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RESEARCH

Comparative Efficacy of Sodium Metasilicate and Organic Source Combination on Sugarcane (*Saccharum officinarum* L.) for Reducing the Post-harvest Deterioration Losses

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Abstract

Sugarcane must be processed quickly after being harvested because it is a destructible commodity. Harvested cane may degrade for a variety of reasons, including exposure to microbes, mechanical or manual harvesting, cultivar, maturity, cut-to-crush interval, and storage. Due to the quick loss of sucrose and deterioration after harvest, sugarcane needs to be treated at the right time and way. The higher sugar content of mature internodes offers the perfect conditions for microbial growth, which enters the harvested stalk through wounds or cut ends. The bacteria *Leuconostoc spp.* is primarily responsible for these post-harvest losses, which negatively affect sugar percent. The trials were carried out to assess the efficacy of Sodium metasilicate (SMS), Benzalkonium chloride (BKC), Nisin (Lactobacteria), and Neem sources on sugarcane for reducing the post-harvest degradation losses. An investigation is underway now to reveal that foliar spray of neem cake @ 5% + dried neem leaves extract @ 5% (in heaping) is the most effective and eco-friendly substance that might be able to significantly enhance sugar recovery. This treatment was comparable with the chemical formulation of SMS @ 2% (3 days before harvest) + BKC @ 2000 ppm (in heaping) which might be a consequence of controlling the proliferation of *Leuconostoc spp.* bacterium. Likewise, the juice obtained from these treatments has a lower rate of inclination in pH, reducing sugar, total soluble solids, titrable acidity index, invertase activity, higher sucrose, and commercial cane sugars (CCS) recovery, furthermore with relatively smaller losses in cane weight. Hence, these treatments offer a significant potential role in reducing post-harvest deterioration losses in the sugar industry.

Keywords Sodium meta silicate · Neem · Nisin · *Leuconostoc* · Quality parameters

1 Introduction

India is the second-largest producer of sugar, it plays a significant role in the global sugar trade. The sugarcane cultivation area of India was 4316 thousand tons in 2000–01 which declined to 4201 thousand tons in 2005–06 and increased to 4732 thousand tons in 2017–18. The productivity of sugarcane was 68.58 tons/ha in 2000-01which was increased to 79.65 tons/ha in 2017–18 [1]. In 2019–20, India contributed the highest share of sugarcane production globally (24%) followed by Brazil (21%) and Thailand (10%). After harvest the deterioration in sugarcane is the utmost crucial problem of Indian sugar industries and has attracted widespread attention in recent years. Bio-deterioration due to microbial invasion and proliferation in harvested canes leads to a loss of up to 62% [2]. *Leuconostoc*, *Lactobacillus*

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saccharomyces, *Rodotorula,* and some other bacteria serve to cause the inversion of sucrose and a significant amount of dextran, acids, and ethanol to be produced, which alters the kinetics of sucrose crystallization [3, 4]. It causes heavy losses in the sugar mills economy.

In sugar industries, the crushing of stale sugarcane resulted in losses of 12–50% in sugar recovery [2]. Based on research evidence, more losses accordingly one thousand six hundred crores challenged by sugar industries due to the supply of sucrose-degraded canes [5]. There are numerous reasons for post-harvest sugarcane degradation but microbial sucrose losses are primarily caused by storage conditions and this was due to the time frame between harvest and crushing (staling) [6]. Field losses in CCS were in the early season at 0.35, mid-season at 1.0, and late-crushing period at 1.32 units per day [7].

The traditional practice of newly harvested sugarcane is permitted to be left in open fields in piles or transport trucks for a lengthy period of interval which paves the way for ample invasion, growth, and proliferation of microbes that lead to single cane weight loss and reduction in sucrose recovery [4, 8]. The naturally occurring sugarcane enzyme invertase, which is likewise quite active after harvest, was stronger when the ambient temperature was higher. During milling, an abundance of invertases are released and turn sucrose into inverted sugars, thus reducing the purity. In the sugarcane field polysaccharides generate bacteria from mainly *Leuconostoc spp*. which enter through the cut ends and exploited the stored sucrose further reducing the quality of milled juice. Such a condition was obtained when canes are stored in cane centers. This leads to a drop in juice quality, thereby lowering the recovery percentage [9, 10].

The most important and harmful microbes that invade harvested sugarcane stalks are the lactic acid bacteria groups like *Leuconostoc spp*. [11, 12]. This bacterium is soil-borne and obtained freely on sugarcane tissue and juice [10]. This species used sucrose as its main energy and transfer it into different substances like ethanol, organic acids, reducing sugars, and polymers with lengthy and intricate chains [13, 14]. In most of the time, harvested sugarcane stalks build a slimy layer due to the incidence of *Leuconostoc* microbe. In the first 14 h, sucrose losses through microorganisms (93.0%), enzyme activity (5.7%), and acid degradation (1.3%). It has been noted that this bacterium is more prevalent in harvested sugarcane [10, 15, 16].

