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REVIEW ARTICLE

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Revisiting the nutraceutical profile, chemical composition, and health benefits of jaggery: Updates from recent decade

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Abstract

Foods as medicine have been utilized from ancient civilizations and shared from generation to generation as dietary health practices. It provides therapeutic assistance along with nutrition and health benefits. Presently, food products, diet, and individual health are receiving a lot of attention and are in high demand. In this context, jaggery is an important part of food and diet in the rural areas of many regions/countries. It is made up of sugarcane juice and is recognized as a natural source of nutraceuticals due to the presence of different types of essential amino acids, minerals, vitamins, and antioxidant potential along with other biological applications. In this updated review article, we discussed the newest research and information on traditional uses, nutraceutical profiling, chemical composition, and biological applications of jaggery. The published data were collected from different scientific search engines including PubMed, Springer Link, Web of Science, Google Scholar, Science Direct, and Wiley online library. Given these findings, we can conclude that jaggery is a strong source of nutraceuticals and its nutraceutical potential can be enhanced with value addition and other scientific interventions. Detailed investigations on preclinical (in silico, *in vitro*, and *in vivo*) studies along with its actual mechanism of action in depth are required. Additionally, clinical trials also should be conducted to validate the preclinical studies.

KEYWORDS

health benefits, jaggery, pharmaceutical properties, sweetener

1 | INTRODUCTION

The major role of food is to satisfy hunger and simultaneously fulfill the requirement of necessary nutrients in the body; however, nowadays functional food also plays a major role in preventing nutrition-related disorders and enhancing the physical and mental safety of people (Amin et al., 2022; Custódio et al., 2023; Sharifi-Rad, Rodrigues, Sharopov et al., 2020; Sharifi-Rad, Rodrigues, Stojanovic-Radic, et al., 2020; S. Yang et al., 2022; Zhao & Tian, 2022). *Saccharum officinarum* Linn, commonly known as sugar cane belongs to the Poaceae family, cultivated worldwide due to its economic and medicinal properties (Ali et al., 2019). It is cultivated across the globe for its medicinal and economical values (A. Singh et al., 2015). Fatty acids, phytosterols, alcohols, higher terpenoids, glycosides, and flavonoids are the major phytochemicals present in sugar cane juice (Chinnadurai, 2017). One of the major products of sugar cane is "Jaggery," a traditional form of sugar also known as unrefined sugar or noncentrifugal sugar (NCS) (Rao & Singh, 2022, Zidan & Azlan, 2022).

Jaggery is an ancient natural sweetener and used in the traditional system of medicine for a long time back (Jaffé, 2015; Zidan & Azlan, 2022). Ethnobotanically, jaggery has a strong history in the Indian traditional system of medicine and is utilized against different ailments (Harish Nayaka et al., 2009; Nath et al., 2015; Sharma & Sharma, 2012). It is used as a functional food and is a rich source of protein, minerals, vitamins, carbohydrates, phenolic acid, and so forth, and has high nutritive, antioxidant, and medicinal values (Iqbal et al., 2017; Sahu & Paul, 1998; Sahu & Saxena, 1994). Jaggery is a form of functional food that contains a sufficient amount of carbohydrates (sucrose, fructose, and glucose), minerals (calcium, potassium, sodium, iron, zinc, magnesium, etc.), and vitamins (B, C, D, E), which are essential for normal growth and functioning of human health (Anwar et al., 2011; Rao & Singh, 2022; Singh, 2013). Jaggery possesses several therapeutic properties like antioxidant activity, antimicrobial activity, cytoprotective, and neuroprotective activities (Barrera et al., 2020; Harish Nayaka et al., 2009; Sharma & Sharma, 2012) due to the presence of different bioactive compounds. Jaggery may have a better nutrition profile than sugar and be used as a replacement for refined sugar in any foods and drinks (Shrivastav et al., 2016). The main objective of the present study is to provide a systematic and updated review of the scientific data regarding the traditional, nutritional, and biological activities of sugar cane jaggery.

2 | METHODOLOGY

Published data on jaggery has been collected from different scientific search engines including PubMed/Medline, Springer Link, Web of Science, Google Scholar, Science Direct, and Wiley online library by using the next MeSH terms: "Saccharum/chemistry," "Antioxidants/chemistry," "Diet," "Body weight," "Human health," "Sweetening Agents/chemistry," "Temperature," "Food Quality" in the English language. After the critical screening of literature, reviews and book chapters were included in this study; and duplicate articles, nonrelevant to the topic and published in another language articles were excluded. Chemical formulas have been validated using ChemSpider and the scientific name of the plants has been validated using the World Flora Online (Heinrich et al., 2020; The Plant List; WFO, 2021).

