International Journal of Academic and Applied Research (IJAAR)
ISSN: 2643-9603
Vol. 9 Issue 11 November - 2025, Pages: 93-111

Physicochemical Analysis of Crude Brown Sugar: A Review on Implications for Quality and Safety

Olabimtan Olabode.H[1*], Latayo Musa. B[2], Akinlotan Omoyeni. O[3], Rebecca Thomas D[4],

Shirley Obadiah Yakubu[5], Abari Emmanuel [6], Egwim Nkechinyere N[7], Iye Francis[8], Jibrin Abdulrahman Salihu[9]

[1]Industrial and Environmental Pollution Department,
National Research Institute for Chemical Technology, Zaria, Kaduna State, Nigeria.
[2, 8] Scientific and Industrial Research Department,
National Research Institute for Chemical Technology, Kaduna State, Nigeria.
[3]Chemistry Department, Kogi State College of Education (Technical), Mopa, Kogi State, Nigeria.
[4] NARICT Medical Center,
National Research Institute for Chemical Technology, Zaria, Kaduna State, Nigeria.
[5]Department of Science Laboratory Technology,
Federal Polytechnic Kaltungo, Gombo State, Nigeria.
[6]Microbiology Department, Faculty of Life Sciences,
Ahmadu Bello University Kaduna State, Nigeria.
[7]Outstation Department (Entrepreneurial),
National Research Institute for Chemical Technology, Aba, Abia State, Nigeria.
[9]Department of Physical and Life Sciences,
National Space Research and Development Agency, Abuja, Nigeria.

Corresponding Author Email: *olabode4angel@gmail.com*

Abstract: *Recently, crude brown sugar (CBS) a naturally processed non- centrifugal sugar, has gained some awareness as a natural substitute to refined white crystal sugar. Functional and sensory characteristics of CBS retained valuable bioactives of plant phenols, trace minerals and flavonoids, which are the determinants of health and antioxidant properties. Its impeccable taste and colour as well as texture also added to its widespread use and approbation by the locals. The quality and safety of CBS is assessed nutritionally on the basis of an array of physicochemical properties. The moisture and ash content index the processing intensity and sucrose stability, pH and soluble solids levels demonstrate the hydrolytic potential. Colour and turbidity tests indicate the snapshot attractiveness, and proximate compositions (proteins, lipids, carbs and reducing sugar) reflect the distribution of macronutrients. High-level analytics like neutron activation analysis, gas chromatography mass spectrometry and high-performance liquid chromatography are used to identify the contaminants, authenticate and verify regulatory compliances. The result of the current research consistently proves that the nutritiona high and bioactive profile of CBS is high compared to that of refined sugar. Nevertheless, its general quality strongly relies on processing factors such as adjustment of juice pH and the cooking temperature. Such innovations as membrane clarification have potential to extract lower levels of impurities, but maintain good nutritional and sensory qualities. The area of future research sh ound be focu sed on in vivo analyses of CBS bioactive compounds, standardisation of processing protocols and development of novel analytical techniques. Such innovations will be necessary to ensure safety of the product, guaranteeing consistency of quality and solidifying the status of CBS as a natural sweetener which can be marketed globally.*

Keywords: Crude brown sugar; physicochemical parameters; quality assurance (QA); quality control (QC); risk assessment; food safety.

1. INTRODUCTION

Brown sugar, which is traditionally obtained by crushing sugarcane juice or boiling in an open pan, or by mixing refined white sugar with molasses, is a product that is traditionally viewed as having distinct molasses concentration, dark color, and rich flavor profile [1, 2, 3, 4, 5, 6]. Recent production processes, including rotary evaporation and microwave-assisted processing, have come into being to address thermal degradation and shorten the processing time, especially in the production of coconut sap sugar [7, 8]. Due to its purity, refined sugar is often mixed with 3.5 percent molasses to make standardized products of brown sugar commercially [2, 9].

Crude brown sugar has a significant cultural and nutritional value, as it is enriched with minerals, amino acids, and phenolic compounds and a part of the traditional diet of many countries in Asia, Latin America, and Africa [10, 11]. It has been used in Ayurvedic medicine to treat respiratory, digestive, and inflammatory diseases [12, 13]. Another

similar product, coconut sugar, is valued by the food and cosmetic industries due to its mineral and antioxidant properties [14, 15]. Its popularity has also increased due to the intensified consumer desire in developed countries to use natural and minimally processed sweeteners as healthier options over refined sugar [16; 17]. Mass production is now made possible by industrial scale production without compromising the essential sensory attributes, like taste, color, and texture [2, 9, 18, 19]. Thus, crude brown sugar represents both a conventional and the latest dietary product, a symbol to unite the cultural heritage with the latest health-aware consumption patterns.

Figure 1. Locally processed brown sugar in the Northern part of Nigeria.

At the same time, the implementation of quality control and safety assessments can be integrated with circular policies and practices in agrifood systems to promote sustainability [20, 21]. Food safety regulation involves emerging issue identification, frameworks for decontamination efficacy, identifying sentinel contaminants, understanding metabolites/transformation products, developing health-based standards, and enabling sustainable practice in the food chain [22, 23]. This involves characterizing risks with use, identifying pathways of hazards transferring to food with use, monitoring requirements to validate food safety, and identifying needs to support safe use [24]. Feedstock involve validating efficacy of any decontamination, determining fate of contaminants through processing, defining quality specifications for final use product, and assessing fitness of any quality testing [25]. Chemical and waste regulation involves life-cycle assessment to confirm fate in circular systems, evaluating composition of manufactured materials, infrastructure and treatment standards, seperation and segregation tools, regulating hazardous waste management, and identifying and using management tools to segregate waste [26; 27].

Figure 2. Regulatory Aspects related to food safety

1.2 Rationale for conducting physicochemical analysis.

Quality control, safety, and compliance to rules depend on physicochemical assessment of crude brown sugar. This study offers a thorough grasp of the composition and characteristics of the sugar, therefore affecting its suitability for many uses and guaranteeing consumer safety [26; 28]. Defining the compositional profile is one important aspect that includes quantifying sucrose, reducing sugars, moisture, ash, and other trace elements. While reducing sugars affect hygroscopic characteristics and browning, sucrose levels indicate purity and sweetness [29]. Moisture influences stability on microbial sensitivity as ash content exposes information about the origin and treatment of the sugar [30]. Additionally, evaluating qualities like color, crystal size, and clarity as physicochemical tests are influenced by the hue; darker colors that implies lower purity [31, 32]. Safety is top priority with the demand for the detection of heavy metals, pesticide residues, and other hazardous chemicals as trace concentrations of these pollutants also present health issues [33]. Microbial contamination can be avoided by means of adequate sanitation, hygiene, and pest management with compliance on safety criteria via periodic testing. Physical analysis is also necessary for trade facilitation and compliance with legal standards. Many nations have specific laws for sugar products, including restrictions on humidity, ash, and heavy metals [34]. Hence, the goals of this article are to compile and summarize existing information on the composition, qualities, and quality control of crude brown sugar and to find gaps in current research and recommend areas for additional study to improve the quality and safety of crude brown sugar.

Based on its physicochemical composition, it also seeks to assess the possible health advantages and hazards related with the ingestion of raw brown sugar. This might entail investigation of the effects on human health of several elements, including sucrose, reducing sugars, and minerals.

2. COMPOSITION AND PHYSICOCHEMICAL CHARACTERISTICS OF CRUDE BROWN SUGAR

2.1 Chemical Constituents

Crude brown sugar's chemical formation, defined by its sucrose content, moisture levels, reducing sugars, ash content, and mineral composition, is actively influenced by both its

intrinsic characteristics and processing techniques (11,35,36]. The physical and stability-related properties of crude brown sugar texture, caking characteristics, and shelf life are all influenced by its moisture content.

Which is often characterized with a lower water activity (aw < 0.7) than purified sugars, lightly processed brown sugar shows its diminished water content and therefore microbiological stability [11, 37]. Lowering sugars such as glucose and fructose in addition to sucrose gives brown sugar its hygroscopic characteristic [29, 37]. These monosaccharides also participate in non-enzymatic maillard reactions during processing or storage, generating characteristic brown pigmentation and flavor compounds [38, 39]. Ash content, representing the inorganic mineral residue post-combustion, serves as a key indicator of brown sugar's nutritional distinctiveness [40, 41]. Due to retained molasses, unrefined brown sugars invariably exhibit higher ash content than fully refined counterparts, underscoring their mineral retention [35]. Notably, crude brown sugar contains nutritionally relevant minerals including calcium, magnesium, iron, and potassium though their concentrations are contingent upon geographical origin and processing intensity [41].

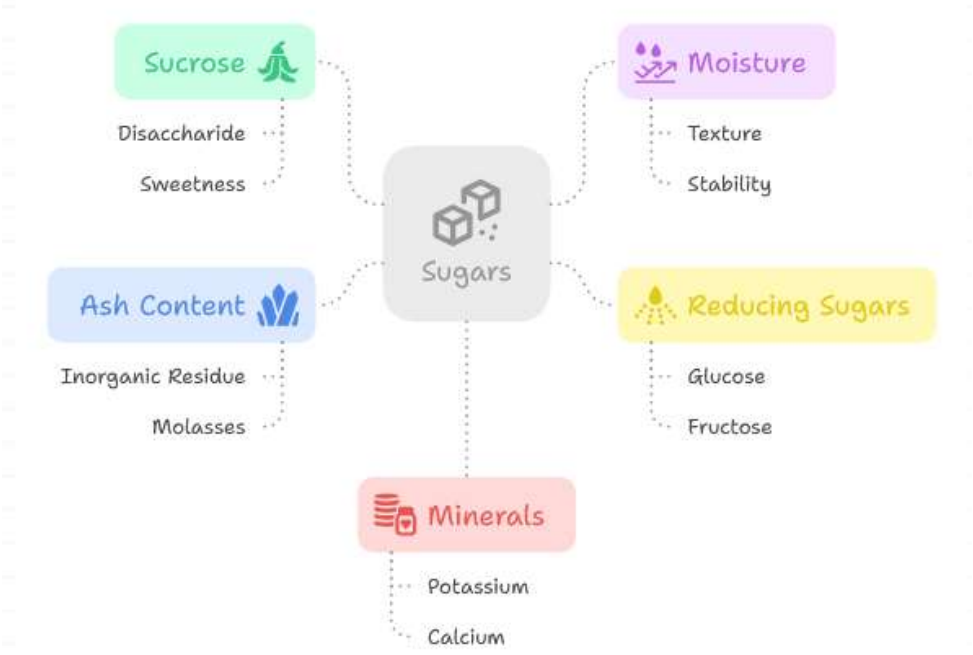

Figure 3. Chemical compositions of crude brown sugar

2.2 Influence of Processing Methods on Composition

The processing methods actively alter the chemical properties of crude brown sugar. In regular production technology, a larger proportion of the natural nutrients with their minerals, polyphenols and organic acids lie in a juice condition. [1, 42]. By contrast, industrial refining methods drastically modify the biochemical profile of the sugar, particularly with key factors like sucrose purity, low sugar concentration, and ash content [43]. Raw sugar from these refineries has ash components, a heterogeneous mixture of sucrose, reducing sugars, and contaminants like starch and dextran. Commonly used purity enhancement pathway of raw sugar quality is an affination process, where sugar crystals are washed to eliminate the covering syrup layer [44].

The processing temperature is also absolutely essential for determining the quality of sugar, as high temperatures during refining can cause thermal decomposition of sucrose, therefore producing additional chemicals like hydroxymethylfurfural (HMF) and caramelisation products [45]. Such thermal effects not only lower sucrose output but might also bring undesirable flavour and hue changes. Due to differences in processing intensity, conventional brown sugar and refined brown granulated sugar exhibit distinct physicochemical properties. Industrial refining processes remove many of the phytochemicals naturally present in sugarcane, including bioactive compounds and micronutrients [35]. As a result, traditional brown sugar retains higher concentrations of minerals such as calcium, magnesium, and potassium, as well as amino acids, compared to its refined counterpart.

