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The Effectiveness of Molasses from a Mixture of Sugar Cane Juice and Brown Sugar

Dwi Rizaldi Hatmoko[1], Agustin Patmaningrum[2], Moh. Rifqi Fauzi[3]

[1] Universitas PGRI Mpu Sindok Nganjuk, Indonesia; dwirizaldi@upms.ac.id
[2] Universitas PGRI Mpu Sindok Nganjuk, Indonesia; agustin@upms.ac.id
[3] Universitas PGRI Mpu Sindok Nganjuk, Indonesia; mrifqifauzi@upms.ac.id

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ABSTRACT

This study aims to analyze the effectiveness of molasses produced from a mixture of sugarcane juice and brown sugar in terms of chemical composition, antioxidant activity, and its potential as a fermentation substrate for ethanol and lactic acid. The study used a literature review approach by reviewing relevant scientific articles, proceedings, and academic books from the last five to ten years. These sources were selected based on the clarity of the method, the relationship to molasses characteristics, and its use in functional foods and the bioindustry. The results of the study indicate that sugarcane molasses is rich in phenolics, flavonoids, and melanoidins with high antioxidant capacity, while brown sugar also has strong antioxidant activity and contributes minerals and Maillard compounds that play a role in redox activity. Sugarcane molasses has been proven effective as a fermentation substrate for the production of ethanol and lactic acid with competitive process performance and relatively low carbon source costs. Theoretically, molasses from a mixture of sugarcane juice and brown sugar has the potential to produce a sweet matrix with a high density of bioactive compounds and favorable fermentative characteristics. However, specific experimental data on the mixed molasses is still limited, so further research is needed to verify its chemical profile, actual antioxidant activity, safety, and fermentation performance.

Corresponding Author:
Dwi Rizaldi Hatmoko
Universitas PGRI Mpu Sindok Nganjuk, Indonesia; dwirizaldi@upms.ac.id

1. INTRODUCTION

The sugarcane agro-industry is one of the largest industrial crop production systems in the world and a vital pillar for the food and energy sub-sectors. FAO data shows that sugarcane will contribute more than 2 billion tons of sugar crop production in 2023, far surpassing sugar beets in the sugar crop group. Behind this significant production figure, the sugarcane processing process produces not only sugar and bioethanol but also significant volumes of by-products (bagasse, vinasse, molasses, and straw). Recent biotechnology studies confirm that these by-products are not simply waste but rather a source of value-added raw materials for biofuels, enzymes, and various other bioproducts when managed within a biorefinery and circular economy framework (Pérez-Contreras et al., 2025).

In line with this, the literature on the utilization of agro-industrial waste and by-products also highlights the need for a paradigm shift from "waste management" to "waste valorization". Dhillon & Kaur (2016) emphasized that agro-industrial waste can be used as a cheap substrate for biocatalytic and fermentation processes, including enzyme and biofuel production, if its chemical characteristics and bioactivity are understood comprehensively. In the context of the sugarcane-based sugar industry, Temesgen et al. (2024) Molasses is described as a key by-product with high economic and ecological value, both as feed, bioenergy raw material, and value-added food raw material. This makes molasses an important focus in the development of sustainable agro-industrial products.

Sugarcane molasses is generally defined as a thick, dark brown syrup obtained after the sugar crystallization process. In addition to being rich in sucrose, glucose, and fructose, molasses also contains minerals, nitrogen compounds, organic acids, and groups of bioactive compounds such as phenolic acids, flavonoids, tannins, and melanoidins. Molasses extraction studies using ultrasound-assisted hydroethanolic extraction techniques show that molasses contains high total phenolics and flavonoids, with 2.5% ethanol solvent at a pH of around 6 producing an extract with the highest phenolic content and antioxidant capacity (Jovanović et al., 2025). This finding confirms that molasses is not only a source of technical sugar, but also a rich matrix of functional compounds that have the potential to be used as natural antioxidants.