3 | A SUMMARY OF JAGGERY: PREPARATION, TYPES, AND FORMS

Jaggery is consumed in different forms (solid, liquid, and powdered) in various parts of the world since ancient times. Sugarcane (*Saccharum officinarum* L.) and the sap of palms including date palm (*Phoenix dactylifera* (L.) Mill.), palmyra palm (*Borassus flabellifer* L.), sago palm (*Caryota urens* L.), and coconut palm (*Cocos nucifera* L.) are the major sources from which jaggery is prepared (Pattnayak & Misra, 2004). Jaggery is a sugar product derived from plants and prepared from sugar cane juice by heating it to obtain thick dark yellow or brown jaggery crystals in solid, granular, or powder form (Singh et al., 2011). The extracted palm sap is boiled and agitated to make the palm jaggery (Azlan et al., 2020). Based on processing (boiling, concentrating, and clarifying) methods, there are usually three forms of jaggery, that is, solid, liquid, and granular. The solid form of jaggery is mostly consumed among other forms and is prepared by clarifying the raw juice at the optimum temperature of 118–120°C. The cooled thick slurry has molded into various shapes (Anwar et al., 2011). The powdered form of jaggery is manufactured by heating the juice at a striking point of 120–122°C temperature (Kumar & Kumar, 2021). After heating, the mixture is then cooled and transferred to the wooden/metallic platform, where it gets solidified and is powdered with the help of wooden scrapers. The prepared powdered jaggery is then sieved and further dried up to 1%–2% of moisture content for better storage. The optimum temperature for the preparation of good quality jaggery is 105–106°C (Nevkar et al., 2008; Sridevi, 2008). The different striking temperatures used in the preparation of jaggery confirm the sterility and quality of the jaggery. Further, value addition and fortification of solid, liquid, and granular jaggery could be done by cocrystallization or mixing technology (Anwar, 2017; Rao & Singh, 2022; L. Yang et al., 2020).

4 | TRADITIONAL USES

For decades, jaggery has been used as a natural source of sugar as well as a taste enhancer and immunity booster in different traditional foods (Huang et al., 2021; Ishak et al., 2021). It is widely used in India, Pakistan, Sri Lanka, Myanmar, and other Asian countries as well as Africa, Latin America, and the Caribbean. Jaggery is commonly known as molasses sugar and is called by different names as "Gur: India, Desi: Pakistan, Naam Taan Oi: Thailand and Hakura: Srilanka" in Asia (Kumar and Singh, 2020; Nath et al., 2015). Ancient references explained multiple uses of sugar cane jaggery in terms of food as well as medicinal products. Jaggery is also included in traditional Persian medicinal beliefs of "humour-producing" foods (P. V. K. Jagannadha Rao et al., 2007), in "Sushruta Samhita" (an Indian ancient scripture) detailed information about its different forms, medicinal properties, and uses is given (H. Sharma, Sharma, & Sharma, 2012). A detailed description of the traditional uses of sugarcane jaggery has been discussed in this section.

In Ayurveda, jaggery is considered to be a good digestive stimulant and an appetizer that is usually consumed after meals to enhance digestion due to its "Ushna" (hot/heat) property. In addition, it may be beneficial in weight loss by inhibiting water retention in the body due to the occurrence of potassium content in it (Tal et al., 2019). Jaggery helps the improving of the digestive fire or "Agni" and appetite due to its "Ushna" (hot) property. This (Agni) facilitates easier digestion and allows for the release of *Ama* (or toxins) from the body. Jaggery has often been considered a strong ingredient for detoxification and stimulating bowel movements it prevents constipation (Ravisankar et al., 2016). Besides, the loss of appetite is correlated with Agnimandya (weak digestion). Loss of appetite is a result of irregular stimulation of *Vata, Pitta*, and *Kapha doshas*, with psychological factors, which further leads to digestion-related problems. Jaggery is complex as compared to refined sugar hence its digestion process is relatively slow which helps in retaining energy for a longer duration and hence helps in proper digestive metabolism (Umate et al., 2021).

