analysis of food. *Detecting Pathogens in Food*. 2003; 18: 294-331.
[35] Kerry JP, O'Grady MN, Hogan SA. Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: A review. *Meat Science*. 2006; 74(1): 113-130.
[36] Civille GV, Oftedal KN. Sensory evaluation techniques-Make "good for you" taste "good." *Physiology and Behavior*. 2012; 107(4): 598-605.
[37] McGrew D. *A review of sensory quality control and quality assurance for alcoholic beverages*. Kansas State University; 2011.
[38] Tan J, Xu J. Applications of electronic nose (e-nose) and electronic tongue (e-tongue) in food quality-related properties determination: A review. *Artificial Intelligence in Agriculture*. 2020; 4: 104-115.
[39] Podrazka M, Báczyńska E, Kundys M, Jeleń PS, Nery EW. Electronic tongue-a tool for all tastes? *Biosensors*. 2017; 8(1): 1-24.
[40] Lan Y, Wu J, Wang X, Sun X, Hackman RM, Li Z. Evaluation of antioxidant capacity and flavor profile change of pomegranate wine during fermentation and aging process. *Food Chemistry*. 2017; 232: 777-787.
[41] Ha D, Sun Q, Su K, Wan H, Li H, Xu N, et al. Recent achievements in electronic tongue and bioelectronic tongue as taste sensors. *Sensor Actuat B-Chem*. 2015; 207: 1136-1146.
[42] Apetrei IM, Apetrei C. Application of voltammetric e-tongue for the detection of ammonia and putrescine in beef products. *Sensors and Actuators, B: Chemical*. 2016; 234: 371-379.
[43] Li LA, Yu Y, Yang J, Yang R, Dong G, Jin T, et al. Voltammetric electronic tongue for the qualitative analysis of milk adulterated with urea combined with multi-way data analysis. *International Journal of Electrochemical Science*. 2015; 10(7): 5970-5980.
[44] Pauliuc D, Dranca F, Oroian M. Raspberry, rape, thyme, sunflower and mint honeys authentication using voltammetric tongue. *Sensors*. 2020; 20(9): 2565.
[45] Zhang X, Zhang Y, Meng Q, Li N, Ren L. Evaluation of beef by electronic tongue system TS-5000Z: flavor assessment, recognition and chemical compositions according to its correlation with flavor. *PLoS One*. 2015; 10(9): e0137807.
[46] Liu M, Wang M, Wang J, Li D. Comparison of random forest, support vector machine and back propagation neural network for electronic tongue data classification application to the recognition of orange beverage and Chinese vinegar. *Sensors and Actuators B: Chemical*. 2013; 177: 970-980.
[47] Liu J, Zuo M, Low SS, Xu N, Chen Z, Lv C, et al. Fuzzy evaluation output of taste information for liquor using electronic tongue based on cloud model. *Sensors*. 2020; 20(3): 686.
[48] Wei Z, Wang J, Zhang X. Monitoring of quality and storage time of unsealed pasteurized milk by voltammetric electronic tongue. *Electrochimica Acta*. 2013; 88: 231-239.
[49] Sliwinska M, Wisniewska P, Dymerski T, Wardencki W, Namiesnik J. Advances in electronic noses and tongues for food authenticity testing. In: Downey D. (ed.) *Advances in Food Authenticity Testing*. Woodhead Publishing; 2016. p.201-225. Available from: https://doi.org/10.1016/B978-0-08-100220-9.00008-4.
[50] Kaushal S, Nayi P, Rahadian D, Chen HH. Applications of electronic nose coupled with statistical and intelligent pattern recognition techniques for monitoring tea quality: A review. *Agriculture*. 2022; 12(9): 1359.
[51] Liu M, Han X, Tu K, Pan L, Tu J, Tang L, et al. Application of electronic nose in Chinese spirits quality control

and flavour assessment. *Food Control*. 2012; 26(2): 564-570.
[52] Wisniewska P, Sliwinska M, Dymerski T, Wardencki W, Namiesnik J. Differentiation between spirits according to their botanical origin. *Food Analytical Methods*. 2016; 9(4): 1029-1035.
[53] Ahuja T, Mir IA, Kumar D. Biomolecular immobilization on conducting polymers for biosensing applications. *Biomaterials*. 2007; 28(5): 791-805.
[54] Retama JR, Mecerreyes D, Lopez-Ruiz B, Lopez-Cabarcos E. Synthesis and characterization of semiconducting polypyrrole/polyacrylamide microparticles with Gox for biosensor applications. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2005; 270-271: 239-244. Available from: https://doi.org/10.1016/j.colsurfa.2005.06.007.
[55] Vanderroost M, Ragaert P, Devlieghere F, De Meulenaer B. Intelligent food packaging: The next generation. *Trends in Food Science and Technology*. 2014; 39(1): 47-62.
[56] Mavani NR, Ali JM, Othman S, Hussain MA, Hashim H, Rahman NA. Application of artificial intelligence in food industry-a guideline. *Food Engineering Reviews*. 2022; 14(1): 134-175. Available from: https://doi.org/10.1007/s12393-021-09290-z.
[57] Nicolotti L, Mall V, Schieberle P. Characterization of key aroma compounds in a commercial rum and an Australian red wine by means of a new sensomics-based expert system (SEBES)-an approach to use artificial intelligence in determining food odor codes. *Journal of Agricultural and Food Chemistry*. 2019; 67(14): 4011-4022. Available from: https://doi.org/10.1021/acs.jafc.9b00708.
[58] Shaw B, Suman AK, Chakraborty B. Wine quality analysis using machine learning. In: *Emerging technology in modelling and graphics: proceedings of IEM graph 2018*. Springer Singapore; 2020. p.239-247.