This compositional disparity underscores the nutritional trade-offs between fully processed and minimally processed sugar products, highlighting the potential health implications of processing choices.

2.3 Physical Properties

The physical properties of brown sugar consisting of appearance, granular size, shade differences, and the degree of hygroscopicity eventually become determinant factors for consumer acceptance and applicable function [46]. However, brown sugar is more natural than white sugar, conserving different amounts of molasses depending on the industrial processes; this standard variable influence sensory features and technological behavior [47].

The molasses contributes to the very soft texture and drying consistency of the sugar, while also standing against the crystalline formation and solubility of this sugar [46]. Granule size distributions of brown sugar range from fine to moderately coarse, with finer particles dissolving more quickly in liquid applications. The color variation ranges from light golden to deep brown hues depending on the molasses content and processing conditions, with darker sugars having a more pungent flavor [2]. Several studies explain that the hygroscopic nature of brown sugar, induced by the presence of molasses, causes it to absorb moisture and clump during storage [47]. However, this moisture absorption benefits brown sugar by keeping baked goods fresh and maintaining texture with effective packaging to control adverse effects, including vacuum sealing or moisture-barrier packaging [48]. Several interacting factors influence consumer preferences for brown sugar, but sensory traits are much significantly noted [49]. Visual appearance, namely color intensity, can be a cue for consumers and is generally related to taste expectation and perception of naturalness. Regional and cultural preferences influence patterns even more, with some markets appearing to favor specific color palettes or textures according to traditional usage. Brown sugar's profile has been raised in the marketplaces as a result of rising consumer demand for natural and minimally processed foods [50; 51].This trend mirrors a more health-conscious tendency where brown sugar is generally considered a natural alternative to the highly refined white sugar, even if it has the same number of calories as other forms of sugar. Usually, emphasizing this natural association, along with sustainability objectives and marketing campaigns.

2.3 Geographic, Seasonal, and Processing-Related Variations

Crude brown sugar composition and quality show high variability which depends on environmental, agronomic and technological factors [51].

regarding moisture, minerals, phenolics, and antioxidants [56, 57].

The physicochemical characteristics of the process are determined by geographic location, seasonal variations, and processing conditions and are also influenced by storage and packaging practices. Differences in minerals and sugar composition of sugarcane grown in different regions are dependent on the soil type, climate, and sugarcane cultivars diversity. The seasonal factors, especially the time of harvest are significant to influence the sugar quality because changes in temperature and precipitation influence the maturity of sugarcane and consequently the produced chemical properties. There are also some differences between conventional and refined brown sugar, and empty differences in sulfur dioxide content and other chemical properties [11]. The lack of standard processing guidelines causes quality inconsistencies, which are a challenge to artisanal and small-scale producers. Also the sugarcane variety, pH and cooking temperature are also parameters that have a great impact on the end product. Maillard reaction products and flavour components change in storage processes and, therefore, modify the sensory and chemical characteristics of the sugar [39]. Storage and packaging is important in the physicochemical stability of brown sugar. The long storage may lead to darkening, higher moisture level, and higher water activity (52, 53]. Literature shows that vacuum packaging with freezing is most appropriate in the preservation of colour, texture and dissolution rate of powdered food as compared to natural storage (54, 55].

Maillard reaction throughout storage aids in the loss of reducing sugars like fructose and glucose [52]. Frozen vacuum storage proves to be the one with the highest preservation efficiency, which is demonstrated among other storage conditions, which are frozen, vacuum, natural, and constant humidity [52, 53]. In addition to the storage conditions, regional and processing difference affects the nutritional and physicochemical composition of unrefined cane sugar, in particular

Table 1. Comparative physicochemical parameters of CBS from different regions/sources.

Source / Region & Type	Moisture / $a_{t(W)}$	Sugar Composition	Ash / Minerals	pH / Acidity	Color / Other Observations	Phenolics / Antioxidants
Brazil – Artisanal Rapadura [58]	—	Sucrose 13–44 % lower due to inversion	K highest, then Ca, Mg; levels vary widely.	pH below (5.9)	—	—

Latin America – Panela Standards (Colombia) [59]	Moisture up to 9 %	Sucrose 73–83 %	Ash 0.8–1.9 %	Reduc. sugars 5.5–12 %	Color (%T at 550 nm) transmittance 30–85 %	—
Global – NCS Overview [60]	—	Carbohydrates >90 %, sucrose ~80 %	Minerals up to ~3 % (Ca, K, Mg, Fe, Zn, Cu, Cr.	—	—	—
Non-Centrifugal Cane Sugar (NCS/Panea [45]	—	—	—	pH & °Brix measured in beverages; color varied by heating	Heating increases color intensity	—
Cultured NCS (sugars): Granule vs. Spray-dried [42]	—	Sucrose ~91.9–95.5 %; glucose 2.9–4.6 %; fructose 1.6–3.7 %	—	—	Granulated darker; spray-dried lighter	Total phenolics 0.4–0.6 %, flavonoids 0.2–0.4 %
International Study – Refined vs. Unrefined Sugars [59,61]	—	—	Ash content higher in unrefined types	pH range 4.68–6.91	Color, turbidity, soluble solids assessed	Unrefined had elevated antioxidants, minerals, phenolics
NCS Storage Impact Study [39]	Moisture and water activity increased over 1 year	Fructose and glucose decreased; sucrose stable	—	—	Darker color developed; browned via Maillard products	—
Nutritional Review of NCS Globally [41]	—	—	Notes broad presence of minerals and vitamins	—	—	Antioxidant activity attributed to phenolics and flavonoids

3. ANALYTICAL METHODS FOR PHYSICOCHEMICAL CHARACTERIZATION

3.1 Moisture Content Determination

A critical determinant of brown sugar's quality, microbiological stability, and shelf life is its moisture content [52]. Accurate determination of moisture content is therefore essential for quality control, as excessive moisture can accelerate microbial growth, induce caking, and reduce shelf stability. Several analytical methods are available for moisture determination in brown sugar. The oven-drying method is a simple and widely used technique, involving the drying of a known mass of brown sugar at a fixed temperature (105 °C) until a constant weight is achieved [62; 63]. Moisture content is calculated from the difference between the initial and final weights. However, this method may yield inaccurate results when the sample contains volatile compounds, as these can evaporate with water during heating. For higher accuracy, particularly in samples with low water content or those rich in volatile compounds, the Karl Fischer titration method is preferred [64, 65]. This technique is based on a specific chemical reaction between water and the Karl Fischer reagent a mixture of iodine, sulfur dioxide, pyridine, and methanol. The volume or coulombic charge of reagent consumed is stoichiometrically proportional to the water content in the sample. Karl Fischer titration can be conducted via volumetric or coulometric approaches,

with the latter being more suitable for detecting extremely low moisture levels.

3.2 Impact on Microbial Stability and Shelf-Life

Moisture content plays a decisive role in the microbial stability and shelf life of brown sugar. Elevated humidity levels promote the growth of microorganisms, yeasts, and molds, as water is essential for microbial metabolic processes [66; 67]. In particular, high water activity (aw) provides a favorable environment for microbial proliferation, accelerating spoilage. Excess humidity can cause brown sugar to become sticky and soft, creating conditions conducive to microbial colonization [66]. Such contamination can lead to fermentation, discoloration, and the development of undesirable odors and flavors, ultimately rendering the product unsuitable for human consumption [52; 66]. Maintaining low moisture levels is therefore critical for extending the product's shelf life with effective storage practices such as cold, dry environments, vacuum packaging, and frozen storage help to limit moisture absorption and suppress microbial deterioration. Comparative studies have shown that vacuum packaging and frozen storage markedly reduce changes in moisture content, color, hardness, and dissolution rate when compared to natural storage [68; 69]. Water activity (aw) measures the amount of unbound water available for microbial growth and chemical reactions. Brown sugar and refined brown granulated sugar typically have aw values below 0.7, a level at which the growth of most spoilage microorganisms is inhibited [70; 71]. Nevertheless, maintaining low aw is essential to prevent the proliferation of xerophilic molds and osmophilic yeasts, which can survive in low-moisture environments.

3.2 Ash and Mineral Content

3.2.1 Significance of Total Ash and Minerals

The ash content of brown sugar represents the total mineral residue remaining after the organic matter has been completely incinerated [11]. The mineral composition of brown sugar is largely determined by factors such as the sugarcane variety, soil chemistry, and manufacturing processes employed during production [35]. From a nutritional perspective, minerals present in brown sugar such as calcium, magnesium, potassium, iron, and zinc play essential roles in various physiological functions, including bone health, enzymatic activity, electrolyte balance, oxygen transport, and immune function [10; 72]. Table 2 presents the key minerals commonly found in brown sugar, alongside their physiological functions and relevant literature references.

Table 2. Functional Roles of Common Nutritionally Important Minerals [73].

Mineral	Physiological Role
Calcium (Ca)	Important for bone health, muscle function, and nerve transmission
Magnesium (Mg)	Involved in energy production, muscle relaxation, and nerve function
Potassium (K)	Crucial for maintaining fluid balance, nerve function, and muscle contractions
Iron (Fe)	Essential for oxygen transport in the blood and energy production
Zinc (Zn)	Plays a role in immune function, wound healing, and cell growth

3.2.2. Instrumentation for Analysis

Several analytical techniques are available for determining the ash and mineral content of brown sugar. The selection of a suitable method depends on factors such as the specific elements of interest, the required sensitivity, and the available instrumentation.

(i) Atomic Absorption Spectroscopy (AAS): This technique measures the concentration of specific elements by atomizing the sample and passing light of a defined wavelength through the atomic vapor. The extent of light absorption is directly proportional to the concentration of the target element [74].

(ii) Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES): In this method, the sample is introduced into an inductively coupled plasma, where atoms are excited to higher energy states. As they return to their ground state, they emit light at characteristic wavelengths, with emission intensity correlating to elemental concentration [75; 76].

(iii) Machine Learning and Digital Image Processing: A novel, environmentally friendly approach has been developed for mineral analysis in brown sugar. This method enables the simultaneous assessment of sucrose, reducing sugars, minerals, and ICUMSA color, offering a rapid and accurate quality control solution without the need for chemical reage nts [77].

3.3 pH and Acidity

The pH of crude brown sugar is a key indicator of its microbial susceptibility and freshness. Both acidity and pH are critical parameters influencing the overall quality and sta bility of brown sugar. In both conventional brown sugar and refined brown granulated sugar, pH values are generally low reported as less than 0.7 indicating minimal variation between the two product types [78]. In stored cane brown sugar, increases in moisture content and water activity can lead to changes in pH, which in turn may enhance microbial growth potential [79].

Therefore, regular monitoring of these parameters is essential for assessing product quality and predicting shelflife. Implementing effective storage strategies, such as frozen storage or vacuum packaging, can minimize changes in pH and acidity, along with other physicochemical properties, thereby maintaining product stability and quality [80; 81]. These methods help control factors that could otherwise trigger undesirable pH shifts and acidity fluctuations during storage.

sucrose and reducing sugar levels during processing and storage.

3.4 Sucrose and Reducing Sugars

The sweetness and caloric value of brown sugar primarily originate from sucrose, a non reducing disaccharide [9; 77]. Reducing sugars such as glucose and fructose also contribute to sweetness but increase the risk of fermentation during storage [82; 83]. The Maillard reaction, a non enzymatic browning process, consumes reducing sugars, altering sugar composition, flavor, and color [52]. Since elevated reducing sugar levels promote moisture absorption and microbial growth, the sucrose-to-reducing sugar balance is critical for shelf stability [84]. Storage strategies such as freezing and vacuum packaging minimize changes in sugar composition, moisture, and physicochemical quality [85; 86]. Moisture and water activity shifts also influence pH, affecting microbial susceptibility [87]. Analytical techniques include polarimetry for sucrose quantification [88], Fehling's titration for reducing sugars [89], and HPLC for precise sugar profiling [90].

