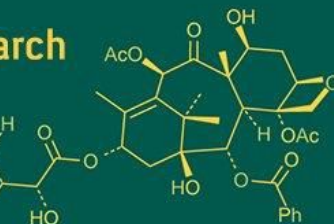


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Preservation methods and value addition in sugarcane juice: Technological approaches: A review

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Abstract

Sugarcane juice is a highly nutritious and refreshing natural beverage, rich in essential sugars, minerals, and antioxidants. However, its high perishability due to microbial activity and enzymatic browning significantly limits its shelf life, posing a challenge for large-scale commercialization. This review explores recent advancements in preservation methods and value addition techniques for sugarcane juice, with a focus on technological innovations and associated challenges. Preservation strategies such as thermal processing, high-pressure processing (HPP) and the application of natural preservatives are evaluated for their effectiveness in extending shelf life while maintaining sensory and nutritional quality. Additionally, the review discusses value addition through the incorporation of functional ingredients, flavour enhancements, and the development of ready-to-serve and value addition of products. The review concludes by highlighting the need for integrated preservation systems and sustainable technologies to enhance the commercial viability of sugarcane juice while meeting quality and safety standards.

Keywords: Enzymatic browning, preservation, value addition, high pressure processing

Introduction

The scientific name for sugarcane is *Saccharum officinarum*, which belongs to the Poaceae family. Both tropical and subtropical regions are used to cultivate it. In India, it has expanded significantly after Brazil. 1.8 billion tons of sugarcane are produced worldwide, making it the greatest crop. distinct places of India have distinct types of sugarcane that grow all year round. In Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, Gujarat, Madhya Pradesh, Goa, Pondicherry, and Kerala, topical sugarcane is grown.

Among the many nutrients found in sugarcane are minerals such as calcium, potassium, zinc, iron, phosphorus, and vitamins A, B complex, and C. There are also several items that include antioxidants including flavonoids, polyphenolic chemicals, and fibers, such as sugarcane juice and jaggery.

In tropical and subtropical regions, sugarcane juice is a significant natural health beverage among sugarcane products. In India, sugarcane juice is the most popular beverage and is prized for its sweet flavor and scent. However, the sugarcane juice is manufactured and sold in unsanitary conditions and in unofficial marketplaces since it is freshly extracted using a mechanical crusher and sold to the general public by street sellers. Saccharose, organic acids, and minerals including potassium, iron, salt, calcium, and magnesium are all abundant in sugarcane juice.

Because sugarcane juice contains a higher percentage of water, its preservation and storage stability are the main issues. A number of factors, such as light, heat (physical), oxygen (chemical), enzymes (biochemical), and microorganisms (biological), affect sugarcane juice's characteristics (Kunitake *et al.*, 2014) [24]. Microbial spoiling is the main reason, which happens when bacteria, molds, and yeasts turn carbohydrates into acids and gums. This causes significant changes in storage conditions. Enzymatic inversion has an impact on sugarcane juice quality, and the primary enzymes responsible for the juice's discoloration are polyphenol oxidase (PPO) and peroxidase (POD) (Singh *et al.*, 2006) [43].

As soon as the juice is extracted, the fermentation process begins. When not stored properly, the fresh juice turns brown and becomes sour a few hours after extraction due to enzymatic reactions and spoiling-causing microbes, which might provide a health risk to customers.

Health benefits of sugarcane

Patients with jaundice might benefit from sugarcane juice, according to the Unani medical system. For quick alleviation, people with jaundice are advised to consume a lot of sugarcane juice, which is said to be good for the liver. Modern pharmacological research has shown that sugarcane has a variety of bioactivities, including anti-inflammatory, analgesic, antihyperglycemic, diuretic, and hepatoprotective effects, which supports the presumptions of these traditional Indian medicinal systems (Amandeep Singh *et al.*, 2015) [43]. The water activity and pH value are 0.99 and higher than 4.6, respectively, and it has 80% water and 20% total soluble solids (TSS).