Biologically, sugarcane molasses has been widely reported to have antioxidant and antimicrobial activities. Shafiqa-Atikah et al. (2020) reported that molasses extract was able to show total phenols of around several mg GAE per gram of extract and strong free radical scavenging activity based on DPPH assay, along with the ability to inhibit the growth of pathogenic food bacteria such as Staphylococcus aureus and Escherichia coli. The positive relationship between phenolic content and antioxidant activity in molasses extract indicates that processing processes that maximize the formation or preservation of phenolic compounds will have a direct impact on the functional potential of the final product. On the other hand, the variability of molasses composition due to differences in sugarcane varieties, cultivation conditions and process parameters (pH, temperature, cooking time) still poses a challenge in quality standardization.

Compared with fresh sugarcane juice, several metabolite studies have shown that molasses has a significantly higher phenolic content and antioxidant capacity due to the accumulation of Maillard reaction products and the concentration of minor compounds during heating and evaporation. The metabolite profile indicates a shift from a matrix dominated by simple sugars in juice to a more complex system in molasses, containing various phenolic acids, flavonoids, and melanoidins that act as electron donors and radical scavengers. Therefore, engineering the molasses formation process is key to directing the functional quality of the product, not just the sugar yield aspect.

On the other hand, brown sugar (palm sugar or sugar from the sap of other palms) is a very popular sweet commodity in Indonesia. This sugar is produced by heating the sap to form a brown solid or semi-solid sugar rich in compounds from the Maillard reaction. Recent research has shown that palm sugar and coconut sugar retain significant antioxidant capacity, including through the formation of melanoidins during heating (Swasti et al., 2024). The Trolox equivalent antioxidant capacity (TEAC) test shows that palm sugar has a higher antioxidant capacity than coconut sugar, while also containing furfural and hydroxymethylfurfural (HMF) at acceptable levels. This fact indicates that heating palm sap not only reduces nutritional value but also produces new compounds that can act as antioxidants, while also raising safety concerns if the formation of mutagenic compounds is not controlled.

Other literature that examines the quality of palm sugar in various production centers in Indonesia also confirms the presence of strong antioxidant activity as measured by the DPPH method, with IC_{50} values within the range categorized as strong antioxidant activity. (Sia et al., 2023). Meanwhile, animal studies have shown that palm sugar consumption can increase levels of endogenous antioxidant enzymes such as SOD and GPx and reduce biomarkers of oxidative stress. (Suoth et al., 2020). This combination of findings strengthens the position of brown sugar not only as a traditional sweetener, but also as a candidate for a functional ingredient that has the potential to provide health benefits if processed and consumed properly..

The characteristics of industrial sugarcane juice, brown sugar, and sugarcane molasses are summarized, it can be seen that each material has its own advantages and limitations. (Tabel 1).

Tabel 1. General comparison of sweet raw materials based on palm and sugar cane.

Material	Main Sources and Processes	Dominant Components	Main Bioactive Characteristics
Sugarcane juice	Fresh Saccharum officinarum stem juice	Sucrose, glucose, fructose	Phenolics and flavonoids are relatively lower; antioxidant activity is moderate
Brown sugar/palm sugar	Palm sap (aren/coconut) is heated until it thickens	Sucrose, minerals, melanoidin	High antioxidant capacity; limited amounts of HMF and furfural are formed
Sugarcane molasses	By-product of sugar crystallization from sugar cane juice	Dissolved sugar, ash, phenolic compounds	High total phenols, strong antioxidant activity; antimicrobial potential

In agro-industrial terms, Indonesia is promoting increased bioethanol production based on local raw materials such as sugarcane and its byproducts, including molasses, to support the national energy mix and biofuel policy. However, the competing needs for bioenergy, exports, and the food industry create new challenges at the supply chain level. Several policy studies indicate that molasses in Indonesia is used as a feedstock for bioethanol, a food additive, and a raw material for other industries, necessitating more efficient and high-value utilization strategies. In this context, the development of alternative forms of molasses that can be produced on a small- to medium-scale, for example from fresh sugarcane juice combined with brown sugar, is of interest.