Machine learning and digital imaging further enable rapid, eco-friendly quality assessment [91]. Processing parameters, such as boiling temperature and stirring speed, affect sugar p rofile, moisture, and color, while mineral composition varying between organic and conventional systems enhances nutritional value [92].

Cane brown sugar produced by evaporating juice without refining retains original constituents [93]. However, degradation during storage, linked to moisture fluctuations, sugar loss, and polarization changes, compromises firmness and crystalline structure [94] . Thus, maintaining sweetness, stability, and quality requires strict control of

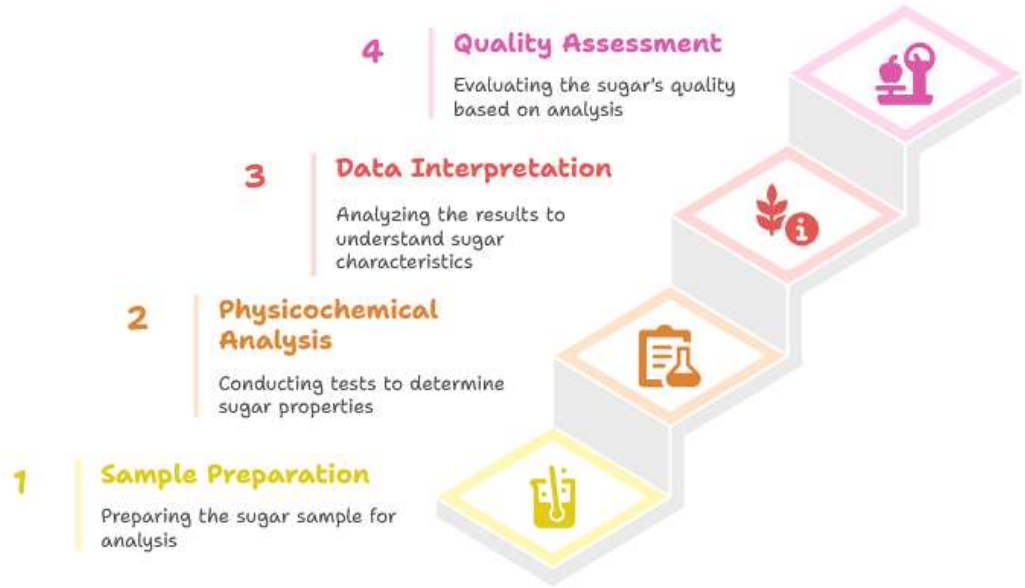

Figure 4. Flowchart of standard physicochemical analysis protocols for Crude Brown Sugar.

4. QUALITY INDICATORS OF CRUDE BROWN SUGAR

4.1 Standards and Regulatory Limits

The quality of crude brown sugar is regulated by various national and international standards established by food safety agencies. These regulatory frameworks are designed to ensure product uniformity and consumer safety. Several key organisations set guidelines for brown sugar and other food products.

(i) *Codex Alimentarius*:
A collection of internationally recognized standards, codes of practice, guidelines, and recommendations concerning food production, processing, and safety are maintained by the Codex Alimentarius Commission, jointly established by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) [95; 96]. While Codex standards are not legally binding in most countries, they serve as benchmarks for national food regulations.

(ii) *National Agency for Food and Drug Administration and Control (NAFDAC)*:
In Nigeria, NAFDAC regulates the manufacture, importation, exportation, advertisement, distribution, sale, and use of food, pharmaceuticals, cosmetics, medical devices, chemicals, and packaged water. It enforces specific quality and safety requirements before products can enter the market [97; 98].

(iii) *U.S. Food and Drug Administration (FDA):*
In the United States, the FDA is responsible for protecting and promoting public health through food safety regulation and monitoring.
It sets and enforces standards to ensure that food products, including sugar, are safe for consumption and properly labeled [99; 100]. The marketability, safety, and stability of brown sugar depend heavily on its physicochemical properties, which also influence sensory attributes such as flavour, colour, and texture. These factors directly affect its shelf life and resistance to microbial spoilage. Table 3 and 4 summarise the key physicochemical parameters like water activity, colour, pH, sucrose content, reducing sugars, ash content, moisture content, and bulk density along with their significance, typical ranges or values, and relevant literature references. These indicators are widelyrecognised as critical quality markers in both conventional and processed brown sugars.

Table 3. Physicochemical Properties of Brown Sugar and Their Quality Implications [52; 77; 101]

Parameter	Description / Significance	Typical Values or Notes
Water Activity	Measures unbound water available for microbial growth and chemical reactions; low aw (<0.7) inhibits microbial growth and prolongs shelf life	Traditional and refined brown sugars: aw < 0.7
Color	Key quality attribute; measured via L* (lightness), a* (redness), b* (yellowness)	Varies between traditional and refined types
pH	Influences overall quality; pH of palm sugar can be adjusted during production	Affects final product quality
Sucrose Content	Main sugar, provides sweetness and energy; critical for quality	Major constituent of brown sugar
Reducing Sugars	Includes glucose and fructose; affects fermentation and browning during storage	Higher levels can lead to browning and spoilage
Ash Content	Indicates total mineral content; varies with sugarcane product type	Higher in less refined sugars
Moisture Content	Affects texture, stability, and shelf life; high moisture promotes microbial growth and clumping	Should be kept low for stability
Bulk Density	Physical property affecting handling and packaging	Varies with processing and granule size

Table 4. Physicochemical Parameters, Standards, and Implications for Brown Sugar Quality [35; 77; 102]

Parameter	Standard / Typical Range	Significance for Quality	Risks of Deviation / Non-Compliance
Water Activity (aw)	< 0.7	Inhibits microbial growth and prolongs shelf life	aw > 0.7 promotes microbial spoilage, reducing shelf life
Color	Within acceptable L* (lightness), a* (redness), b* (yellowness) ranges	Key quality attribute; indicates processing consistency	Deviations suggest poor processing/storage; reduces consumer appeal
pH	Product-specific optimum	Influences taste, stability, and sugar crystallization	Incorrect pH affects sensory quality and texture

Sucrose Content	Meets or exceeds minimum standard	Provides sweetness, energy value, and purity indicator	Low levels suggest adulteration or poor processing
Reducing Sugars	Controlled within acceptable levels	Influence browning, flavor, and fermentation potential	High levels cause excessive browning and spoilage
Ash Content	Within defined purity limits	Reflects mineral content and processing quality	Excessive ash affects taste and signals contamination
Moisture Content	Below standard limit for stability	Prevents clumping, microbial growth, and texture loss	High moisture shortens shelf life, promotes spoilage
Bulk Density	Product-specific range	Affects handling, packaging, and shipping	Poor bulk density complicates storage and reduces marketability

4.2 Shelf Life and Microbial Safety

The storage conditions and physicochemical ch aracteristics of crude brown sugar greatly affect its microbial safety and shelf life. While improper stor age and processing can worsen these problems, leading to spoilage and possible health risks factors including moisture content and pH are crucial in influencing microbial development [52].

4.2.1 Physicochemical Determinants of Microbial Growth

High water activity and moisture level in brown sugar encourage microbial development, therefore lowering its shelf life [52]. Microorganisms need water to flourish; Water activity assesses how much unbound water is accessible for microbial metabolism [35]. A water activity of above 0.7 may support the growth of many spoilage bacteria [35]. Minimally refined brown sugar often has lower moisture content than refined and normal brown sugars, therefore aiding in better shelf life stability [35].

Vacuum packaging and frozen storage are effective in min imising moisture fluctuations throughout storage, therefore limiting microbial development.

Brown sugar's pH affects the growth of several kinds of microbes [77] . While fungi may endure more acidic conditio ns, most bacteria like a neutral to lightly alkaline environment [77]. The pH adjustsment during the production process can influence brown sugar's final quality and microbial stability [77]. Maintaining an appropriate pH level is essential to stop the propagation of unwanted microbes [77]. The high sugar concentration in brown sugar establishes an osmotic en vironment that can restrict some microbes but favour others [77]. Though fructose and glucose contribute to the flavour, some microorganisms may utilise them as a food source [52]. The balance between water activity and sugar content is crucial in defining the total microbial stability [77] .

4.2.2 Effects of Improper Storage and Processing

The inappropriate storage conditions especially high humidity and temperature can severely affect the shelf life and microbiological safety of brown sugar. Extra moisture increases the moisture levels and hence contributes to microbial growth and decay [55]. Similarly, variations in temperature accelerate both Maillard and other degradation reactions, reducing the overall quality of the product [52].

According to empirical evidence, frozen storage and vacuum packaging can maintain the quality of brown sugar by stabilizing moisture levels, color, and any other physicochemical characteristics [55; 69; 103].

Processing techniques also affect the load of microbes, as well as, shelf stability. Poor purification or poor sanitation during the manufacturing process may cause microorganisms to be added to the final product [104]. On the same note, parameters altering the cooking temperature and the rate of stirring during evaporation influence the physicochemical and microbial properties of sugar [105]. The packaging material selection plays a key role in preserving the product; porous materials will allow the introduction of moisture that will help the microbes to develop, and the airtight packaging will block the influx of moisture and maintain the product fresh [55]. The latter has specifically noted vacuum packaging to be extremely effective in increasing shelf life through reducing exposure to oxygen and moisture [55].

Regulation of the most important physicochemical parameters and proper storage and hygienic processing are the necessary factors to maintain both shelf stability and microbiological safety [52]. The quality, safety, and nutritional value of brown sugar are also protected by maintaining the best environmental conditions, food safety standards, and using optimal packaging.

5. CONTAMINANTS AND HEALTH RISKS ASSOCIATED WITH CBS

5.1 Heavy Metals and Impurities

Heavy metal contamination in crude brown sugar poses potential health risks, with the severity depending on both contamination levels and consumption patterns.

The presence of toxic metals such as lead (Pb), cadmium (Cd), and arsenic (As) can be attributed to multiple sources, including contaminated soil and irrigation water, processing machinery, and packaging materials [34; 106].

These heavy metals are among the most hazardous contaminants, as they can bioaccumulate in the human body overtime, leading to a range of chronic health issues, includi ng neurological, renal, and carcinogenic effects [34].

In addition to heavy metals, crude brown sugar may also contain non-metallic contaminants such as organic matter, soil particles, and residues from processing agents [35]. While these impurities may not pose immediate toxicological hazard s, they can negatively impact the product's appearance, texture

and overall quality [35].

Table 5. Heavy Metal Contaminants in Brown Sugar, Sources, and Health Implications [34]

Contaminant	Potential Sources	Health Risks
Lead (Pb)	Contaminated soil, water, or processing equipment	Damages nervous system, kidneys, and immune system; harmful even at low levels, especially for children and pregnant women
Cadmium (Cd)	Soil uptake during sugarcane growth; contaminated processing equipment	Causes kidney damage, bone problems, and increases cancer risk
Arsenic (As)	Irrigation water, soil, and certain pesticides	Carcinogenic; linked to skin lesions, cardiovascular disease, and neurological issues

5.1.1 Sources of Contamination

Heavy metal contamination in crude brown sugar can originate from multiple stages of production, beginning with the cultivation of sugarcane. Soil pollution often linked to industrial activities, mining operations, and the use of contaminated irrigation water can introduce elevated levels of metals such as lead, cadmium, and arsenic into the crop [107]. Since sugarcane plants readily absorb these metals from the soil, they may be transferred to the final sugar prod uct [107]. Water sources used for irrigation and processing are another critical pathway. Industrial effluents, agricultural runoff, and polluted groundwater can all contain heavy metals and other hazardous substances, which, if used in sugarcane farming or manufacturing, can directly contaminate the end product [34]. Processing equipment including mills, evaporators, and crystallizers can also contribute to contamination, particularly if constructed from materials co ntaining heavy metals or if poorly maintained and cleaned [34]. Additionally, packaging materials may introduce pollutants through leaching, especially when non-food-grade materials or packaging containing heavy metals are used [34]. Mitigating these risks requires implementing preventive measures at every production stage, from soil and water quality control to equipment maintenance and the use of certified food-grade packaging materials [34; 107].