Chromium levels in the body's cells are also believed to be raised by consuming sugarcane juice instead of white sugar. The organoleptic community will accept it. high levels of proteins, antioxidants, phytonutrients (including chlorophyll), and other beneficial substances (Singh *et al.*, 2015) [43]. Sugarcane juice contains vital nutrients that promote health. These nutrients help stabilize blood sugar levels, kill cancer cells, help people lose weight, prevent tooth decay, and help the kidneys work properly by maintaining a clear urine flow (Singh *et al.*, 2014) [43].

One of the many health benefits of consuming sugarcane juice is that it can prevent cancer, fight prostate cancer, inhibit breast cancer cell activity, and enhance the kidneys, stomach, eyes, brain, heart, and sex organs. Additionally, fevers that result in a substantial loss of protein can be treated with its help. (Panigrahi *et al.*, 2021) [31]. Sugarcane is commonly known as "noble cane." Extending natural immunity against infections is one of its many biological benefits.

Preservation techniques

Sugarcane juice's constitution, which includes water, sugars, organic acids, and other substances, makes it perishable. Following rapid extraction and during processing, it is more vulnerable to deterioration due to both microbial and non-microbial processes. Many researchers are researching on sugarcane juice preservation using various approaches, such as preservatives, heat treatments, dehydration procedures, and some non-thermal technologies, because to its nutritional qualities and health advantages.

Natural preservatives

A possible strategy to increase the shelf life of sugarcane juice is the inclusion of natural preservatives including lemon juice, lemongrass essential oil, moringa extract, aonla extract, and ginger extract. In addition to preventing microbiological growth and enzymatic browning, these natural additions maintain the juice's nutritional value and flavor.

In their 2015 study, Begum, K., *et al.* used the mucilage components of ladies finger (*Hibiscus esculentus* Linn) as a herbal clarificants to preserve sugarcane juice. The largest proportion of sucrose and lesser reducing sugar in several clarificant treatments resulted in the maximum self-life.

Citrus acid, which is abundant in lemon juice, lowers the pH of SCJ and produces an acidic environment that is not conducive to microbial development. Additionally, it has ascorbic acid, a strong antioxidant that preserves the juice's purity.

The high concentration of citral and geraniol in lemongrass essential oil gives it antibacterial qualities. Combining it

with lemon juice has been shown to lower the microbial burden and deactivate the enzyme polyphenol oxidase (PPO), which causes browning in SCJ.

Bioactive substances with antibacterial and antioxidant properties, including polyphenols, flavonoids, and tannins, are abundant in moringa extracts. According to Keshav Khillare and Genitha Immanuel, adding moringa extract to SCJ has been demonstrated to maintain its phenolic content and extend its shelf life while being stored.

The high vitamin C content and antioxidant qualities of aonla, also known as Indian gooseberry, are well-known. Aonla extract can raise the pH of SCJ and help it hold onto its bioactive ingredients, which will increase its stability and quality over time. Bioactive substances like gingerol, which have antibacterial and antioxidant qualities, are found in ginger. Ginger extract can decrease enzymatic activity and prevent microbiological development when added to SCJ, increasing the juice's shelf life.

Chemical preservatives

Shakoor, S., *et al.* (2025) [42] investigated how adding sodium benzoate and citric acid together with microwave pasteurization at 90 °C may improve the sugarcane juice's shelf life and storage stability. The shelf life was demonstrated to be extended to 15 days at room temperature (26 °C) and 35 days at 100 °C with the addition of preservatives such as citric acid (0.3 percent), sodium benzoate (0.015 percent), potassium sorbate (0.025 percent), and sucrose (10 percent). Singh and associates (2014) [43]. Pasteurization with chemical treatment (potassium metabisulphite 150 ppm and citric acid 0.05%) for 10 minutes at 80 °C; sterilization at 80 °C for 20 minutes; and pasteurization at 80 °C for 10 minutes with chemical treatment (potassium metabisulphite @ 150 ppm and citric acid 0.05%) were the three treatments.

It was discovered that unsaturated gaseous hydrocarbons, such as passing acetylene and ethylene gases through the juice for 15 minutes, were helpful in maintaining the sucrose content and reducing PPO activity. (2015) Hussain *et al.* (2012) [16] carried out four distinct sugarcane juice preservation studies. The juice was pasteurized for 10 minutes at 70, 80, and 90 degrees Celsius in the first experiment. Concentration preservatives included citric acid (0 gm, 0.5 gm, 1 gm, and 1.5 gm/1,000 ml) and potassium metabisulphite (KMS) (0 ppm, 50 ppm, 100 ppm, 150 ppm, and 200 ppm).