The combination of sugarcane juice and brown sugar in molasses formation theoretically has the potential to produce a matrix with a unique bioactive profile. Sugarcane juice contributes simple sugars, vitamins, and sugarcane-specific phenolics, while brown sugar contributes minerals, melanoidins, and phenolics typical of palm sap. Heating the mixture is thought to trigger the formation of melanoidins and other complex compounds that can enhance antioxidant capacity, while also influencing the color, aroma, and viscosity of the final product. Furthermore, the initial composition of the sap and process parameters (material ratio, temperature, time, pH) will determine the extent to which phenolic compounds are preserved or degraded, and the extent to which mutagenic compounds such as HMF are formed (Swasti et al., 2024).

Despite this promising potential, studies specifically addressing "molasses from a mixture of sugarcane juice and brown sugar" are still very limited. Existing literature tends to separate studies of sugarcane products (juice, sugar, molasses) from palm sap products (palm sugar/coconut sugar) without examining the synergy between the two within a single product matrix. Meanwhile, recent reviews on the valorization of sugarcane industry byproducts have focused more on industrial molasses in the context of biorefineries and bioenergy, rather than new molasses formulations designed as functional food ingredients (Temesgen et al., 2024; Ungureanu et al., 2022). This creates a knowledge gap, particularly regarding how the combination of sugarcane juice and brown sugar affects the physicochemical characteristics, total phenolic content, antioxidant activity, and its potential use as agro-industrial raw material..

Thus, the main problem that arises is the lack of adequate and standardized data regarding the effectiveness of molasses produced from a mixture of sugarcane juice and brown sugar, both in terms of functional properties (antioxidant activity, phenolic content, antimicrobial potential) and in terms of its potential use as a raw material for sustainable agro-industry. Variations in processing techniques at the small-scale producer level—for example, differences in mixture composition, temperature, and cooking time—have the potential to produce products with very heterogeneous quality, making them difficult to use as a reference for industrial-scale development. Therefore, a systematic literature review is needed to summarize, compare, and critique research findings related to the effectiveness of molasses from a mixture of sugarcane juice and brown sugar, as a scientific basis for further experimental research.

2. METHODS

This research uses a literature review approach, focusing on the effectiveness of molasses derived from a mixture of sugarcane juice and brown sugar in the context of agro-industry and biology. In this approach, literature is positioned as the primary "data" that is systematically analyzed, so that the literature review is not merely a summary of theories but a research method in its own right (Snyder, 2019). The study subjects were not individuals or physical samples, but rather scientific documents including journal articles, proceedings, theses, dissertations, and scientific books related to chemical characteristics, antioxidant activity, fermentation potential, and the use of molasses as a raw material for food and bioindustry. Document selection was carried out by prioritizing publications from the last five to ten years, in line with recommendations for the use of up-to-date sources in literature-based research (Morin, Olsson, & Atikcan, 2021; Galvan & Galvan, 2023). However, some frequently cited classical works are retained if they are relevant as a theoretical basis.

The research procedure begins with determining the focus of the study and keywords related to sugarcane juice, brown sugar/palm sugar, molasses, antioxidant activity, phenolic components, and fermentation (e.g., sugarcane juice, cane molasses, palm sugar, antioxidant activity, phenolic content, ethanol fermentation, lactic acid fermentation). A well-planned keyword-based approach is essential to ensure repeatability and consistency of the search (Yoganingrum, 2020). These keywords were used to search various online databases such as Google Scholar, ScienceDirect, PubMed, national journal portals, and university book catalogs. The initial search results were then filtered based on title and abstract to select documents that were truly relevant to the topic of molasses from sugarcane juice and/or brown sugar, both as single products and in mixtures. These search and filtering stages followed the general principles of systematic and general literature reviews, which emphasize transparency and traceability of the study selection process (Purssell & McCrae, 2024).