Table 6. Preventive Measures for Minimizing Heavy Metal Contamination in Brown Sugar Production [34]

Preventive Measure	Description / Implementation
Soil Testing	Test sugarcane field soil periodically for heavy metals and other pollutants; fix contaminated soil before planting.
Water Treatment	For irrigation and processing, use clean, uncontaminated water; treat water if necessary, to get rid of heavy metals and impurities.
Equipment Maintenance	Regularly clean and maintain foodgrade equipment; examine for corrosion or damage that could cause pollution.
Packaging Standards	Make sure foodgrade packaging materials devoid of heavy metals and hazardous chemicals are employed; appropriate sealing prevents storage and transportation contamination
Monitoring and Testing	Monitor and test brown sugar on a regular basis for heavy metals and pollutants; apply quality control to guarantee compliance with safety guidelines.

5.2 Microbial Contamination and Toxicity

The moisture content in crude brown sugar is particularly high and makes it highly prone to microbiological contamination especially in presence of fungi and bacteria that may lead to spoilage and production of mycotoxins that are toxic to humans [78]. Contamination may occur anywhere in the supply chain such as harvesting to storage with moisture serving as the main contributor to microbial growth. Poor storage facilities like high moisture levels, high temperature, and poor ventilation, even accelerate more the growth of microbes [78].

Strong preventive measures such as good ventilation, effective control of temperatures and use of sanitized processing equipment are, therefore, essential in order to avoid the risk of contamination. In addition, the risk of microbes is intensified by lapses in hygiene throughout processing, with the inherent quality of raw materials having an equally strong effect. Sugarcane that is broken or contaminated by soil offers a good location where the microbes can be established [108].

Fungal contamination, in particular, molds and yeasts, also affects the integrity of products due to their capacity to

metabolize the available carbohydrates in brown sugar, thus influencing the change of color, texture, and flavor in an undesirable manner. Some molds produce mycotoxins, which are detrimental secondary metabolites and are highly hazardous to health [109]. The ingestion of the brown sugar that is contaminated with mycotoxins has been reported to increase hepatic injury as well as immune suppression, renal dysfunction, and the risk of cancer, especially hepatocellular carcinoma; prolonged exposure worsens the negative effects (110; 111].

The presence of bacteria also endangers the quality of sugar via fermentation actions that produce undesirable byproducts, bad smells, and volatile substances [112]. Moreover, biologically active bacteria found in the contaminated sugar can cause foodborne diseases in the form of nausea, vomiting, diarrhea, and abdominal pain [113]. In some cases, microbial contaminants in the product might trigger allergic reactions in consumers with serious effects such as mild dermatological irritation to allergic anaphylaxis [113].

5.2.1 Mitigation Strategies

Minimizing microbial contamination in crude brown sugar r equires the implementation of effective preventive strategies. Reducing moisture content is critical, as lower water activity inhibits bacterial and fungal growth. This can be achieved through appropriate drying
techniques and the use of moisture-resistant, food-grade packaging. Storage under cool, dry, and well-ventilated conditions is essential, with continuous monitoring of temperature and humidity to prevent microbial proliferation [78]. Strict sanitation protocols during processing further reduce the risk of contamination. All equipment should be regularly cleaned and sanitized to prevent microbial ingress. Routine quality control, including microbiological and mycotoxin testing, ensures product safety and compliance with food safety standards.

5.3 Adulteration Practices

Food adulteration is a major risk to the safety and genuineness of crude brown sugar [114; 115]. The most popular include the use of artificial colorants and non-approved sweetening options to improve the outlook, taste, or to reduce the production cost [114]. The use of colorants (both natural caramels and synthetic dyes) is often aimed at covering up poor quality ingredients or to imitate the best products [77]. However, synthetic dyes are critically dangerous to health, such as hypersensitivity reactions, organ-toxicity, and possible carcinogenicity [115; 116]. Similarly, illegal use of unapproved sweeteners, including aspartame, saccharin, and sucralose, is also being practised to enhance the sweetness, in violation of regulatory thresholds and creating safety concerns [117; 118; 119; 120]. Such adulteration activities do not only pose a threat to the health of the consumer, but also distort the market information concerning the real quality and nutritional content of crude brown sugar.

5.3.1 Impact on Safety and Authenticity

Adulteration of raw brown sugar with the use of artificial colorants and unapproved sweeteners is extremely harmful to the health of consumers and reduces the authenticity of the product [93; 114]. Inclusion of such additives may induce harmful substances in the food supply, and artificial dyes vary in studies of animal's hyperactivity in children, allergic reactions, as well as carcinogenicity [121]. Similarly, overuse of some artificial sweeteners has been associated with metabolic disorders, gut microbiome disproportion and other unfavorable health effects [122; 123]. In addition to the health effects, adulteration is misleading to consumers since it changes the natural color and flavor of the product that is traditionally obtained via sugarcane molasses [114]. This type of practices distorts the quality of goods, betrays consumers and destroys the confidence of people in the food industry, thus, ultimately, damaging their reputation in the long term.

5.3.2 Detection and Prevention

To accomplish the protection of safety and product integrity of crude brown sugar, it is important to apply sophisticated methods of analysis to identify adulteration (63; 124; 125]. Near-infrared (NIR), Raman, and fluorescence spectroscopy are spectroscopic modalities that are extremely effective in explaining the chemical composition as well as in the identification of adulterants [126; 127]. Other current developments include artificial-intelligence image classification and deep-learning algorithm to examine microscopically the sugar-crystal morphology, and thus disclose the adulteration hidden adulteration markers [126].

Further adulterant identification with high analytical accuracy occurs with chromatographic techniques, such as gas chromatography-mass spectrometry (GC-MS) or high-performance liquid chromatography (HPLC) [128].

The prevention of adulteration requires the implementation of a powerful quality-control system throughout the production and supply chain. Integrity can be maintained through routine inspection of raw materials and finished products, strict product labeling, and full product traceability [93; 114]. Consumer vigilance is also an important element since timely reporting of suspected adulteration can enhance regulatory deterrence. In the majority of countries that manage safety laws, food adulteration becomes a violation of these laws, and world regulatory authorities like the U.S. Food and Drug Administration (FDA) or European Food Safety Authority (EFSA) apply authenticity criteria, and violators are prosecuted [129; 130].

5.3.3. Heavy Metal Contamination in Crude Brown Sugar

Excessive levels of metal contaminations in sugar products, have been described in a number of regions with different levels of the exceedance of the national and international MPLs. This is usually due to environmental factors like

contaminated farm irrigations, soil geochemistries and as well as airborne particulate.

These also include deposition processes or contamination due to processing, such as the use of contaminated equipment, container or even product packaging [106; 131].

The most common polluting metal to be detected in the water are lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg) and chromium (Cr). The metals are connected to serious public health issues, such as neurodevelopmental deficits and kidney toxicity to carcinogens of various types at higher concentrations [132]. Table 7 contains a comparative summary of the effects and presence of contaminants found in recent studies on sugar and sugarcane derivatives that include contaminant concentrations, geographic distribution, and health risk.

Table 7. Reported levels of contaminants and health concerns in CBS samples from literature.

Study	Country	Contaminant (reported concentration, mg·kg⁻¹)	Key health concerns / remarks
Alcívar et al., Agriculture 2024 — survey of sugarcane & derivatives (panela, white, brown sugar). [133]	Ecuador — commercial brands of panela, white & brown sugar	Pb (brown sugar, brand M1): 0.30 ± 0.08 mg·kg⁻¹; Pb (panela): 2.3 ± 1.04 mg·kg⁻¹; Pb (white sugar): 1.6 ± 0.74 mg·kg⁻¹. Cd: <0.035 mg·kg⁻¹ in derivatives (below LOD).	Lead exceeded some national/international MPLs in panela & white sugar; brown sugar was below some standards but exceeded the Mercosur limit authors flagged neurodevelopmental and cardiovascular risks (children especially) and called the levels a consumer health risk.
Dos Santos, Quináia & Felsner, Food Chemistry 2018 — GF-AAS direct analysis of brown sugar. [134]	Brazil (method paper; commercial brown sugar samples)	Cr: <0.0328 – 0.160 mg·kg⁻¹ (reported 32.8–160 ng·g⁻¹ → 0.0328–0.160 mg·kg⁻¹). Pb: <0.0493 – 0.211 mg·kg⁻¹. Cd: <0.0045 – 0.0070 mg·kg⁻¹.	Metal levels were attributed to anthropogenic sources and production/processing practices. Authors emphasise the need for routine monitoring (Pb/Cd/Cr) because of neurotoxicity (Pb), renal toxicity (Cd) and carcinogenicity (Cr VI species if present).
Babeker et al. / Sudanese sugar industry survey (Directive Publications raw sugar, 2017 season). [135]	Sudan — raw/industrial sugar samples	Pb (mean): 6.74 mg·kg⁻¹; Cd (mean): 0.62 mg·kg⁻¹; As (mean): 2.73 mg·kg⁻¹; Hg: 0.005–0.10 mg·kg⁻¹ in some samples (most samples <LOD).	Reported Pb and As values in some factories were high (Pb ≫ Codex MPL for many sugars). Authors recommended QA labs and corrective measures. High Pb/As exposures → neurodevelopmental effects, nephrotoxicity, carcinogenic and cardiovascular risks.
Wang *et al*. (SSRN working paper) — four types of commercial sugars (including brown sugar). [136]	China — commercial sugars	Authors report a pattern where As was the principal toxicant in brown sugar (statistical correlation with Cd noted); individual concentration table in paper (see original). Overall THQ/HI in the sampled sugars were reported < 1 (no immediate carcinogenic risk in that dataset).	Authors highlight that inorganic arsenic can be the dominant toxic element in brown sugar (As is of greatest long-term concern: carcinogenicity, skin lesions, cardiovascular disease, diabetes). They recommend element-specific monitoring.
INIS / IAEA survey (neutron activation analysis) — inorganic elements in sugar samples (crystal/refined and brown sugar). [137]	Brazil / multi-country samples (technical report)	Brown sugar samples were found to contain As, Ca, Co, Cr, Cs, Fe, K, Na, Sb, Sc, Sm, Sr, Th, Zn (presence/identity reported; concentrations vary by sample). Precise concentrations per element in the report.	Presence of multiple inorganic elements indicates uptake/contamination during cultivation/processing. Policy implication: screen for both essential and toxic trace elements; risk depends on concentration and speciation (e.g., inorganic As >> organic As in toxicity).