In their research, Paraluppi and Ceccato Antonini (2019) [32] found that applying potassium metabisulphite (KMS) to sugarcane reduced 1 log cycle yeast in 3 hours and around 2-3 log reductions in bacteria in 6-9 hours. observed decreases were conducted at an 800 mg/L KMS concentration. The study by Shakoor, S., *et al.* (2025) [42] effectively showed that preservatives and microwave pasteurization may preserve the safety and quality of sugarcane juice, producing premium bottled goods with a 40-day shelf life.

Hurdle processing

Mathew *et al.* (2016) [27] sugarcane juice can be preserved up to 30 days in refrigerator condition with 0.5ml lime juice, 0.2 ml ginger extract, and 125 ppm of sodium metabisulfite per 100 ml of sugarcane juice and microwave pasteurization for one min.

The combination of pasteurization and chemical

preservative can extend the shelf life of the sugarcane juice, Chauhan *et al.* (2002) ^[10] Pasteurized juice at 70 °C for 10 min after addition of citric acid (40mg) per 100 ml and 150 ppm of potassium metabisulfite and it was stable for 90 days. Heat treatment at 85 °C for 10 min with fresh lemon juice to maintain the pH of 4.2 and ascorbic acid (40ppm) extended shelf life of sugarcane juice for 45 days at around 30 °C (Verma and Yadav, 2016) ^[47].

Pasteurization of juice at 80 °C for 15 min with the combination of sodium benzoate enhanced storability up to 60 days. Combination of natural preservative 3ml lemon and 1g salt, 0.6 ml ginger per 100 ml of sugarcane juice and 225 ppm of KMS pasteurization of sugarcane juice at 75 °C for 10 min improve the shelf life for 60 days (Khare *et al.*, 2012) ^[22].

Dehydration

Dehydration, a preservation method that involves removing moisture from food under carefully monitored settings, may help lower food items' moisture content and water activity, which in turn helps to lessen microbial assault and spoiling. Because sugarcane juice contains organic acids and is highly wet, dehydrating it is quite challenging. Since sugarcane juice has unfavourable qualities and is extremely difficult to handle due to its high sugar content, several researchers and food technologists are attempting to preserve it using dehydration techniques such as foam mat drying, spray drying, and freeze drying.

Spray drying

Spray drying technology is a good substitute for traditional drying since it's quick, affordable, and adaptable. In the process of spray drying, the feed is sprayed through a heated drying medium to transform it from a fluid condition (solution, dispersion, or paste) into a dried fraction. Spray drying combines several steps, including atomization, air and spray mixing, evaporation, and product separation. The chemical, food, and pharmaceutical sectors all make extensive use of the technology. Several foods, including tamarind, have been found to be preserved by spray drying. Numerous researchers have been trying to improve the spray drying conditions for powdered sugarcane juice over the past 20 years. The inlet and outlet air temperatures should be higher than 90 and 120 degrees Celsius. Other factors that affect the spray drying of sugarcane juice include the number of soluble solids in the feed, the type of drying agents used, the feed flow rate, atomizer speed, and pressure. Maltodextrin, gum acacia, and carboxymethyl cellulose are examples of drying agents.

Hari *et al.* (2013) compared several drying agents, including lactose, soluble starch, maltodextrin, and sucrose, in order to determine the ideal manufacturing parameters for sugarcane juice powder. The 20% maltodextrin that was produced as a drying agent at an input temperature of 160 °C is appropriate for making powdered sugarcane juice. According to Nishad *et al.*, 15% brix and 30% maltodextrin at inlet and outlet temperatures of 150 and 100 °C, respectively, demonstrated good sensory qualities of the finished powder, including taste, aroma, and acceptability, among other drying agents like liquid glucose, maltodextrin, gum Arabic, and carrot fiber.