The next stage is a more in-depth selection and screening of literature through full text reading. At this stage, inclusion and exclusion criteria are applied, including: (1) containing information on the chemical composition, antioxidant activity, or fermentation performance of molasses, sugarcane juice, and brown sugar; (2) explaining clearly enough the research procedures, types of materials, and analytical methods used; (3) published in accredited scientific journals, scientific proceedings, or credible academic books; and (4) written in Indonesian or English. Establishing these criteria is important to maintain the quality and validity of the synthesis, as emphasized in the guidelines for preparing high-quality reviews (Snyder, 2019; Purssell & McCrae, 2024). Documents that did not contain searchable data (e.g., popular reports, opinion articles, or manuscripts without clear methods) were excluded from the analysis. To facilitate bibliography and citation management, reference management tools (e.g., Mendeley or Zotero) and electronic spreadsheets were used to record key data from each source, as is common in modern peer review practice (Galvan & Galvan, 2023).

Data collection was conducted by extracting key information from each selected literature into a summary table. This information included: researcher identity and year, material type (sugarcane juice, brown sugar, industrial molasses, or a mixture), process conditions (material ratio, heating temperature and duration, pH), measured parameters (e.g., total phenolic content, total flavonoids, antioxidant capacity using various test methods, ethanol or lactic acid fermentation yield and efficiency), and key findings related to the effectiveness of molasses. This systematic data extraction practice aligns with the principle of evidence synthesis, which emphasizes structured recording prior to the analysis stage (Schmidt et al., 2025). Where available, information on safety aspects (e.g. levels of HMF or other contaminants) and agro-industrial implications is also recorded to support the discussion.

The analysis techniques used are descriptive and analytical. The collected data were not combined in the form of a statistical meta-analysis, but were synthesized narratively by grouping the findings based on major themes, such as: (1) chemical characteristics and bioactive components of molasses from sugarcane juice and brown sugar; (2) antioxidant activity and other biological potential; and (3) the use of molasses as a fermentation substrate and raw material for agro-industrial products. This narrative synthesis approach is generally used when the studies being reviewed are heterogeneous in terms of design, variables, and units of measurement so that they are not easily combined quantitatively (Snyder, 2019; Morin et al., 2021). Within each theme group, research findings were compared to identify consistent patterns, emerging differences, potential contributing factors, and any remaining gaps in knowledge. This narrative synthesis then served as the basis for developing a discussion and drawing conclusions regarding the effectiveness of molasses from a mixture of sugarcane juice and brown sugar, while also providing recommendations for further research.

3. FINDINGS AND DISCUSSION

This discussion focuses on the effectiveness of molasses produced from a mixture of sugarcane juice and brown sugar by linking it to three main dimensions: (1) chemical quality and bioactive compound content, (2) functional potential as a source of antioxidants, and (3) feasibility as a fermentation substrate (bioethanol and lactic acid) within a sustainable agro-industrial framework. The analysis is structured critically, considering the latest empirical evidence while also opening up space for counter-arguments and limitations of the literature review approach.

Effectiveness of chemical composition: molasses mixture of sugarcane juice–brown sugar as a bioactive rich matrix

Recent research results confirm that sugarcane molasses is one of the richest fractions of bioactive compounds along the sugarcane processing chain. Farmani et al. (2025) showed that sugarcane molasses extract contains phenolics, flavonoids, tannins, and anthocyanins in high concentrations, with an antioxidant capacity (DPPH inhibition) ranging from 56–68% depending on the extraction conditions, especially when using 2.5% hydroethanol solvent at pH 4.11–5.11. These findings strengthen the view that molasses is not just a thick liquid waste, but a "concentrate" of functional compounds formed as a consequence of heating, concentration, and the Maillard reaction.

In terms of palm sugar, empirical evidence also points to a significant bioactive profile. Research at the Sumowono conference reported that palm sugar has an IC_{50} DPPH value between 50–100 μg/mL, with some of the best samples reaching around 74.73 μg/mL, which is categorized as having strong antioxidant activity. A more recent study by Swasti et al. (2024) showed that coconut sugar and palm sugar still retained significant antioxidant activity after high heating, mainly due to the formation of melanoidins, although mutagenic compounds such as HMF and furfural were simultaneously formed in certain levels.