6. CHALLENGES AND FUTURE DIRECTIONS

6.1 Emerging Analytical Techniques for Better Detection and Quality Monitoring

Traditional methods for detecting contaminants and assessing crude brown sugar quality are often time-consuming, labour-intensive, and costly [134]. Recent advances in analytical technology offer faster, more accurate, and cost-effective alternatives for quality monitoring [134]. Key emerging techniques include:

(i) *Metal–Organic Framework (MOF)-Derived Porous Carbon Materials*
MOF-derived porous carbon materials provide high surface area and tunable pore structures, enabling rapid and highly sensitive detection of
contaminants such as heavy metals, drug
residues, and food additives [138; 139].
(ii) *Spectroscopic Methods*
Infrared spectroscopy and Raman spectroscopy allow rapid, non-destructive analysis of crude brown sugar, e nabling the assessment of chemical composition, purity, and potential adulteration without sample destruction [138] .
(iii) *Biosensors*
Advanced biosensors can be engineered to detect specific microbial pathogens or toxins in crude brown sugar, offering early warning capabilities for potential contamination events and enabling timely interventions [138]. The integration of these emerging techniques into quality control frameworks could significantly improve the safety and authenticity of crude brown sugar in both domestic and international markets

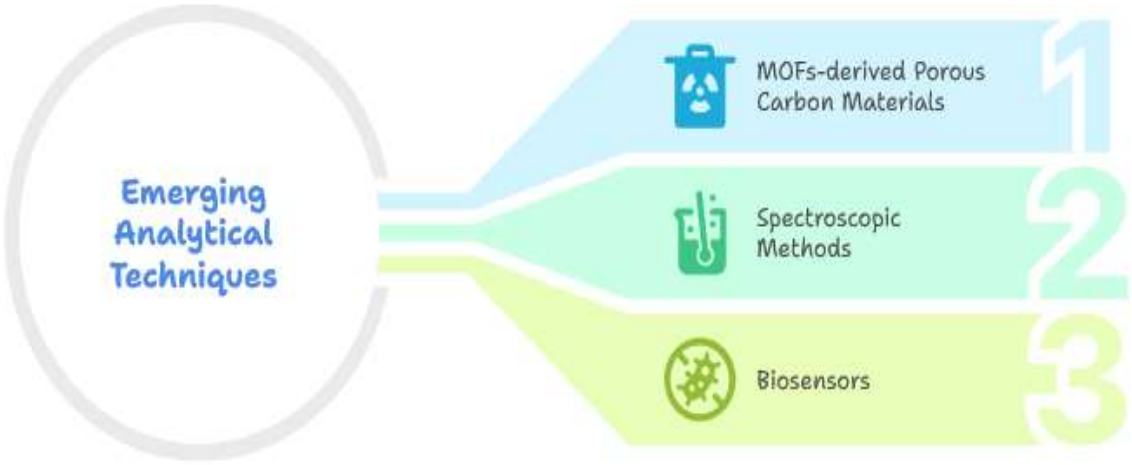

Figure 5. Emerging and future Analytical Techniques for brown sugar

6.2 Future Directions

Future research should prioritise the development and valid ation of advanced analytical techniques specifically tailored for crude brown sugar [138]. Comprehensive studies are required to determine the prevalence and concentration levels of various contaminants across different production regions, alongside evaluations of intervention strategies aimed at reducing contamination [77]. Moreover, the integration of d igital technologies, such as blockchain, could significantly enhance supply chain traceability and transparency, thereby improving consumer confidence and regulatory compliance [139]. Using blockchain, production, processing, and distribution data can be recordee in real-time, giving an unrevisable record that can be used to verify authenticity and safety. Effective progress in this area will require multidisciplinary collaboration between researchers, regula tory authorities, and industry stakeholders to harmonise methodologies, share data, and implement best practices on a global scale [138]. This type of collaboration is crucial to the sourcing of consistent safety and quality of crude brown sugar products in local and foreign markets.

7. CONCLUSION

Physicochemical analysis, which involves the physical and chemical characteristics of crude brown sugar, is important in determining the quality, safety, and authenticity of crude brown sugar. It defines the important parameters like levels of sugar, moisture, and impurities hence allowing the identification of the adulterants, contaminants, and non-conformity to the set standards that may be hazardous to health. Other methods like spectroscopy and chromatography give a clear insight into the composition, source of raw material, processing and storing capability of the sugar. The most important quality issues are adulteration, when refined sugar, corn syrup or other non-food products are introduced to add volume or change the look, and contamination with heavy metals, pesticides or microbes. These contaminants may be soil, water or processing equipment, which may result in toxic exposure or food poisoning. High moisture also encourages the growth, spoilage and toxin production of microbes. Sugar molecules are also destroyed by improper processing and storage that cause low taste, color, and

nutritional value. These problems need to be solved by having strong monitoring and control throughout the supply chain. Nevertheless, the lack of equal standards in certain area allows quality inconsistency and increases the chances of adulteration. By adopting rigorous monitoring, which is by It is necessary to develop harmonised science-based standards of parameters e.g., sugar content and moisture and contaminants levels and to revise them on a regular basis, depending on new risks. It is important to have cooperation among regulatory bodies, industry players and research institutions to have effective monitoring and standardisation of safety and authenticity of crude brown sugar.

carrying out regular samples, testing and inspecting the facilities, one can keep up with the safety regulations. State-of-the-art analytical technologies like spectroscopy and biosensors are fast and cost-efficient in quality screening.

REFERENCES

1. Liu, J., Wan, P., Xie, C., & Chen, D. (2024). Brown sugar aroma: Key aroma-active compounds, formation mechanisms and influencing factors during processing. *Journal of Food Composition and Analysis*. https://doi.org/10.1016/j.jfca.2024.106076.
2. Asikin, Y., Nakaza, Y., Oe, M., Arakaki, E., Maeda, G., Kaneda, H., Takara, K., & Wada, K. (2025). The Effect of Raw Sugar Addition on Flavor and Retronasal Olfaction Profiles of Processed Brown Sugar. *Foods*, 14. https://doi.org/10.3390/foods14091480.
3. Kumar, R., & Kumar, M. (2021). Performance evaluation of improved and traditional two pan jaggery making plants: A comparative study. *Sustainable Energy Technologies and Assessments*, 47, 101462. https://doi.org/10.1016/J.SETA.2021.101462.
4. Tyagi, S., Kamboj, S., H., Tyagi, N., Narayanan, R., & Tyagi, V. (2021). Technological advancements in jaggery-making processes and emission reduction potential via clean combustion for sustainable jaggery production: An overview. *Journal of environmental management*, 301, 113792. https://doi.org/10.1016/j.jenvman.2021.113792
5. Shiralkar, K., Kancharla, S., Shah, N., & Mahajani, S. (2014). Energy improvements in jaggery making process. *Energy for Sustainable Development*, 18, 36-48. https://doi.org/10.1016/J.ESD.2013.11.001.
6. Jaffé, W. (2015). Nutritional and functional components of non-centrifugal cane sugar: A compilation of the data from the analytical literature. *Journal of Food Composition and Analysis*, 43, 194-202. https://doi.org/10.1016/J.JFCA.2015.06.007.
7. Asghar, M., Yusof, Y., Mokhtar, M., Yaacob, M., Ghazali, H., Varith, J., Chang, L., & Manaf, Y. (2020). Processing of Coconut Sap into Sugar Syrup using Rotary Evaporation, Microwave and Open-Heat Evaporation Techniques. *Journal of the science of food and agriculture*. https://doi.org/10.1002/jsfa.10446.
8. Tao, Y., Yan, B., Zhang, N., Wang, M., Zhao, J., Zhang, H., Chen, W., & Fan, D. (2021). Microwave vacuum evaporation as a potential technology to concentrate sugar solutions: A study based on dielectric spectroscopy. *Journal of Food Engineering*, 294, 110414. https://doi.org/10.1016/j.jfoodeng.2020.110414.
9. Yang, L., Shen, S., Wang, Z., Yang, T., Guo, J., Hu, R., Li, Y., Burner, D., & Ying, X. (2020). New Value-Added Sugar and Brown Sugar Products from Sugarcane: A Commercial Approach. *Sugar Tech*, 1-5. https://doi.org/10.1007/s12355-020-00811-4
10. Suárez, N., Abreu, R., Reis, L., Curi, P., Schiassi, M., Souza, V., & Pio, R. (2020). Consumer profile: blackberry processing with different types of sugars. *Food Science and Technology International*. https://doi.org/10.1590/fst.23020.
11. Azlan, A., Khoo, H., Sajak, A., Kadir, N., Yusof, B., Mahmood, Z., & Sultana, S. (2020). Antioxidant activity, nutritional and physicochemical characteristics, and toxicity of minimally refined brown sugar and other sugars. *Food Science & Nutrition*, 8, 5048 - 5062. https://doi.org/10.1002/fsn3.1803.
12. Umate, P., Khobragade, P., Thanvi, H., & Zilate, S. (2021). A Review on the Clinical Aspect of Guda (jaggery) in Brihatrayi and laghutrayi. *International journal of current research and review*, 13, 51-63. https://doi.org/10.31782/IJCRR.2021.13718.
13. Yadav, M. (2024). Nutritional and Medicinal Property of Jaggery: An Overview. *Journal of Medical Science and clinical Research*. https://doi.org/10.18535/jmscr/v12i04.04.
14. Hebbar, K., Ramesh, S., Ghosh, D., Beegum, P., Pandiselvam, R., Manikantan, M., & Mathew, A. (2022). Coconut Sugar- a Potential Storehouse of Nutritive Metabolites, Novel Bio-products and Prospects. *Sugar Tech*, 24, 841 - 856. https://doi.org/10.1007/s12355-021-01101-3.
15. Saraiva, A., Carrascosa, C., Ramos, F., Raheem, D., Lopes, M., & Raposo, A. (2023). Coconut Sugar: Chemical Analysis and Nutritional Profile; Health Impacts; Safety and Quality Control; Food Industry Applications. *International Journal of Environmental Research and Public Health*, 20. https://doi.org/10.3390/ijerph20043671
16. Eggleston, G., Aita, G., & Triplett, A. (2021). Circular Sustainability of Sugarcane: Natural, Nutritious, and Functional Unrefined Sweeteners That Meet New Consumer Demands. *Sugar Tech*, 23, 964 - 973. https://doi.org/10.1007/s12355-021-00994-4.
17. Arshad, S., Rehman, T., Saif, S., Rajoka, M., Ranjha, M., Hassoun, A., Cropotova, J., Trif, M., Younas, A., & Aadil, R. (2022). Replacement of refined sugar by natural sweeteners: focus on potential health benefits. *Heliyon*, 8. https://doi.org/10.1016/j.heliyon.2022.e10711.
18. Velásquez, F., Espitia, J., Mendieta, O., Escobar, S., & Rodríguez, J. (2019). Non-centrifugal cane sugar processing: A review on recent advances and the influence of process variables on qualities attributes of final products. *Journal of Food Engineering*. https://doi.org/10.1016/J.JFOODENG.2019.03.009.
19. Hutami, R., Pribadi, M., Nurcahali, F., Septiani, B., Andarwulan, N., Sapanli, K., Zuhud, E., Manar, P., Ichsan, N., & Wahyudi, S. (2023). Proses Produksi Gula Aren Cetak (Arenga pinnata, Merr) Di Indonesia. *Jurnal Ilmiah Pangan Halal*. https://doi.org/10.30997/jiph.v5i2.10237.
20. Kumar, M., Sharma, M., Raut, R., Mangla, S., & Choubey, V. (2022). Performance assessment of circular driven sustainable agri-food supply chain towards achieving sustainable consumption and production. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2022.133698.
21. Van Leeuwen, S., Verschoor, A., Van Der Fels-Klerx, H., Van De Schans, M., & Berendsen, B. (2024). A novel approach to identify critical knowledge gaps for food safety in circular food systems. *NPJ Science of Food*, 8. https://doi.org/10.1038/s41538-024-00265-y.
22. Khamidulina, K., Tarasova, E., Proskurina, A., Nazarenko, A., & Dorofeeva, E. (2025). [Current issues of regulation of contaminants in food]. *Voprosy pitaniia*, 94 1, 50-63. https://doi.org/10.33029/0042-8833-2025-94-1-50-63.
23. Singh, R., & Puniya, A. (2024). Role of Food Safety Regulations in Protecting Public Health. *Indian journal of microbiology*, 64 3, 1376-1378. https://doi.org/10.1007/s12088-024-01240-7.
24. Vergis, J., Pollumahanti, N., Sahu, R., Rawool, D., & Barbuddhe, S. (2025). Ensuring Food Safety: Microbiological Risk Assessment Strategies. *Current Opinion in Food Science*. https://doi.org/10.1016/j.cofs.2025.101272.
25. Kusenberg, M., Eschenbacher, A., Djokic, M., Zayoud, A., Ragaert, K., De Meester, S., & Van Geem, K. (2021). Opportunities and challenges for the application of post-consumer plastic waste pyrolysis oils as steam cracker feedstocks: To decontaminate or not to decontaminate? *Waste Management (New York, N.y.)*, 138, 83 - 115. https://doi.org/10.1016/j.wasman.2021.11.009.
26. Nurzhan, A., Ruan, X., & Chen, D. (2025). A Review of Life Cycle Assessment Application in Municipal Waste Management: Recent

Advances, Limitations, and Solutions. *Sustainability*. https://doi.org/10.3390/su17010302.