Jaggery has some health claims to prevent anemia due to the number of ferrous salts which are formed during its preparation in iron vessels (Samson et al., 2022). Iron is beneficial for health, especially for those who are suffering from anemia and iron deficiency. An imbalanced *Pitta dosha* has been considered a major cause of anemia in Ayurveda, although it has been reported that old jaggery can balance this *dosha* and can reduce anemic symptoms (Resmi et al., 2016). Since ancient times jaggery has been used for treating asthma, dry cough, and the common cold. Recent research confirmed the benefits of jaggery in chronic cough to reduce throat irritation due to soothing effects on soft tissues of the throat (Ogawa et al., 2013). Sahu and Saxena (1994) reported the protective effect of jaggery against pollution in employees working in smoky and dusty environments. Regular consumption of jaggery helps in preventing the harmful effect of pollution on the lungs (Sahu and Saxena, 1994). On the other hand, it also produces warmth in the lungs and dilates the respiratory tract, and helps with cough, asthma, and breathing troubles by replacing sugar intake with jaggery (Sahu and Paul, 1998). Jaggery is used to help in promoting the relaxation of muscles and nerves by enhancing their functions to prevent fatigue depending on the amount of magnesium (Kumar and Singh, 2020). In the ayurvedic medicine system, jaggery is also considered a significant antioxidant and a blood purifier (Harish Nayaka et al., 2009; Singh & Singh, 2008). It is added as a source of sugar or minerals in different ayurvedic tonics which are used to treat various ailments (Sekar & Mariappan, 2008; Singh 2013). Jaggery is also used to strengthen the immune system against the common cold and flu (Deotale et al., 2019).

5 | NUTRITIONAL ATTRIBUTES OF JAGGERY

In recent decades, functional foods have been evaluated by researchers due to their ability to prevent, and treat chronic diseases or their symptoms (Salehi et al., 2020; Sharifi-Rad, Dey, et al., 2021). Jaggery is considered one of the nutritive and healthiest sugars in the world (Singh, 2013), and its nutraceutical profiling has been evaluated by several authors (Lamdande et al., 2018; Rao & Singh, 2022). Regarding this, P. V. Jagannadha Rao et al. (2010) reported the proximate composition of jaggery granules of sugarcane, date palm, and palmyra palm. The highest sucrose content was found in sugar cane jaggery (84.40%), whereas the highest amount of reducing sugar (12.41%) and protein (2.80%) content was observed in the palmyra palm. Jaggery granules also showed the presence of fat, protein, and minerals like iron, calcium, phosphorus, and magnesium (P. V. K. Jagannadha Rao et al., 2007; P. V. Jagannadha Rao et al., 2010). The study on the nutritional composition of jaggery (100 g) prepared from sugar cane showed the presence of carbohydrates (sucrose: 72–78 g; fructose and glucose: 1.5–7 g), minerals (Ca: 40–100 mg; Mg: 70–90 mg; P: 20–90 mg; Na: 19–30 mg; Fe: 10–13 mg; Mn: 0.2–0.4 mg; Zn: 0.2–0.4 mg; Cl: 5.3–0.0 mg; 0.1–0.9 mg), vitamins (vitamin A: 3.8 mg; vitamin B_2: 0.06 mg; vitamin B_1, B_5, and B_6: 0.01 mg; vitamin C: 7.00 mg; vitamin: D_2: 650 mg; vitamin E: 111.30 mg), and protein (280 mg) in significant amount (Singh, 2013).

The highest value of sucrose (99.70%–99.95%) was observed in refined sugar, but glucose (2%–4%), fructose (2%–4%), inorganic ash (2%–4%), ash organic (1%–3%), amino acids (0.5%–0.25%), and total polysaccharides

(0.3%–0.6%) were found in cane juice. Refined sugar was reported with less amount of mineral content than sugar cane juice and molasses (mineral content in sugar cane and molasses: P: 0.4%–2.0% and 3.5%; Na: 0.03%–0.1% and 0.1%; chloride: 0.10%–0.29% and 1.3%; Ca: 0.17%–0.32% and 0.7%; Mg: 0.20%–0.33% and 0.3%; Fe: 0.07%–0.14% and 0.02%; phosphate: 0.01%–0.40% and 0.3%; sulfate: 0.11%–0.52% and 1.5%) (Eggleston, 2018). Several other important nutritional composition findings of jaggery are mentioned in Table 1.