According to studies, stale canes are inclined to hold more of this bacterium and produce dextran than sugarcane harvested recently [17]. This is true because *Leuconostoc mesenteroides / dextranicum* secrete the dextrasucrase enzyme, which is necessary for the synthesis of dextran [18–20]. Alteration in the establishment of dextran in stale and newly harvested canes is due to the time frame being more among harvesting and crushing. Extended sugar crystals, increased viscosity, filters blockage due to dextran, and insoluble solids were also obtained as this bacterium is washed off into juice during the cane refining process, it causes sucrose to be converted into a polymer called dextran [21, 22]. Higher sugar content (15%) and pH of 5.0–5.5 of cane juice make a perfectly congenial environment for these bacteria to occur [23]. This pH changes the quality of harvested cane which leads to losses in sucrose levels [17].

The BKC is a well-known quaternary ammonium with strong bactericidal and fungicidal qualities that works well as a surfactant, disinfectant, deodorising, and cleaning agent for hard surfaces [24, 25]. The safety to be considered that this chemical used in sugarcane, where the end product, sucrose is converted into crystalline form was taken into account while using them. Due to their anti-bacterial properties, the chemical SMS is applied as an aqueous formulation to harvested sugarcane which minimizes the sucrose losses [18]. Although many steps have been taken to stop these sucrose losses by microbes, little progress has been made in eliminating them. The goal of the current study is to learn how different chemicals act and put an effort to reduce post-harvest deterioration losses in sugarcane. To compare the fresh and stale canes and find out how antibacterial and anti-inversion chemicals affect post-harvest quality losses.

2 Materials and Methods

2.1 Experimental Site and Initial Soil Characteristics

The experimental farm was situated at an altitude of 4.6 m above MSL in Tamil Nadu's North Eastern Zone at 11o46″N latitude and 79o46″E longitude. Clayey loam soil with a pH of 7.2 and bore well irrigation make up the soil type. The mean annual rainfall is 1210 mm. This area experiences a warm and humid climate. In Cuddalore, the summer season began in April and lasted until June, which was very hot. During these months, the temperature ranges from 23 to 40 degrees Celsius. The winter season begins in December and lasts until January with temperatures ranging from 12 to 30 degrees Celsius.

2.2 Experimental Design and Treatment Schedule

The treatment package was arranged in a randomized complete block design with three replications. The pile of whole cane stalks that had been harvested with their cut ends and growth cracks which were thought to be the sites of microbial invasion were sprayed with each treatment. Rolling crushers were used to crush the canes, and juice was taken from each pile control at 0, 3, 6 and 9 days after harvest to estimate the microbial population. Juice from various treatments was used to assess the percentage of sucrose in the

juice as well as other factors like pH, reducing sugar, total soluble solids, titrable acidity index, invertase activity, and commercial cane sugar.

2.3 Treatments Schedule

Treatments		Application rate ppm or (%)	Time of application
Tr.1	Heaping of sugarcane (control)	–	After harvest
Tr.2	Heaping and covering with trash	–	After harvest
Tr.3	Sodium metasilicate (Pre-harvest spray)	2%	(3 days before harvest)
Tr.4	Sodium metasilicate (Pre-harvest spray) + foliar spray of benzalkonium chloride	2% + 2000 ppm	(3 days before harvest) + In heaping
Tr.5	Foliar spray of benzalkonium chloride (Anti-inversion and Anti-bacterial)	2000 ppm	In heaping
Tr.6	Foliar spray of neem cake + dried neem leaves extract	5% + 5%	In heaping
Tr.7	Foliar spray of Nisin (Lactobacteria)	500 ppm	In heaping

2.4 Selection of Cultivar, Planting, and Agronomic Practices

The sugarcane (variety -CoC 25 86032 with a duration of 10–12 months) was planted in the early season (December 2018 to January 2021). The 7 months old cane nursery was obtained for the preparation of setts and 75,000 two-budded setts/ha were used. The setts were soaked in fungicide (Carbendazim 0.1% + 2.5 kg urea in 250 L of water) for 15 min and then treated with *Azospirillum* (2000 g/ha) for 15 min before planting. After irrigating the plots, setts were placed in the center of the furrows continuously by keeping the buds in the lateral position and pressed gently beneath the soil. FYM was applied at 12.5 t/ha at last ploughing, incorporated, and then leveled. All the plots were kept weed-free up to 120 days after planting (DAP), as the period is considered the critical period of crop-weed competition. Earthing up was done three times on 120, 150, and 180 DAP.

The experimental plots were applied with inorganic fertilizers as per blanket recommendation (275:62.5:112.5 kg of N, P_2O_5, K_2O/ha). The entire quantity of P was applied as basal through DAP. Remaining nitrogen in the form of urea and potassium as muriate of potash was applied in four equal splits at 30, 60 90, and 120 DAP. The soil of the experimental site was sandy loam in texture with low available nitrogen of 45 kg/ac, higher available phosphorus of 10 kg/ac, higher available potassium of 135 kg/ac, available micronutrients were Fe of 17.80 ppm; Mn of 8.52 ppm; Zn of 1.17 ppm; Cu of 1.45 ppm present in the soil and EC of 0.15 dSm^{-1}. The plant's dried leaves were removed, and the green leaves were tied together by gathering all the canes into a single bundle. At the point of physiological maturity, the crop was manually harvested.