With an atomizer speed of 22,000 rpm, Avila *et al.* optimized the spray drying parameters, which included inlet and exit temperatures of 130 and 75 °C, 40 brix of feed, and

20% maltodextrin. These circumstances produced a powder with a solubility of around 98% and a moisture content of about 1.11%. A 12 percent maltodextrin inlet temperature of 150 degrees Celsius was improved by Ramli *et al.* (2022) to produce sugarcane juice powder with good physicochemical and functional qualities.

Freeze drying

Among the drying processes used by food industries, Because of its low process temperature and quick transition from a hydrated to a dehydrated state, freeze drying produces high-quality products while reducing degradative reactions like the Maillard reaction, protein denaturation, and enzymatic reactions that are frequently encountered during the drying process (Liapis *et al.*, 1985) ^[26]. This method is sluggish, but it has the benefit of not allowing product to stick to the drier surface, which happens when heat is used (Santo *et al.*, 2013) ^[40].

The robust structure that is produced by freezing the material surface where sublimation occurs is another crucial aspect of the sublimation separation process; it is crucial to avoid collapses of the solid matrix after drying. Consequently, a pore that is easily rehydrated with the addition of water may be achieved. Microorganisms are not destroyed by freeze drying, but they are prevented from growing in the dried substance (BOSS, 2004) ^[6].

According to Magro *et al.*, freeze drying produced a powdered sugarcane juice with high solubility. One feature of the procedure is its ease of rehydration by the addition of water. The low temperature used in freeze drying inhibits enzymatic and chemical reactions, resulting in a high-quality product. With a moisture percentage of 6.97%, the sugarcane juice powder obtained satisfies the current legal requirements for vegetable products. Microorganisms cannot develop under the conditions of the acquired water activity value of 0.49 and the rise in the end product acidity of 12.99%, which makes product conservation easier. Due to the processing time the freeze-drying process might take several hours to generate the powder there is relatively little literature on the subject of sugarcane juice freeze drying.

2.4.3 Foam mat drying

Foam drying can be used to dry foods that are sticky, heavy in sugar, or sensitive to heat (Qadri, *et al.* 2020) ^[34]. The process involves turning the fruit from liquid to stable foam (by shaking, bubbling, or whipping), adding surfactants, and drying it using a variety of methods (Çalışkan Koç *et al.* 2022) ^[8]. The cost-effectiveness of creating easily reconstituted juice powders, compatibility with most types of juice, quick reconstitution, retention of nutritional value, and quick drying at moderate temperatures are some advantages of this technology Azizpour and Abbasi (2016) ^[1].

Marques *et al.* used different ratios of the foaming agents Emustab®, Super Liga Neutra®, and calcium carbonate to examine the foam properties of sugarcane juice and the feasibility of foam mat drying. examined the foam's drying kinetics at 50, 60, and 70 degrees Celsius using empirical models Page Henderson and Newton in conjunction with non-linear regression. Their results showed that all models matched drying very well, with determination coefficients above 0.99. The dehydrated product had an average moisture content of 3.23% and a water activity of 0.360. The material was 90.53% soluble in powder form and 100%

soluble in flake form. Thus, it was theoretically feasible to use the foam mat drying technique to generate dehydrated cane juice with 100% rehydration potential and chemical and microbiological stability.

Non thermal techniques

Thermal processing can result in unfavourable alterations to a product's nutritional value and sensory qualities; for instance, it might give juice an unwanted jaggery taste (Chauhan *et al.* 2002) ^[9]. Increasingly, the food business and its experts are focusing their attention and efforts on developing minimum or non-thermal heat treatment for food product preservation. Since the organoleptic qualities of food items are minimally lost when non-thermal treatment is used (Oms-Oliu *et al.* 2012) ^[30].

Over the last few decades, a number of non-thermal pasteurization techniques have been put forth, such as ultrasonic (US), pulsed electric field (PEF), high hydrostatic pressure (HHP), and high-pressure homogenization (HPH). These new methods appear to have the potential to produce fruit juices that are safe, "fresh-like," and have a long shelf life (Singhe, & Yu, 2012) ^[43].