6 | CHEMICAL COMPOSITION

Phytochemicals or secondary metabolites extracted from plant species attributes to various nutritional and therapeutic properties (Amin et al., 2022; Salehi, Shetty, et al., 2019; Salehi, Prakash Mishra, et al., 2021). These secondary metabolites consist of various classes of organic compounds including phenols, flavonoids, tannins, alkaloids, terpenoids, glycosides, etc. (Salehi, Quispe, et al., 2021; Sharifi-Rad, Quispe, Herrera-Bravo, et al., 2021). Several analyses of the chemical composition of jaggery confirm the presence of various active compounds in different types of jaggery (Mohan & Singh, 2020; Verma et al., 2019). A comparative study of total phenols content and phenolic acids were performed in jaggery, refined sugar, white sugar, and brown sugars. The maximum amount of phenol content was recorded in jaggery (3837 ± 154 μg gallic acid equivalent [GAE]/g) followed by brown sugar (372 ± 1.44 μg GAE/g), white sugar (31.5 ± 1.44 μg GAE/g), and refined sugar (26.5 ± 3.79 μg GAE/g), respectively. However, the highest amount of phenolic acids such as gentisic acid (130 ± 5.49 μg/g), gallic acid (122 ± 6.07 μg/g), protocatechuic acid (60.0 ± 3.47 μg/g), ferulic acid (34 ± 1.26 μg/g), 4-hydroxyphenyl acetic acid (29.5 ± 2.08 μg/g), vanillic acid (25.6 ± 1.82 μg/g) were reported in jaggery relative to other sugars (Harish Nayaka et al., 2009). Another study on total phenol content (TPC) was measured for refined sugar, raw sugar, jaggery, and molasses, and the result showed 3285 μg GAE/g of phenol content in jaggery (Iqbal et al., 2017). Alarcón et al. (2021) investigated the chemical characteristics and colorimetric properties of noncentrifugal cane sugar (traditional NCS bricks, granulated NCS, powdered NCS, syrup of 50/70° Brix (S50) obtained via different processing technologies (Alarcón et al., 2021). The phenolic content in NCS was determined between the range of 0.4% and 0.6% and the flavonoid content was between 0.2% and 0.4%, respectively. Phenolic acids like vanillic acid (0.70–1.45 μg/100 g), protocatechuic acid (0.36–0.94 μg/100 g), chlorogenic acid (2.08–3.82 μg/100 g), syringic acid (1.08–2.80 μg/100 g), ferulic acid (0.50–0.95 μg/100 g), and p-coumaric acid (0.69–1.35 μg/100 g) were found in the different NCS samples (Alarcón et al., 2021). A

TABLE 1 The nutritional content of noncentrifugal cane sugar.

Composition (Arif et al., 2019; Jaffé, 2015; Sahu and Saxena, 1994; Singh et al., 2011)	
Proximate composition	**Minimum–maximum range (%)**
Ash	36
Carbohydrate	83.90–97.2
Reducing sugar	10.5
Total sugar	87.5–95.4
Sucrose	76.55−89.48
Fiber	–
Protein	1.7
Fats	0.10
Mineral content (per 100 g)	**Minimum–maximum range (μg/mL)**
Iron	1.60–02.50
Calcium	13.70–240.00
Copper	0.17–8.50
Chloride	5.30–250.00
Iodine	0.01–0.01
Chromium	11.90–16.00
Phosphorus	2.00–125.00
Sodium	15.50–79.00
Potassium	14.00–1100.00
Zinc	0.10–1.76
Magnesium	31.00–120.00
Cobalt	9.90–9.90
Manganese	0.35–1.66
Selenium	0.00–0.00
Vitamins (per 100 g)	**Minimum–maximum range (μg/mL)**
Vitamin A	0.00–3.8
B carotene	0.00–16.15
Vitamin B_1	0.01–0.05
Vitamin B_2	0.04–0.11
Vitamin B_3	0.08–7
Vitamin B_5	0.01–1.38
Vitamin B_6	0.01–0.72
Vitamin B_9	0.00–10.00
Vitamin B_{12}	–
Vitamin C	0.00–17.6
Vitamin D_2	0.00–6.5
Vitamin E	0.00–55.65
Vitamin PP	7.00