If this profile is projected onto molasses resulting from a mixture of sugar cane juice and brown sugar, theoretically the chemical composition will be a combination:

a. high soluble carbohydrates (sucrose, glucose, fructose) from sugar cane juice and palm sap,
b. minerals and organic acids from both materials,
c. Maillard compounds (melanoidins) are formed more intensely due to double heating (sugarcane juice + palm sap/brown sugar).

Conceptually, this formulation has the potential to produce molasses with a higher density of bioactive compounds than pure sugarcane molasses, particularly in terms of melanoidin and phenolic variations. However, this argument remains inferential as no studies have explicitly characterized molasses from a sugarcane juice–brown sugar mixture.

A counter-argument that needs to be raised is that increasing chemical complexity does not always equate to increased "effectiveness." Excessively high temperatures and heating times have the potential to degrade pH- and temperature-sensitive phenolics, as indicated in studies of sugarcane molasses extraction, where highly acidic conditions can reduce total phenolics. MDPI in palm sugar, Swasti et al. (2024) also showed that heating triggers the formation of HMF and furfural which are mutagenic, although the levels are still below the toxic threshold. Food Research This means that in the design of a molasses process for a mixture of sugarcane juice and brown sugar, effectiveness needs to be measured as a compromise between increasing bioactive compounds and limiting the formation of negative compounds

Effectiveness as a source of antioxidants: between in vitro capacity and physiological significance

Recent research has shown that the antioxidant capacity of sugarcane molasses is highly dependent on extraction conditions and pH environment. Farmani et al. (2025) reported that a combination of 2.5% hydroethanol solvent and pH 4.11–5.11 yielded the highest total phenolic and DPPH radical scavenging capacity, with an IC_{50} of approximately 2.53 mg/mL. On the other hand, a spectrophotometric report by Molina-Cortés et al. (2020) confirmed a positive correlation between phenolic content and antioxidant capacity of B- and C-sugarcane molasses, strengthening the causal relationship between phenolic structure and redox activity.

For palm sugar, Swasti et al. (2024) showed that the antioxidant activity (TEAC) of palm sugar can reach around 110 ppm, while coconut sugar is around 55 ppm, with a significant contribution from melanoidins as a result of the Maillard reaction. These data are consistent with reports that the IC_{50} of palm sugar from Sumowono is in the strong antioxidant range. This phenomenon provides a theoretical basis that a mixture of sugarcane juice and brown sugar heated to form molasses will have an antioxidant profile determined not only by native phenolics, but also by the full spectrum of melanoidins and other Maillard products.

However, antioxidant effectiveness cannot be measured solely from the DPPH or ABTS assay. The in vitro DPPH assay only reflects the ability of a molecule to scavenge radicals in a simple chemical system, not necessarily reflecting its bioavailability and activity in vivo. On the other hand, Farmani et al. (2025) confirmed that molasses bioactives tend to work optimally in acidic conditions (pH 4–5), which is relevant to the gastric lumen, but effectiveness at neutral pH (blood, extracellular fluid) may be reduced. This indicates that the location and method of consumption (e.g., as an acidic beverage, fermented syrup, or food additive) are crucial for the biological effectiveness of mixed molasses.

Another counterargument arises from the perspective of nutrition and metabolic health. While molasses and brown sugar contribute antioxidant compounds and minerals, both ingredients remain sources of simple sugars with a significant glycemic load. Studies of functional foods generally emphasize the risks when "antioxidant" claims are used to mask high sugar intake, particularly in populations at risk of diabetes or metabolic syndrome. In this context, the effectiveness of mixed molasses as a functional food needs to be balanced: not just "how high the DPPH activity is," but also the sugar profile, glycemic index, and consumption patterns in the community.