In order to inactivate dangerous bacteria in food items, high hydrostatic pressure (HHP) processing employs pressures of up to 1000 MPa, either with or without heat (Ramaswamy *et al.*, 2005) ^[35]. According to Terefe *et al.* (2014) ^[45], high-pressure processing is thought to be an effective technique for inactivating POD and PPO in fruit juices. In contrast to the pasteurized juice, which had a 45-day shelf life, the HPP samples in multi-layered polyethylene terephthalate had a shelf life of up to 100 days when refrigerated at 523 MPa and 50 °C for 11 minutes (Sreedevi *et al.*, 2020) ^[44].

HPP (600 MPa for 6 min) preserves antioxidant capacity, physicochemical characteristics, sucrose neutral invertase activity, and sensory qualities of sugarcane juice (Huang *et al.*, 2015) ^[15]. The juice has been guaranteed to be microbiologically safe for 28 days at 4 °C. Sugarcane juice treated with HPP showed a notable color change based on the physicochemical characteristics of the sugarcane. According to Martín *et al.* (2002), HPP has been shown to satisfy the FDA's 5-log decrease of microorganisms in fruit juices and drinks without compromising the fresh fruit's nutritional value and sensory appeal.

The advantages of HHP over thermal processing are numerous. With less processing time, it may provide a safe product. Because of the lower processing temperatures, the food may retain its most fresh flavor and taste. Additionally, because it simply uses electrical energy and produces no waste by-products, it is ecologically beneficial (Ramaswamy *et al.*, 2005; Toepfl *et al.*, 2006) ^[35, 46]. Total plate count, yeast count, mold count, and coliform were all inactivated by sugarcane juice treated with 600 MPa pressure at 60 °C for 6 minutes, while enzymes (polyphenol oxidase (PPO) and peroxidase) were completely inactivated at 600 MPa at 60 °C for 8 minutes (Chauhan *et al.*, 2017) ^[10]. PEF processing provides several benefits over thermal processing. Because of the extremely short processing time and low processing temperatures, foods can retain their natural nutritional and sensory qualities. When comparing PEF processing to traditional thermal processing, energy savings are also significant. Additionally, it produces no waste, making it ecologically benign (Toepfl *et al.*, 2006) ^[46]. These benefits have led to the widespread application of PEF processing in the fields of microbial inactivation and

shelf-life extension in the preservation of food products, including fruit and drinks.

Applying a pulsed electric field with a processing intensity of 20 kV/cm and 150 pulses when lemon and ginger are present can preserve fresh sugarcane juice for 14 days. According to Kayalvizhi *et al.* (2016) ^[20], the treated juice's microbiological contaminants and nutritional content did not significantly alter while stored at 4 °C. The authors found that by minimizing adverse alterations and preserving the beverage's nutritional and sensory qualities, PEF processing greatly improves the microbiological safety and stability of sugarcane juice.

The primary uses of ozone in the sugarcane sector are for color reduction and juice preservation. Lime carbonation and advanced fenton oxidation have a greater impact on the purified juice's quality attributes (Gharib-Bibalan *et al.* 2018) ^[14]. Combining ozone (1.2 g/h for 10 min), lactic acid (0.5%), and pasteurization (85 °C for 15 min), Garud *et al.* (2017b) ^[13] reduced the overall bacterial count by 4.3 logarithmic units and stopped 60 and 72% of the sugarcane juice's polyphenol oxidase and peroxidase activities, respectively. The sugarcane juice's microbiological and sensory qualities were preserved by the aforementioned procedure for a month while it was refrigerated.

Value addition

Techniques for creating novel concentrated sugarcane juice products, such as jams, jellies, gummies, sweets, jaggery, and sugarcane juice powder made with spray drying and freeze-drying techniques. Additionally, a variety of value-added goods, such as rosagolla, peda, curd, and laddu (puffed grains, almonds, and sesame, among others), are historically made with jaggery rather than sugar; however, neither scientific literature nor process technologies are accessible for commercial use (Anwar *et al.* 2011) ^[3]. The primary product of sugarcane, sugar is used to make a variety of processed goods, including confections, baked goods, and traditional sweets. In addition to sugar, this study discussed other value-added products made from sugarcane.