comparative analysis among granulated sugar, light jaggery block, regular jaggery block, muscovado sugar, brown sugar, and cane honey was done in terms of TPC assay, total flavonoid content (TFC) assay, and high-performance liquid chromatography (HPLC) (Barrera et al., 2020). The result showed that maximum and minimum TPC and TFC content was measured for granulated jaggery (TPC: 3.64 ± 0.03; TFC: 5.8 ± 0.4) and brown sugar (TPC: 0.58 ± 0.016; TFC: 1.09 ± 0.09), respectively. The HPLC result showed the presence of chlorogenic acid, coumaric acid, caffeic acid, ferulic acid, flavones, tricin, and apigenin in regular jaggery block, granulated sugar, light jaggery block, muscovado sugar, brown sugar, and cane honey; however, luteolin was not detected in cane sugar and brown sugar (Aynalem and Duraisamy, 2022; Barrera et al., 2020). Chen et al. (2020) identified a total of 37 aromatic compounds including 4 alcohols, 8 carboxylic acids, 1 sulfur, 10 pyrazines, 3 esters, and 9 heterocyclic compounds in NCS by gas chromatography-olfactometry-mass spectrometry (GC-O-MS) analysis. Aromatic compounds like furfuryl alcohol, 2-ethyl-1-hexanol, 2,3-butanediol, 5-methyl furfuryl alcohol, phenylacetic acid, tetra decanoic acid, hexadecanoic acid, 3-phenyl-2-propenoic acid, dodecane-1-ol, hexanal, phenylacetic acid, 3-phenyl-2-propenoic acid, 2-methylpyrazine, 2,6-dimethylpyrazine, 2,5-dimethylpyrazine, 2,3-dimethylpyrazine, 2-ethyl-5-methylpyrazine, 2,3,5-trimethylpyrazine, 2-ethyl-6-methylpyrazine, 2-methyl-6-vinylpyrazine, 2-acetyl-6-methylpyrazine, 2,6-di-tert-butyl-pmethylphenol, 4-ethenyl-2-methoxyphenol, 2,4-di-tert-butylphenol, 4-ethenyl-2,6-dimethoxyphenol, 4-allyl-2,6-dimethoxyphenol, 2-methoxy-4-acetylphenol, 2-acetylfuran, 2-acetylpyrrole, 2-formylpyrrole, dibutyl phthalate, 1,3-dimethylbenzene, (+)-limonene, styrene, dimethyl sulfoxide were detected in NCS by GC-O-MS (Chen et al., 2020). The chemical structure of bioactive compounds present in the jaggery and summarized data regarding phytochemicals are shown in Figure 1 and Table 2.

7 | BIOLOGICAL APPLICATIONS

Regarding biological applications, a limited number of investigations have been carried out (Figure 2).

7.1 | Antibacterial

Due to the widespread use of antibiotics, antibiotic resistance of various strains of bacteria may occur, as a result of which researchers have evaluated various natural antimicrobial alternatives (Ghenea et al., 2021; Salehi, Jornet, et al., 2019; Zlatian et al., 2018). Barrera et al. (2020) investigated the antioxidant and antimicrobial activity of light jaggery block, granulated sugar, muscovado sugar, cane honey, regular jaggery block, and brown sugar. (Figure 2) The result showed that 1, 1-diphenyl-2-picrylhydrazyl (DPPH) assay, 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) scavenging activity was found to be highest in granulated jaggery (DPPH half-maximal inhibitory concentration[IC_{50}]: 1.24 ± 0.05; ABTS: 13.3 ± 0.3 µmol Trolox/g) and lowest was reported in brown sugar (DPPH IC_{50}: 6.5 ± 0.2; ABTS: 2.1 ± 0.2 µmol Trolox/g), respectively (Barrera et al., 2020). The antibacterial activity of granular jaggery against cariogenic bacterial strains *Streptococcus mutans* and *S. sobrinus* was found to be highest among all the other forms of sugar under experiment (Barrera et al., 2020). Other bioactive antibacterial compounds were isolated from molasses such as dehydroconiferylalcohol-9′-O-β-D-glucopyranoside, isoorientin-7,