Thus, from an antioxidant perspective, the molasses mixture of cane juice–brown sugar is potentially effective as a source of redox-active compounds, but such effectiveness must be understood as a function of:

a. pro-antioxidant phenolic and melanoidin composition,
b. possible formation of HMF/furfural,
c. context of consumption and total sugar load in the diet.

Effectiveness as a fermentation substrate: opportunities and challenges

In the bioenergy sector, VHG fermentation is one of the key technologies for increasing ethanol productivity and reducing distillation costs. Cruz et al. (2021) showed that fed-batch fermentation with a mixture of sugarcane juice and molasses at a sugar concentration of around 300 g/L produced ethanol up to 135 g/L with a yield of around 90%, while also achieving complete sugar consumption. These results confirm that the combination of sugarcane juice and molasses is able to provide a nutritional and osmotic balance that supports the performance of Saccharomyces cerevisiae under VHG conditions.

Conceptually, molasses from a mixture of cane juice and brown sugar occupies a similar position:

a. the dominant sugar composition is sucrose with a glucose–fructose fraction,
b. mineral content that can act as an enzymatic cofactor,
c. the presence of nitrogen compounds and vitamins in small amounts.

Experiments in other systems have shown that sugar type influences fermentation dynamics and the antioxidant activity of the product. Research on kombucha whey has shown that the use of different sugar sources (white sugar, coconut sugar, palm sugar) alters the final antioxidant activity and physicochemical properties of the beverage, with coconut sugar producing the highest DPPH activity. These findings suggest that the choice of sugarcane- and palm-based sugar blends also has the potential to modulate the fermentation metabolite profile, both for fermented beverages and for ethanol.

On the lactic acid pathway, Mabia et al. (2025) reported that sugarcane molasses from Ivory Coast treated with acid hydrolysis was able to produce lactic acid up to 52.4 g/L with a yield of 0.95 g/g and a productivity of 0.73 g/L·h using Limosilactobacillus fermentum ATCC 9338. A simple economic analysis showed a reduction in carbon source costs of more than 70% compared to refined sugar. Bacillus amyloliquefaciens-based metabolomics studies on sugarcane molasses also indicated that molasses can support very high lactic acid titers (around 178 g/L) when fermentation conditions are optimized.

If the molasses mixture of cane juice and brown sugar has a comparable soluble sugar content and inhibitor profile, this substrate should theoretically be suitable for use in lactic acid fermentation. However, this is where an important counterargument arises:

a. The melanoidin, HMF, and furfural content of the brown sugar fraction has the potential to inhibit the performance of fermentation microbes, especially lactic acid bacteria which are generally more sensitive to inhibitors than ethanol yeast.
b. Variability of raw materials (cane variety, palm type, cooking method) risks producing molasses with highly fluctuating inhibitor concentrations, thus disrupting the reproducibility of the fermentation process.

Pendekatan Mabia et al. (2025), A study using acid hydrolysis pretreatment and optimized fermentation conditions indicates that the effectiveness of molasses substrates is not only determined by the initial composition, but also by process engineering. For molasses mixed with sugarcane juice and brown sugar, effectiveness as a fermentation substrate can only be achieved if there are pretreatment and quality control strategies that can reduce inhibitors and standardize the fermentable sugar content.

Perspectives of sustainable agro-industry and circular bioeconomy

From an agro-industrial perspective, the development of molasses from a mixture of sugarcane juice and brown sugar is in line with the trend of by-product valorization and circular bioeconomy. Farmani et al. (2025) emphasized that sugarcane molasses has high potential as a raw material for the extraction of bioactive compounds based on green technology, such as ultrasound-assisted extraction, which is in line with sustainable development goals through the utilization of value-added side-streams. Mabia et al. (2025) explicitly link lactic acid production from sugarcane molasses to reduced raw material costs and utilization of agro-industrial residues in a developing country context.