27. Ceraso, A., & Cesaro, A. (2024). Life Cycle Sustainability Assessment of municipal solid waste management systems: a review. *Journal of environmental management*, 368, 122143. https://doi.org/10.1016/j.jenvman.2024.122143.
28. De Laurentiis, V., Caldeira, C., Sala, S., & Tonini, D. (2024). Life cycle thinking for the assessment of waste and circular economy policy: status and perspectives from the EU example. *Waste management*, 179, 205-215. https://doi.org/10.1016/j.wasman.2024.02.037.
29. Kearsley, M. (2007). The control of hygroscopicity, browning and fermentation in glucose syrups. *International Journal of Food Science and Technology*, 13, 339-348. https://doi.org/10.1111/J.1365-2621.1978.TB00811.X.
30. Nuumani, R., Vladisavljević, G., Kasprzak, M., & Wolf, B. (2020). In-vitro oral digestion of microfluidically produced monodispersed W/O/W food emulsions loaded with concentrated sucrose solution designed to enhance sweetness perception. *Journal of Food Engineering*. https://doi.org/10.1016/j.jfoodeng.2019.109701.
31. ana, M., Cianciabella, M., Daniele, G., Badiani, A., Rocculi, P., Tappi, S., Gatti, E., Marcazzan, G., Magli, M., Medoro, C., & Predieri, S. (2023). Influence of the Physical State of Two Monofloral Honeys on Sensory Properties and Consumer Satisfaction. *Foods*, 12. https://doi.org/10.3390/foods12050986.
32. Liu, T., VanSaders, B., Keating, J., Glotzer, S., & Solomon, M. (2021). Effect of Particles of Irregular Size on the Microstructure and Structural Color of Self-Assembled Colloidal Crystals. *Langmuir: the ACS journal of surfaces and colloids*. https://doi.org/10.1021/acs.langmuir.1c01898.
33. Alengebawy, A., Abdelkhalek, S., Qureshi, S., & Wang, M. (2021). Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. *Toxics*, 9. https://doi.org/10.3390/toxics9030042.
34. Mekassa, B., Etana, E., & Merga, L. (2024). Proximate analysis, levels of trace heavy metals and associated human health risk assessments of Ethiopian white sugars. *Journal of Agriculture and Food Research*. https://doi.org/10.1016/j.jafr.2024.101086.
35. Sampaio, M., Machado, M., Lisboa, M., Vieira, M., Zimmer, T., Otero, D., & Zambiazi, R. (2022). Physicochemical Characterization and Antioxidant Activity of Refined and Unrefined Sugarcane Products from Southern Brazil. *Sugar Tech*, 25, 295-307. https://doi.org/10.1007/s12355-022-01146-y.
36. Khan, Q., Qin, Y., Guo, D., Yang, L., Song, X., Xing, Y., & Li, Y. (2023). A Review of the Diverse Genes and Molecules Involved in Sucrose Metabolism and Innovative Approaches to Improve Sucrose Content in Sugarcane. *Agronomy*. https://doi.org/10.3390/agronomy13122957.
37. Ramón, M., Francisco, C., María, D., & Diego, M. (2017). Statistical Criteria for Modelling of Water Desorption Isotherms of Sugars. Estimation of Sucrose Hygroscopic Properties from Glucose and Fructose Data. , 1. https://doi.org/10.22606/AFSE.2017.11003.
38. . Shakoor, A., Zhang, C., Xie, J., & Yang, X. (2022). Maillard reaction chemistry in formation of critical intermediates and flavour compounds and their antioxidant properties. *Food chemistry*, 393, 133416. https://doi.org/10.1016/j.foodchem.2022.133416.
39. Chen, P., Cheng, F., Wei, L., Wang, S., Zhang, Z., Hang, F., Li, K., & Xie, C. (2022). Effect of Maillard reaction browning factors on color of membrane clarification non-centrifugal cane sugar during storage. *Food Science and Technology*. https://doi.org/10.1590/fst.43722.
40. Mangwanda, T., Mani, J., Johnson, J., Jackson, S., McKeown, T., & Naiker, M. (2023). Physicochemical and Nutritional Analysis of Molasses for Rum Fermentation. *Foods 2023*. https://doi.org/10.3390/foods2023-15137.
41. Bettani, S., Borges, M., Soares, M., Liska, G., & Rodrigues, C. (2024). Relationship between the mineral content of sugarcane and its genuine derivative, non-centrifugal raw cane sugar. *Food research international*, 192, 114783. https://doi.org/10.1016/j.foodres.2024.114783.
42. Alarcón, Á., Palacios, L., Osorio, C., Narváez, P., Heredia, F., Orjuela, Á., & Hernanz, D. (2020). Chemical characteristics and colorimetric properties of non-centrifugal cane sugar ("panela") obtained via different processing technologies. *Food chemistry*, 340, 128183. https://doi.org/10.1016/j.foodchem.2020.128183.
43. Ibrahim, A., Gad, A., Dardeer, H., & Gaber, A. (2022). Novel green biodegradable clarifying agents in sugar refining process using functionalized chitosan nanocomposites. *Sustainable Materials and Technologies*. https://doi.org/10.1016/j.susmat.2022.e00525.
44. Hammam, T., Zaghlool, M., El-Sherif, S., El-Naggar, E., & Ferweez, H. (2021). Efficacy of Affination on Quality Parameters of White Sugar During Refining Process. *Asian Journal of Applied Chemistry Research*. https://doi.org/10.9734/ajacr/2021/v9i130206.
45. Asikin, Y., Nakaza, Y., Maeda, G., Kaneda, H., Takara, K., & Wada, K. (2023). Evaporation Temperature Alters Physicochemical Characteristics and Volatile Maillard Reaction Products of Non-Centrifugal Cane Sugar (NCS): Comparison of Polyethylene Membrane and Retronasal Aroma Simulator Techniques for the Extraction of Volatile Organic Compounds in NCS. *Applied Sciences*. https://doi.org/10.3390/app13116402.
46. Athaya Milda Putri Yuwana, Desiana Nuriza Putri*, Noor Harini (2002). "Hubungan antara atribut sensori dan kualitas gula merah tebu: pengaruh pH dan kondisi karamelisasi." *Teknologi Pangan: Media Informasi dan Komunikasi Ilmiah Teknologi Pertanian*. https://doi.org/10.35891/tp.v13i1.2767.
47. Amin Farshchi, Meishan Guo, Jabbar Gardy, Xun Zhang, Ali Hassanpour , Majid Naderi (2024). "The Effect of Surface Chemistry on the Caking Behaviour of Sucrose Crystals." *Journal of Food Engineering*. https://doi.org/10.1016/j.jfoodeng.2024.112386
48. Slade, L., Kweon, M., & Levine, H. (2020). Exploration of the functionality of sugars in cake-baking, and effects on cake quality. *Critical Reviews in Food Science and Nutrition*, *61*(2), 283–311. https://doi.org/10.1080/10408398.2020.1729694
49. Jie Liu, Peng Wan, Caifeng Xie, De-Wei Chen (2021). "Key aroma-active compounds in brown sugar and their influence on sweetness." *Food chemistry*, 345: 128826. https://doi.org/10.1016/j.foodchem.2020.128826.
50. Gu, J. (2020). A Study on the Changes of Chinese Food Culture and Trends of Sugar Consumption in Late Qing and Early Republican China. 151-185. https://doi.org/10.24161/chr.124.151.
51. Baka, W., Rianse, U., Widayati, W., Sidu, D., I., Rianse, S., Abdullah, W., Zulfikar, L., Z., Baka, L., Abdi, A., & Cahyono, E. (2016). Analysis of Correlation between Brown Sugar Attributes and the Consumer Preferences. 444 Int. J. Business Innovation and Research, Vol. 11, No. 3
52. Asikin, Y., Kamiya, A., Mizu, M., Takara, K., Tamaki, H., & Wada, K. (2014). Changes in the physicochemical characteristics, including flavour components and Maillard reaction products, of non-centrifugal cane brown sugar during storage. *Food chemistry*, 149, 170-7. https://doi.org/10.1016/j.foodchem.2013.10.089.
53. Hirose, N., Maeda, G., Takara, K., & Wada, K. (2015). Changes in the Physicochemical and Flavor Characteristics of the Okinawan Brown Sugar "Kokuto" during Storage at Ambient Temperature. *Food Preservation Science*. https://doi.org/10.5891/jafps.41.253.
54. How, Y., Teo, M., In, L., Yeo, S., Bhandari, B., & Pui, L. (2023). Powder characteristics, moisture sorption isotherm, and shelf-life prediction of freeze-dried recombinant Lactococcus lactis NZ3900-fermented milk powder. *Drying Technology*, 41, 2501 - 2515. https://doi.org/10.1080/07373937.2023.2255646.
55. Londhe, G., Pal, D., & Raju, P. (2012). Effect of packaging techniques on shelf life of brown peda, a milk-based confection. *Lwt - Food Science and Technology*, 47, 117-125. https://doi.org/10.1016/J.LWT.2011.12.025.
56. Weerawatanakorn, M., Asikin, Y., Kamchonemenukool, S., Tamaki, H., Takara, K., & Wada, K. (2020). Physicochemical, antioxidant, volatile component, and mass spectrometry-based electronic nose analyses differentiated unrefined non-centrifugal cane, palm, and coconut sugars. *Journal of Food Measurement and Characterization*, 15, 1563 - 1577. https://doi.org/10.1007/s11694-020-00749-x.