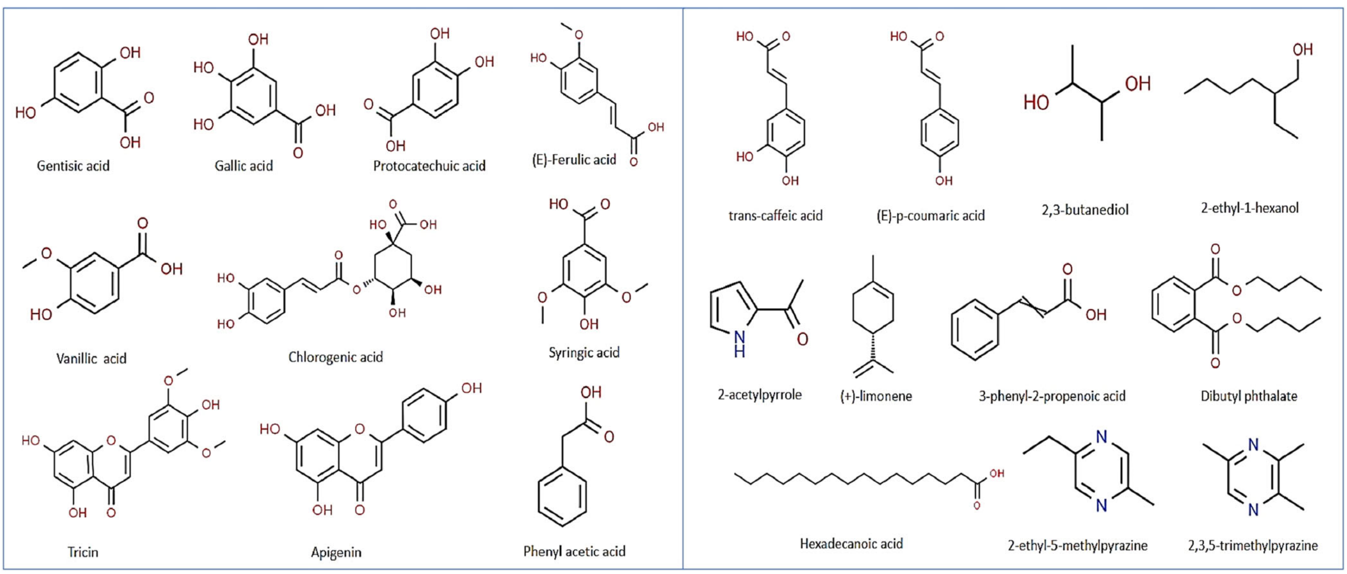

FIGURE 1 Chemical structure of the most representative bioactive compounds of jaggery.

TABLE 2 Summarized data regarding phytochemicals in jaggery.

Phytochemicals	Type/content in jaggery	Reference
Phenolic acids	Gentisic acid (130 ± 5.49 μg/g), gallic acid (122 ± 6.07 μg/g) protocatechuic acid (60.0 ± 3.47 μg/g), ferulic acid (34 ± 1.26 μg/g, 4-hydroxyphenyl acetic acid (29.5 ± 2.08 μg/g), vanillic acid (25.6 ± 1.82 μg/g), syringic acid (1.08–2.80 μg/100 g), p-coumaric acid (0.69–1.35 μg/100 g)	Harish Nayaka et al. (2009); Alarcón et al. (2021)
Phenols	3285 μg GAE/g	Iqbal et al. (2017)
Flavonoids	0.2%–0.4%	Barrera et al. (2020)
Aromatic compounds	Furfuryl alcohol, 2-ethyl-1-hexanol, 2,3-butanediol, 5-methyl furfuryl alcohol, phenylacetic acid, tetra decanoic acid, hexadecanoic acid, 3-phenyl-2-propenoic acid, dodecane-1-ol, hexanal, phenylacetic acid, 3-phenyl-2-propenoic acid, 2-methylpyrazine, 2,6-dimethylpyrazine, 2,5-dimethylpyrazine, 2,3-dimethylpyrazine, 2-ethyl-5-methylpyrazine, 2,3,5-trimethylpyrazine, 2-ethyl-6-methylpyrazine, 2-methyl-6-vinylpyrazine, 2-acetyl-6-methylpyrazine, 2,6-di-tert-butyl-pmethylphenol, 4-ethenyl-2-methoxyphenol, 2,4-di-tert-butylphenol, 4-ethenyl-2,6-dimethoxyphenol, 4-allyl-2,6-dimethoxyphenol, 2-methoxy-4-acetylphenol, 2-acetylfuran, 2-acetylpyrrole, 2-formylpyrrole, dibutyl phthalate, 1,3-dimethylbenzene, (+)-limonene, styrene	Chen et al. (2020)

Abbreviation: GAE, gallic acid equivalent.

3′-O-dimethyl ether (Takara et al., 2007). Future studies are necessary for elucidating the mechanisms regarding this property.

7.2 | Antioxidant

Free radicals occur as a result of normal processes of energy production in the human body or may be exogenous(Mititelu et al., 2020; Sharifi-Rad, Quispe, Imran, et al., 2021). To neutralize them, natural antioxidants are a good alternative (M. S. Islam et al., 2021; M. T. Islam et al., 2021). Nayaka and co-workers reported the comparative effects of jaggery on free radical-induced damage of NIH3T3 fibroblast cells, erythrocytes, and DNA damage along with scavenging and reducing power assay. Under this study, brown, white, and refined sugars were procured from local sugar factories and jaggery was obtained from the local market. From an antioxidant perspective, jaggery presented strong antioxidant potential in scavenging assay (half-maximal effective concentration: 7.81 μg/mL) and reducing assay compared to other sugars, while Jaggery also showed 70% of DNA protective activity (Harish Nayaka et al., 2009) (Figure 2). Other preclinical *in vivo* studies have shown that in laboratory animals, jaggery has antioxidant effects, stimulating the production of catalase, glutathione, superoxide dismutase, and reduced glutathione in the liver (Eggleston, 2018a; Singh et al., 2010).