In the context of Indonesia, which is rich in sugarcane and palm oil, the molasses sugarcane juice–brown sugar mixture offers a unique opportunity:

a. Product diversification: not only as a liquid sweetener, but as a raw material for antioxidant extracts, fermented drinks, ethanol, and lactic acid.
b. Value chain integration: brown sugar artisans and sugar cane factories can be connected in a partnership model that reduces waste, increases sales value, and expands the product portfolio.
c. Branding of local functional foods: the combination of sugarcane-palm bioactives can be the basis for the narrative of typical tropical functional products, as long as the health claims are supported by adequate scientific data.

However, from a critical perspective, the risk of romanticizing the concept of a circular bioeconomy needs to be addressed. Economic and ecological effectiveness is determined not only by waste utilization, but also by:

a. carbon footprint of prolonged heating processes,
b. energy consumption in the concentration and fermentation stages,
c. management of new waste arising from the extraction or fermentation process.

In other words, molasses from a mixture of sugarcane juice and brown sugar has the potential to be an important element in a sustainable agro-industrial system, but sustainability claims are only valid if accompanied by a comprehensive life cycle analysis and techno-economic study.

Critical synthesis and implications for further research

Overall, the literature review shows that:

a. Sugarcane molasses has been shown to be rich in phenolics and bioactives with high antioxidant capacity,
b. Brown sugar/palm sugar also contributes antioxidants and melanoidins, as well as the potential for HMF/furfural formation,
c. Sugarcane molasses is effective as a fermentation substrate for ethanol and lactic acid with competitive process performance,
d. the concept of molasses valorization is in line with the circular bioeconomy trend and the development of value-added bioproducts.

From this point, the effectiveness of molasses from a mixture of cane juice and brown sugar can be understood as a strong hypothesis but has not been fully confirmed experimentally. Arguments supporting its effectiveness include:

a. potential bioactive synergy between sugarcane and palm oil,
b. possible increase in antioxidant activity due to the combination of phenolics and melanoidins,

c. suitability of sugar profile for fermentation under VHG conditions or low cost lactic acid production.

On the other hand, counter-arguments that need to be accommodated include:

a. risk of phenolic degradation and formation of mutagenic compounds during repeated heating,
b. higher fermentation inhibitor potential than pure sugarcane molasses,
c. uncertainty of in vivo antioxidant bioavailability and the metabolic impact of persistently high sugar intake.

The implication is that further research is ideally:

a. Produce direct experimental data on the chemical characteristics, antioxidant profile, and HMF/furfural content of molasses mixture of sugarcane juice–brown sugar under various process conditions.
b. Testing fermentation performance (ethanol and lactic acid) using mixed molasses as a substrate, by measuring titer, yield, productivity, and microbial tolerance to inhibitors.
c. Develop a process optimization model that balances the objectives: enhancement of bioactive compounds, limitation of negative compounds, and fermentation efficiency.

Thus, this discussion positions molasses, a mixture of sugarcane juice and brown sugar, as a promising candidate, but still requires rigorous empirical evidence. Current literature provides a strong theoretical basis for proposing that effectiveness can be achieved, as long as the process design considers chemical, biological, and agro-industrial aspects in an integrated manner.

4. CONCLUSION

Literature reviews indicate that sugarcane molasses contains phenolics, flavonoids, melanoidins, and high antioxidant capacity. While palm sugar has also been shown to contribute strong antioxidant activity and essential minerals, despite the risk of HMF and furfural formation upon heating. The combination of sugarcane juice and palm sugar processed into molasses theoretically has the potential to produce a sweet matrix with a high density of bioactive compounds and a sugar composition suitable as a fermentation substrate for ethanol and lactic acid. However, the presence of Maillard reaction products and fermentation inhibitors needs to be controlled to achieve functional and fermentative effectiveness, rather than simply adding chemical complexity. The currently available evidence strongly supports the potential use of mixed molasses within a sustainable agro-industrial framework. However, specific experimental data on molasses from a mixture of sugarcane juice and palm sugar are still limited, requiring further targeted research to verify its chemical quality, actual antioxidant activity, safety, and fermentation performance.

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