Jaggery cubes

A frequent non-centrifugal sweetener is this one. Small cottage companies often create it by concentrating sugarcane juice. Solid jaggery in a range of shapes and sizes is usually produced by pouring the concentrated syrup into molds (Deokate, 2013; Verma *et al.*, 2019) ^[47]. This gives you energy for longer and doesn't hurt your body. However, because it is ultimately sugar, this does not verify that it is safe for diabetics to consume.

Due to its preparation in iron vessels, jaggery additionally accumulates a significant amount of ferrous salts (iron) during the process. Additionally beneficial to health is this iron, especially for people who are iron deficient or anemic. Vitamin C is a vital antioxidant that helps prevent cancer, heart disease, and stress. It also helps keep the immune system strong, neutralizes pollutants, is necessary for the development of antibodies, increases the absorption of nutrients, including iron, in the stomach, and is a blood thinner. Aonla, a natural source of vitamin C, was therefore added to jaggery for human benefit (Anwar *et al.*, 2009) ^[3].

Liquid jaggery

It is an intermediary product that is gathered during the production of jaggery. In Tamil Nadu, Maharashtra, Gujarat,

and Andhra Pradesh, it is used as a sweetener in food and beverages. Depending on the variety and agroclimatic zone, the concentrated juice is extracted from the boiling pan at a striking point temperature of 103 to 106 °C. Citric acid is added at 0.04 percent (400 mg/kg of liquid jaggery) to prevent crystallization and make the liquid jaggery look nice. Potassium metabisulphite is added at 0.1% (1 g/kg of liquid jaggery) or benzoic acid at 0.5% (5 g/kg of liquid jaggery) to extend the shelf life of the liquid jaggery without lowering its quality. About 33% water, 50% sucrose, 20% invert sugar, 0.3% calcium, 11% iron, 3% phosphorus, and 0.10 percent protein were included in a typical sample of liquid jaggery.

Granulated jaggery

Granular jaggery is made in a similar manner, depending on concentration. A wooden scraper is used to brush the concentrating slurry in order to create grains. After cooling, the granular jaggery is sieved. High-quality granular jaggery is observed to have crystals less than 3 mm.

It has been discovered that adding lime to cane juice raised its pH to 6.0–6.2 and its striking point temperature to 120 °C produces high-quality granular jaggery with a high sucrose content of 88.6%, low moisture content of 1.65%, and good color, friability, and crystallinity. Granules of jaggery that have been sieved to a size of approximately 3 mm, sun-dried, and have a moisture content of less than 2%, packed in polyethylene polyester bags or bottles, can be kept for more than two years, even during the monsoon season, with minimal deterioration in quality (Nath *et al.*, 2015) ^[29]. The process of manufacturing jaggery and processing granulated jaggery was standardized by Verma *et al.* (2019 & 2021) ^[47].

Concentrates and squash

In their 2016 study, Jalli and Sri formulated a sugarcane-based squash that included orange juice in a 3:1 ratio., included a preservative (0.6g KMS or 1.0g sodium benzoate/liter squash). The ingredients for sugarcane squash were sugarcane juice, sweet orange juice, sugar, coconut water, and ginger for seasoning. Sugarcane juice (60%) and sweet orange (20%), coconut water (10%), sugar (7%), and ginger (3%) were the most popular ways to cook squash. Few research have been conducted on concentrated fresh sugarcane juice in the form of squash because of how perishable it is.

Conclusion

The limited shelf life of sugarcane juice owing to enzymatic browning and microbiological spoiling presents significant obstacles to its enormous potential as a natural, useful beverage. This review focused on the effects of several preservation procedures on microbiological stability, nutritional retention, and consumer acceptance. These approaches included thermal, chemical, and new non-thermal methods such high-pressure processing, UV treatment, and membrane filtering. In order to increase shelf life and market appeal, value addition by fortification, fermentation, and blending has also become a practical tactic. But issues like exorbitant prices, legal restrictions, and little knowledge among small-scale producers continue to be major obstacles to broad adoption. Future initiatives should concentrate on supporting sustainable practices, incorporating preservation technology,

and advocating for affordable and scalable solutions in order to overcome these problems. The seasonal, perishable nature of sugarcane juice may be changed into a shelf-stable, value-added beverage with substantial economic potential with more research and development.

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