7.3 | Cytoprotective

The jaggery showed strong cytoprotective effects against tert-butyl hydroperoxide-induced cell death at the concentration of 4 mg/mL and continued up to 20 mg/mL without any toxic effects (Figure 2). Brown sugar displayed dose-dependent activity up to 20 mg/mL; however, refined and white sugars showed low activity (Harish Nayaka et al., 2009). Singh et al. (2008) studied the *in vivo* protective activity of jaggery on arsenic-induced genotoxicity in Swiss albino mice and showed that jaggery has a significant ability to encounter genotoxic effects induced by arsenic (Singh et al., 2008). Another *in vivo* study on Swiss albino mice showed that jaggery at a concentration of 250 mg/kg can antagonize the adverse effect of arsenic with 0.05 ppm and 5 ppm concentrations (Singh et al., 2010). Aqueous extract of jaggery protects CCl_4-induced hepatic-renal damage in rats (Sharma et al., 2013). Along with lead supplementations of jaggery, higher urinary δ-aminolevulinic acid excretion takes place and reduces the uptake of lead in the liver (Flora & Singh, 1988). Less than 5 mg/mL concentration, jaggery exhibits more than 95% cytoprotective on NIH 3T3 fibroblasts and erythrocytes (Harish Nayaka et al., 2009). Also, jaggery exhibits nephroprotective activity against acetaminophen (APAP)-induced renal damage in rats (Sharma & Sharma, 2012).

7.4 | Other biological properties

Transportation of animals can cause physiological alterations by loading, handling, and transport. To overcome this problem, jaggery with vitamin C and vitamin C plus electrolytes was evaluated by different researchers on the goat model (Ahmad Mir et al., 2019; Ayari et al., 2018; Gupta et al., 2019, 2021). In all studies, the result showed a reduction of transportation stress by jaggery with vitamin C and vitamin C plus electrolytes in the experimental goat model (Ahmad Mir et al., 2019; Ayari et al., 2018; Gupta et al., 2019, 2021), while, jaggery along with fenugreek helps in increased milk production in cattle even in winter