57. Sia, J., Yee, H., Santos, J., & Abdurrahman, M. (2010). Cyclic voltammetric analysis of antioxidant activity in cane sugars and palm sugars from Southeast Asia. *Food Chemistry*, 118, 840-846. https://doi.org/10.1016/J.FOODCHEM.2009.05.030.
58. Braun, C., Oliveira, A., Pedro, F., Arruda, G., Lima, M., & Villa, R. (2016). Physicochemical, microbiological and microscopic evaluation of artisanal rapaduras produced in Cuiabá, Mato Grosso, Brazil. *Acta Scientiarum-technology*, 38, 407-413. https://doi.org/10.4025/ACTASCITECHNOL.V38I4.28441.
59. Rodríguez, A., Sandoval, E., Lopera, J., Valens, C., Vargas, J., Sánchez, J., Araque, A., & Orozco, G. (2021). Comportamiento agroindustrial de seis variedades de Caña de azúcar (Saccharum spp.) para Panela en Barbosa (Colombia). *Ciencia y Agricultura*, 18, 15-28. https://doi.org/10.19053/01228420.V18.N3.2021.12823.
60. Ayustaningwarno, F., Asikin, Y., Amano, R., Vu, N., Hajar-Azhari, S., Anjani, G., Takara, K., & Wada, K. (2023). Composition of Minerals and Volatile Organic Components of Non-Centrifugal Cane Sugars from Japan and ASEAN Countries. *Foods*, 12. https://doi.org/10.3390/foods12071406.
61. Lee, J., Ramalingam, S., Jo, I., Kwon, Y., Bahuguna, A., Oh, Y., Kwon, O., & Kim, M. (2018). Comparative study of the physicochemical, nutritional, and antioxidant properties of some commercial refined and non-centrifugal sugars. *Food research international*, 109, 614-625. https://doi.org/10.1016/j.foodres.2018.04.047.
62. Carlson, J., Klinger, B., Schueller, J., & Kawlewski, R. (2013). Sugar-end Management implications for the method chosen to measure dry-substance. https://doi.org/10.5274/ASSBT.2013.56.
63. ucat, G., Felsner, M., Quináia, S., & Da Costa Neto, P. (2018). Isothermal Thermogravimetry and Factorial Design Applied to Development and Validation of an Oven Drying Method for Cane Syrups. *Orbital: The Electronic Journal of Chemistry*, 10, 247-253. https://doi.org/10.17807/ORBITAL.V10I3.1114.
64. Isengard, H., & Heinze, P. (2003). Determination of total water and surface water in sugars. *Food Chemistry*, 82, 169-172. https://doi.org/10.1016/S0308-8146(02)00540-X.
65. Kestens, V., Conneely, P., & Bernreuther, A. (2008). Vaporisation coulometric Karl Fischer titration: A perfect tool for water content determination of difficult matrix reference materials. *Food Chemistry*, 106, 1454-1459. https://doi.org/10.1016/J.FOODCHEM.2007.01.079.
66. Wijonarko, G., Purbowati, I., Widjojoko, T., & Maksum, A. (2022). The Influence of Agroclimate, Gandatapa Village, Sumbang Subdistrict on Microbial Profile, Brix Values, and Total Sugar, Naturally Spread Coconut Sap. *Indonesian Journal of Food Technology*. https://doi.org/10.20884/1.ijft.2022.1.2.7226.
67. Lee, K., Kim, J., Chun, J., Heo, H., Park, C., & Choi, S. (2023). Miyeokgui (Undaria pinnatifida Sporophyll) Characteristic under Different Relative Humidity: Microbial Safety, Antioxidant Activity, Ascorbic Acid, Fucoxanthin, α-/β-/γ-Tocopherol Contents. *Foods*, 12. https://doi.org/10.3390/foods12122342.
68. Nisari, M., Başmısırlı, E., Aykemat, Y., Aytekin-Sahin, G., İnanç, N., & Dishan, A. (2024). Effects of home vacuum packaging method at different storage conditions on total antioxidant and phenolic compound levels in berry fruits. *International Journal of Food Engineering*, 21, 51 - 61. https://doi.org/10.1515/ijfe-2024-0091
69. Sospeter, E., Ding, P., Fang, T., Misran, A., & Abas, F. (2025). Long-term frozen storage affects the volatile compound profile, physicochemical and antioxidant content of vacuum-packed Musang King durian fruit. *Journal of food science*, 90 3, e70118. https://doi.org/10.1111/1750-3841.70118.
70. Mizzi, L., Maniscalco, D., Gaspari, S., Chatzitzika, C., Gatt, R., & Valdramidis, V. (2020). Assessing the individual microbial inhibitory capacity of different sugars against pathogens commonly found in food systems. *Letters in applied microbiology*. https://doi.org/10.1111/lam.13306.
71. López-Malo, A., & Alzamora, S. (2015). Water Activity and Microorganism Control: Past and Future. , 245-262. https://doi.org/10.1007/978-1-4939-2578-0_18.
72. Li, P., Cai, W., & Shao, X. (2015). Improved inductively coupled plasma optical emission spectroscopy analysis of trace elements in complex matrices by chemometric resolution. *Journal of Analytical Atomic Spectrometry*, 30, 936-940. https://doi.org/10.1039/c5ja00031a.
73. Saha, S., & Pathak, N. (2021). Mineral Nutrition. *Fundamentals of Animal Nutrition*. https://doi.org/10.1007/978-981-15-9125-9_9.
74. Hina, B., Rizwani, G., Naseeb, U., Huma, A., & Hyder, Z. (2023). Application of Atomic Absorption Spectroscopy to determine Mineral and Heavy Metal distribution level of Medicinal Plants. *Journal of Analytical Techniques and Research*. https://doi.org/10.26502/jatr.38.
75. Wang, T. (2019). Inductively Coupled Plasma Optical Emission Spectrometry. *Ewing's Analytical Instrumentation Handbook, Fourth Edition*. https://doi.org/10.1201/9781315118024-3.
76. Abad-Peña, E., Larrea-Marín, M., Villanueva-Tagle, M., & Pomares-Alfonso, M. (2014). Multielemental inductively coupled plasma optical emission spectrometry analysis of nickeliferous minerals. *Talanta*, 124, 79-88. https://doi.org/10.1016/j.talanta.2014.01.066.
77. Alves, V., Santos, J., Pinto, E., Ferreira, I., Lima, V., & Felsner, M. (2023). Digital image processing combined with machine learning: A new strategy for brown sugar classification. *Microchemical Journal*. https://doi.org/10.1016/j.microc.2023.109604.
78. abriel do Nascimento Santos, Bianca Novaes da Silva, Ícaro Fier, Beatriz Altarugio Galdini1, Isabella Ciarrocchi, Marta Helena Fillet Spoto, Sandra Regina Ceccato-Antonini1, Maria Teresa Mendes Ribeiro, Simone Daniela Sartorio de Medeiros, Marta Regina Verruma-Bernardi (2023). Microbiological, physicochemical and sensory evaluation of different brands of commercial peanut candy "paçoca"." *Revista Brasileira de Tecnologia Agroindustrial* . https://doi.org/10.3895/rbta.v17n2.15576.
79. Dhansu, P., Ram, B., Singh, A., Tomar, S., Karuppaiyan, R., Kumar, R., Chhabra, M., Singh, A., Raja, A., Kaushik, P., & Pandey, S. (2023). Different Treatments for Sugarcane Juice Preservation. *Foods*, 12. https://doi.org/10.3390/foods12020311.
80. Farmani, B., Djordjević, M., Bodbodak, S., Alirezalu, K., & Ghanbarpour, A. (2021). Powdered Activated Carbon Treatment of Sugar Beet Molasses for Liquid Invert Sugar Production: Effects of Storage Time and Temperatures. *Sugar Tech*, 24, 522 - 531. https://doi.org/10.1007/s12355-021-01022-1.
81. Mao, L., Xu, Y., & Que, F. (2007). Maintaining the quality of sugarcane juice with blanching and ascorbic acid. *Food Chemistry*, 104, 740-745. https://doi.org/10.1016/J.FOODCHEM.2006.09.055
82. Zou, Y., Zhong, Y., Huang, L., Xu, W., Wu, Y., Gao, J., Zhong, K., & Gao, H. (2022). Effects of brown sugar addition and fermentation time on metabolites and microbial communities of Yibin Yacai. *LWT*. https://doi.org/10.1016/j.lwt.2022.113720.
83. Ngginak, J., Nge, S., Klau, F., & Bisilissin, C. (2020). Reducing sugar content in siwalan roomie (*borassus flabellifer*) before cooking and liquid brown sugar after cooking., 7, 8-15. https://doi.org/10.31289/biolink.v7i1.2919.
84. Bolshakova, E., Kruchinin, A., Turovskaya, S., Illarionova, E., Yurova, E., Barkovskaya, I., & Galstyan, A. (2024). Effects Provided by Sugar Substitutes upon the Quality Indicators of Model Systems of Sweetened Condensed Milk in Storage. *Journal of dairy science*. https://doi.org/10.3168/jds.2024-25160.
85. Koç Güler, S. (2023). Correlations of color changes encountered throughout storage with polyphenol oxidase enzyme activity, sugar content and total phenolics of hazelnuts. *Erwerbs-Obstbau*, *65*(2), 269–276. https://doi.org/10.1007/s10341-022-00819-y
86. Kaur, G., Kaur, P., & Kaur, A. (2021). Preserving bioactive quality and color of novel frozen lemongrass puree tablets. *Journal of Food Processing and Preservation*, *46*(9). https://doi.org/10.1111/jfpp.16050
87. Ng Cheong, L. R., & Teeluck, M. (2015). The practice of green cane trash blanketing in the irrigated zone of Mauritius: Effects on soil moisture and water use efficiency of sugarcane. *Sugar Tech*, *18*(2),124–133.https://doi.org/10.1007/s12355-015-0374-1
88. Basu, D., & Nguyen, H. B. (2021). Eating healthy: Understanding added sugar through proportional reasoning. *International Journal of*

Environmental Research and Public Health, *18*(23), 12821. https://doi.org/10.3390/ijerph182312821