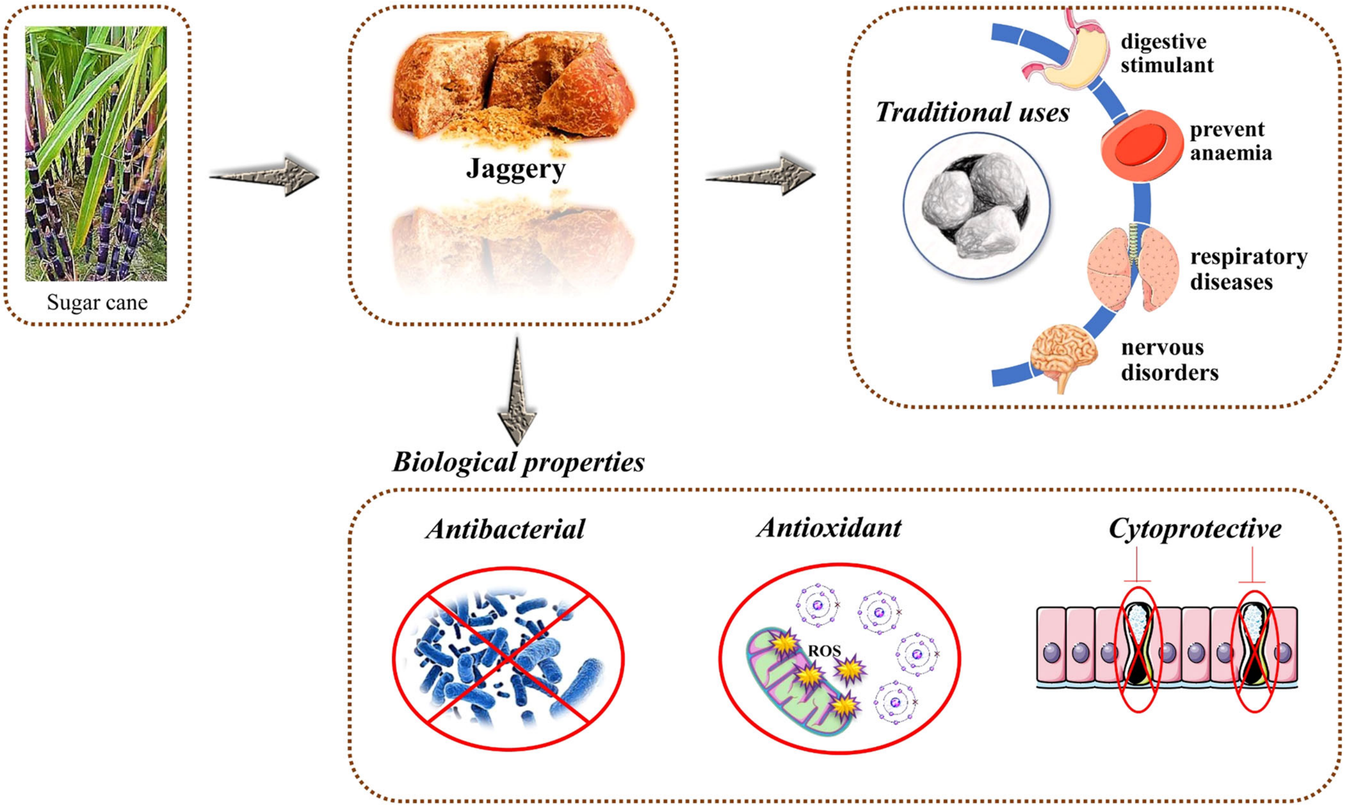

FIGURE 2 Summarized scheme regarding traditional uses and the most important biological properties of jaggery.

months (Aarif et al., 2019). Recently, a research group from China reported jaggery as a potential carbon source and its impact on water quality, growth performance, serum bactericidal capacity, innate immunity, and disease resistance to *Aeromonas hydrophila* in *Orechromis niloticus* (Elayaraja et al., 2020). An interesting recent study showed that natural sweeteners based on 30% jaggery can be used as stabilizers for oral smears, being nontoxic, with a mechanism similar to ethanol denaturation and coagulation of proteins (Pandiar et al., 2017). Another study suggests that the iron from jaggery is more easily assimilated by the body than iron from other natural sugar sources and as a result can prevent anemia (Taneja et al., 2020). Other studies have shown that jaggery can have cardioprotective effects by lowering total cholesterol, low-density lipoprotein cholesterol, and triglycerides (Zidan & Azlan, 2022). Consumption of jaggery also increases potassium intake which is able to reduce blood pressure through arterial vasodilation, thus effectively lowering blood pressure and reducing the risk of atherosclerosis, myocardial infarction, and stroke.

Jaggery also has a high dietary fiber content which helps stimulate intestinal peristaltic movements thus having intestinal anti-inflammatory effects (Zidan & Azlan, 2022). Sugar cane juice has a low glycemic index due to the types of sugars contained which are absorbed and processed more slowly by the body. For people who don't have type 2 diabetes, this drink can actually help regulate blood sugar levels when consumed in moderation (Flórez-Martínez et al., 2023; Zidan & Azlan, 2022).

8 | THERAPEUTIC LIMITATIONS

It is important to mention that excessive consumption of unrefined sugar can trigger some chronic diseases such as obesity, diabetes, cardiovascular diseases, and dental problems (Cavalot et al., 2006; Katschinski et al., 1988; De Koning et al., 2012; Liu and Heaney, 2011; Yabao et al., 2005; Q. Yang et al., 2014). Limitations can only be associated with the excessive amount of it in the daily diet, which leads to the appearance of excess fat in the human body, the additional secretion of insulin by the pancreas, as well as hyperglycemia. This, in turn, can lead to various other diseases. In addition, the unregulated consumption of jaggery by people with diabetes can cause an exacerbation of this disease.

9 | CONCLUSION

According to the analyzed studies, it can be concluded that Jaggery is an important source of nutraceuticals, essential for a healthy lifestyle. Traditionally, jaggery is used to treat the symptoms of various diseases due to the presence of bioactive compounds. A small number of studies have shown its antioxidant, antimicrobial, anticancer, and nephroprotective potential. In the future, detailed investigations on preclinical and clinical studies are needed to understand its chemical composition, molecular mechanisms of action, and its potential use as a new remedy or nutraceutical. The toxicological perspective is also important to investigate in depth. Therefore, future research on different aspects is needed to obtain a higher level of evidence.

AUTHOR CONTRIBUTIONS

Javad Sharifi-Rad: Conceptualization; data curation; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—original draft; writing—review and editing. **Sakshi Painuli**: Data curation; investigation; writing—original draft; writing—review and editing. Bilge Sener: Data curation; investigation; writing—original draft; writing—review and editing. **Mehtap Kılıç**: Data curation; investigation; methodology; validation; writing—original draft; writing—review and editing. **Nanjangud V. A. Kumar**: Data curation; investigation; writing—original draft; writing—review and editing. **Prabhakar Semwal**: Data curation; investigation; resources; writing—original draft; writing—review and editing. **Anca O. Docea**: Data curation; funding acquisition; investigation; writing—original draft; writing—review and editing. **Hafiz A. R. Suleria**: Data curation; investigation; writing—original draft; writing—review and editing. **Daniela Calina**: Conceptualization; data curation; investigation; project administration; validation; visualization; writing—original draft; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

The paper did not involve the use of animal and human participants.

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