89. Di Trani, J. M., Moitessier, N., & Mittermaier, A. K. (2017). Measuring rapid time-scale reaction kinetics using isothermal titration calorimetry. *Analytical Chemistry*, *89*(13), 7022–7030. https://doi.org/10.1021/acs.analchem.7b00693
90. Ma, C., Sun, Z., Chen, C., Zhang, L., & Zhu, S. (2014). Simultaneous separation and determination of fructose, sorbitol, glucose and sucrose in fruits by HPLC–ELSD. *Food Chemistry*, *145*, 784–788. https://doi.org/10.1016/j.foodchem.2013.08.135
91. Shaw, R. (2007). A user-friendly digital image processing procedure: Technical implementation. *SPIE Proceedings*, *6493*, 64930V. https://doi.org/10.1117/12.704338
92. Chen, E., Song, H., Zhao, S., Liu, C., Tang, L., & Zhang, Y. (2021). Comparison of odor compounds of brown sugar, muscovado sugar, and brown granulated sugar using GC-O-MS. *LWT*, *142*, 111002. https://doi.org/10.1016/j.lwt.2021.111002
93. en, J., Yen, G., Tsai, N., & Lin, J. (2021). Risk and Benefit of Natural and Commercial Dark Brown Sugars as Evidenced by Phenolic and Maillard Reaction Product Contents. *Journal of agricultural and food chemistry*. https://doi.org/10.1021/acs.jafc.0c04795.
94. Cai, Y., Abla, M., Gao, L., Wu, J., & Yang, L. (2024). Research on Phenolic Content and Its Antioxidant Activities in Fermented Rosa rugosa 'Dianhong' Petals with Brown Sugar. *Antioxidants*, *13*(5), 607. https://doi.org/10.3390/antiox13050607
95. Tritscher, A., Miyagishima, K., Nishida, C., & Branca, F. (2013). Ensuring food safety and nutrition security to protect consumer health: 50 years of the Codex Alimentarius Commission. *Bulletin of the World Health Organization*, 91 7, 468-8A . https://doi.org/10.2471/BLT.13.125518.
96. Karpov, O. (2025). Creation of Codex Alimentarius and its impact on the establishment of international food safety rules. *Uzhhorod National University Herald. Series: Law*. https://doi.org/10.24144/2307-3322.2025.87.4.40
97. Ali, J., Itua, E., Ekeocha, Z., Clase, K., & Byrn, S. (2024). Reducing the Burden of Inspections on Pharmaceutical Manufacturers by Regulatory Authorities in Benin City, Nigeria. *The Proceedings of the BIRS Community*. https://doi.org/10.7771/2836-5666.1002
98. Olugbenga, E. (2013). The Politics of Pharmaceutical Regulation in Nigeria: Policy Options for Third World Countries. *Public Policy and Administration Research*, 3, 89-100.
99. Eaglstein, W. (2014). Foods, Doctors and the FDA. 37-38. https://doi.org/10.1007/978-3-319-08362-9_9.
100. Stewart, K., & Gostin, L. (2011). Food and Drug Administration Regulation of Food Safety. *Agricultural & Natural Resource Economics eJournal*. https://doi.org/10.1001/jama.2011.885.
101. Della Maggiore Orlandi, R., Verruma-Bernardi, M., Sartorio, S., & Borges, M. (2017). Physicochemical and Sensory Quality of Brown Sugar: Variables of Processing Study. *The Journal of Agricultural Science*, 9, 115. https://doi.org/10.5539/JAS.V9N2P115.
102. Dali, N., Chairunnas, A., Amalia, H., & Puspitasari, S. (2024). The Effect of Acidity Level (pH) and Palm Sugar Sucrose Levels on the Quality of Brown Sugar. *METANA*. https://doi.org/10.14710/metana.v20i1.57772.
103. Odoch, M., Buys, E., & Taylor, J. (2021). Effects of vacuum packaging storage of minimally processed cassava roots at various temperatures on microflora, tissue structure, starch extraction by wet milling and granule quality. *Journal of the science of food and agriculture*. https://doi.org/10.1002/jsfa.11305.
104. Firdaus, F., Desmiarti, R., Praputri, E., & Amir, A. (2022). Production of Cocoa Pulp Syrup by Utilizing Local Sugar Sources. *Journal of Applied Agricultural Science and Technology*. https://doi.org/10.55043/jaast.v6i2.70.
105. Dewi, S., Izza, N., Agustiningrum, D., Indriani, D., Sugiarto, Y., Maharani, D., & Yulianingsih, R. (2014). The Effect of Temperature Cooking of Sugar Juice and Stirring Speed on The Quality of Brown Sugar Cane., 15, 149-158. https://doi.org/10.21776/UB.JTP.2014.015.03.01.
106. Ugulu, I., Bibi, S., Khan, Z., Ahmad, K., Munir, M., Malik, I., Ejaz, A., & Alrefaei, A. (2023). Biomonitoring of Heavy Metal and Metalloid Contamination in Industrial Wastewater Irrigated Areas Using Sugar Beet (Brassica oleracea L.). *Sustainability*. https://doi.org/10.3390/su15129694
107. Rashid, A., Schutte, B., Ulery, A., Deyholos, M., Sanogo, S., Lehnhoff, E., & Beck, L. (2023). Heavy Metal Contamination in Agricultural Soil: Environmental Pollutants Affecting Crop Health. *Agronomy*. https://doi.org/10.3390/agronomy13061521.
108. Misra, V., Solomon, S., Shrivastava, A., Shukla, S., & Ansari, M. (2016). Post-harvest Sugarcane Deterioration: Leuconostoc and Its Effect. *Journal of Functional and Environmental Botany*, 6, 1-7. https://doi.org/10.5958/2231-1750.2016.00001.9
109. . Bhunia, A. (2018). Molds and Mycotoxins., 167-174. https://doi.org/10.1007/978-1-4939-7349-1_8
110. Turner, P., Flannery, B., Isitt, C., Ali, M., & Pestka, J. (2012). The role of biomarkers in evaluating human health concerns from fungal contaminants in food. *Nutrition Research Reviews*, 25, 162 - 179. https://doi.org/10.1017/S095442241200008X.
111. Peraica, M., & Domijan, A. (2012). Mycotoxins and human health. *IARC scientific publications*, 158, 87-104
112. Basso, T., Gomes, F., Lopes, M., Amorim, H., Eggleston, G., & Basso, L. (2013). Homo- and heterofermentative lactobacilli differently affect sugarcane-based fuel ethanol fermentation. *Antonie van Leeuwenhoek*, 105, 169-177. https://doi.org/10.1007/s10482-013-0063-6.
113. Addis, M., & Sisay, D. (2015). A Review on Major Food Borne Bacterial Illnesses. *Journal of Tropical Diseases & Public Health*, , 7. https://doi.org/10.4172/2329-891X.1000176.
114. Iwuozor, K., Anyanwu, V., Olaniyi, B., Mbamalu, P., & Adeniyi, A. (2022). Adulteration of Sugar: A Growing Global Menace. *Sugar Tech*, 24, 914 - 919. https://doi.org/10.1007/s12355-022-01122-6
115. Bachmann, R., Horns, A., Paasch, N., Schrieck, R., Weidner, M., Fransson, I., & Schrör, J. (2022). Minor metabolites as chemical marker for the differentiation of cane, beet and coconut blossom sugar. From profiling towards identification of adulterations. *Food Control*. https://doi.org/10.1016/j.foodcont.2022.108832.
116. Banc, R., Filip, L., Cozma-Petruț, A., Ciobârcă, D., & Miere, D. (2024). Yellow and Red Synthetic Food Dyes and Potential Health Hazards: A Mini Review. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Food Science and Technology*. https://doi.org/10.15835/buasvmcn-fst:2024.0005.
117. Ambroziewicz, Z., Siemiątkowski, R., Łata, M., Dowgiert, S., Sikorska, M., Kamiński, J., Więcław, K., Grabowska, H., Chruściel, J., & Mąsior, G. (2024). Long-Term Health Effects of Artificially Colored Foods in Adults and Children: A Review of Scientific Literature on Attention Deficits, Carcinogenicity, and Allergy Risks. *Journal of Education, Health and Sport*. https://doi.org/10.12775/jehs.2024.76.56522.
118. Milenkovska, F., Gjorgjev, D., Karakasova, L., & Čuleva, B. (2022). Artificial sweeteners in various food products - quantification and intake ASSESSMENT. *Journal of Agricultural, Food and Environmental Sciences*. https://doi.org/10.55302/jafes22764052bm.
119. Singh, S., Kohli, A., Trivedi, S., Kanagala, S., Anamika, F., Garg, N., Patel, M., Munjal, R., & Jain, R. (2023). The contentious relationship between artificial sweeteners and cardiovascular health. *The Egyptian Journal of Internal Medicine*, 35. https://doi.org/10.1186/s43162-023-00232-1.
120. Vellapandian, C. (2024). Exploring the Long-Term Effect of Artificial Sweeteners on Metabolic Health. *Cureus*, 16. https://doi.org/10.7759/cureus.70043.
121. De Oliveira, Z., Da Costa, D., Da Silva Dos Santos, A., Da Silva Júnior, A., De Lima Silva, A., De Santana, R., Costa, I., De Sousa Ramos, S., Padilla, G., & Da Silva, S. (2024). Synthetic Colors in Food: A Warning for Children's Health. *International Journal of Environmental Research and Public Health*, 21. https://doi.org/10.3390/ijerph21060682.
122. Sun, Y., & Xu, B. (2025). A critical review on effects of artificial sweeteners on gut microbiota and gastrointestinal health. *Journal of the science of food and agriculture*. https://doi.org/10.1002/jsfa.14148.
123. Bian, X., Chi, L., Gao, B., Tu, P., Ru, H., & Lu, K. (2017). The artificial sweetener acesulfame potassium affects the gut microbiome

and body weight gain in CD-1 mice. *PLoS ONE*, 12. https://doi.org/10.1371/journal.pone.0178426.

124. Roosmayanti, F., Rismiwindira, K., & Masithoh, R. (2021). Detection of coconut (Cocos nucivera) sugar adulteration in palm (Arenga pinnata Merrill) sugar by Fourier Transform Infrared (FT-IR) Spectroscopy. *Food Research*. https://doi.org/10.26656/fr.2017.5(s2).013.
125. Paradkar, M., Sivakesava, S., & Irudayaraj, J. (2002). Discrimination and classification of adulterants in maple syrup with the use of infrared spectroscopic techniques. *Journal of the Science of Food and Agriculture*, 83, 714-721. https://doi.org/10.1002/JSFA.1332.
126. Kelly, J., & Downey, G. (2005). Detection of sugar adulterants in apple juice using fourier transform infrared spectroscopy and chemometrics. *Journal of agricultural and food chemistry*, 53 9, 3281-6. https://doi.org/10.1021/JF048000W.
127. Du, B., Wu, L., Xue, X., Chen, L., Li, Y., Zhao, J., & Cao, W. (2015). Rapid Screening of Multiclass Syrup Adulterants in Honey by Ultrahigh-Performance Liquid Chromatography/Quadrupole Time of Flight Mass Spectrometry. *Journal of agricultural and food chemistry*, 63 29, 6614-23. https://doi.org/10.1021/acs.jafc.5b01410.
128. Ziani, I., Bouakline, H., Guerraf, E., Bachiri, A., Fauconnier, M., & Sher, F. (2024). Integrating AI and advanced spectroscopic techniques for precision food safety and quality control. *Trends in Food Science & Technology*. https://doi.org/10.1016/j.tifs.2024.104850.
129. Fortin, N. (2016). Regulation of Unintentional Poisonous or Deleterious Substances in Food. , 165-200. https://doi.org/10.1002/9781119341178.ch9.
130. Anagaw, Y., Ayenew, W., Limenh, L., Geremew, D., Worku, M., Tessema, T., Simegn, W., & Mitku, M. (2024). Food adulteration: Causes, risks, and detection techniques—review. *SAGE Open Medicine*, 12. https://doi.org/10.1177/20503121241250184.
131. Beet (Beta Vulgaris) Plant Along Erzincan–Erzurum Highway in Eastern Anatolia Region. *Erzincan Üniversitesi Fen Bilimleri Enstitüsü Dergisi*. https://doi.org/10.18185/erzifbed.1609801.
132. Fareed, G., Baig, J., Kazi, T., Afridi, H., Akhtar, K., & Solangi, I. (2022). Heavy metals contamination levels in the products of sugar industry along with their impact from sugar to the end users. *International Journal of Environmental Analytical Chemistry*, 104, 2407 - 2416. https://doi.org/10.1080/03067319.2022.2062238.
133. Alcívar, M., Vinueza, E., Pernía, B., Álvarez-Montero, X., & Gallardo, A. (2024). Contamination by Cadmium and Lead in Sugarcane and Its Derived Products in Ecuador. *Agriculture*. https://doi.org/10.3390/agriculture14122121.
134. Santos, J., Quináia, S., & Felsner, M. (2018). Fast and direct analysis of Cr, Cd and Pb in brown sugar by GF AAS. *Food chemistry*, 260, 19-26. https://doi.org/10.1016/j.foodchem.2018.03.106.
135. Am, B., Ar, A., Gi, M., Aa, A., & A., B. (2022). Determination of some heavy metals and microbial profile of raw Sugar samples collected from Sudanese Sugar Industries in season 2017 in relation to EU.1998 and ICUMSA,1974 standards. *International Journal of Agricultural Science and Food Technology*. https://doi.org/10.17352/2455-815x.000164.
136. Wang, X., Deng, C., Sunahara, G., Yin, J., Xu, G., & Zhu, K. (2018). Risk Assessments of Heavy Metals to Children Following Non-Dietary Exposures and Sugarcane Consumption in a Rural Area in Southern China. *Exposure and Health*, 12, 1-8. https://doi.org/10.1007/s12403-018-0275-0.
137. Salles, P., Menezes, M., Jacimovic, R., & Campos, T. (2016). Inorganic elements in sugar samples consumed in several countries. *Journal of Radioanalytical and Nuclear Chemistry*, 308, 485-493. https://doi.org/10.1007/s10967-015-4478-6.
138. Zheng, Y., Wang, J., Huang, H., Y., & Zhao, X. (2024). Research and application of MOFs-derived porous carbon materials in food safety detection: A review. *Trends in Food Science & Technology*. https://doi.org/10.1016/j.tifs.2024.104449.
139. Khairunnisa, N., Christiani, F., & Prawiyogi, A. (2024). Supply Chain Transparency: Exploring Blockchain Solutions for Enhanced Traceability and Efficiency. *Blockchain Frontier Technology*. https://doi.org/10.34306/bfront.v4i1.569.