2.5 Quality Parameters Sampling, Juice Extraction, and Analysis

A clean laboratory roller crusher was used to crush three canes from each bundle to extract juice at intervals of three days (0, 3, 6, and 9 days after harvest). Before crushing, the roller crusher was surface cleaned with 0.01% $HgCl_2$ solution and washed three times in hot, sterile water. After being filtered through a four-layer muslin cloth and collected in sterilized glass bottles (500 ml), the juice was then processed for physical, chemical, and microbiological analysis on the same day.

2.6 pH

The pH meter was used to record the juice's pH (Systronics pH system 362, India).

2.7 Reducing Sugars

An aliquot of 0.5 cc of 10% diluted juice was taken in sugar tubes. Using 1.5 ml of distilled water and 2 ml of copper reagent, a final volume of 2 ml was produced. After that, the mixture was submerged for 20 min in a pot of boiling water. Measure the absorbance at 540 nm after adding 2 ml of the arsenomolybdate reagent and 25 ml of distilled water to make the volume equal. The outcomes are presented in mg/ml using the method of [25], the reducing sugar was estimated.

2.8 Total Soluble Solids

Whatman filter paper 40 was used to filter the extracted juice, and a refractometer with 0.01% accuracy was used to determine the percentage of total soluble solids [6].

2.9 Titrable Acidity Index

To determine the titrable acidity, a potentiometric titration using 0.1 N NaOH up to pH 8.1 and 1 ml of the diluted juice in 25 ml of distilled water was used.

2.10 Acid Invertase

By using the procedure of [26], the juice's acid invertase activity was measured through extraction with 1.0 ml of citrate buffer (pH 5.4). One milliliter of 0.2 M sucrose was added to 1.5 ml of 0.1 M citrate buffer (pH 5.4) and one milliliter of juice to start the reaction. The reaction was heated to 37 °C for an hour. The reaction was halted by soaking the tubes in hot water for five minutes. The tubes were centrifuged at 8000 g for 15 min. According to [25] estimates the concentration of inverted sugars in a 0.5 ml aliquot of the supernatant. The acid invertase activity was expressed as Mmol invert sugars/mg protein/min.

2.11 Sucrose

A test tube was filled with an aliquot of 0.01 ml of 10% diluted juice. Resorcinol thiourea 2.0 ml was added to 1.99 ml of distilled water to make the final volume of 2 ml. The 6 ml of conc. HCl was added after a thorough mixing and then the tube was gently shaken. The tubes were then transferred to a water bath that was kept at 80 °C for 20 min after which they were cooled under running water. Within 30 min the absorbance at 490 nm was measured against a reagent blank. The outcome is given in mg/ml juice. The resorcinol-thiourea method, as described by [27], was used to estimate the amount of sucrose in the sample.

2.12 Single Cane Weight pH

Cane weight was determined before the crushing of canes with various treatments.

2.13 Commercial Cane Sugar

Commercial cane sugar (CCS) was computed [25] as the total percent of recoverable sugar in the cane at maturity.

$$\mathrm{CCS\,(t/ha)} = [\mathrm{Cane\ yield\,(t/ha)} \times \mathrm{Sugar\ recovery\,(\%)}]\,/100$$

$$\mathrm{Sugar\ recovery(\%)} = [S - 0.4(B - S)] \times 0.73$$

where

S Sucrose (%)

B Corrected Brix (%)

2.14 Identification of *Leuconostoc* Bacteria

The presence of *Leuconostoc spp.* was investigated by their morphological, biochemical, and cultural characteristics. Gram staining using the standard technique, and a motility test using SIMs medium, were used to identify morphological traits (sulfide indole motility media). The strains obtained were identified using the 16S rDNA sequencing method for molecular characterization. Using a Thermocycler, we amplified the 16S rRNA gene from genomic DNA using the 27F (5′ AGAGTTTGATCMTGGCTCAG 3′) and 1492R (5′ TACGGYTACCTT GTTACGACTT 3′) primers at an initial temperature of 94 degrees Celsius for 2 min, followed by 30 cycles of denaturation at 94 degrees Celsius for 1 min, annealing at 56 degrees Celsius for 1 min, and extension at 72 Single-pass analysis in both the forward and reverse orientations was used to sequence PCR products (Priority Life Science, India). With the help of MEGA11, we were able to look at the sequence data and see how it matched up to other, closely similar sequences in the EzBioCloud database. The MEGA 11 program's neighbor-joining strategy was used to build the phylogenetic tree. Each node has a Bootstrap value (> 50%) based on a sample size of 1,000 tests.

2.15 Statistical Analysis

The data shown is mean values. Statistical analysis was done using the WASP 2.0 Web Agri Stat package software. Information from four independent replicates of each treatment is used to calculate the means and standard errors (±) in the tables and figures.

3 Results and Discussion

3.1 pH of Sugarcane Juice

Sugarcane juice is widely recognized for its high sucrose content and pH range of 5.5–6.5. The pH of the juice falls as the crushing time increases creating an ideal habitat for *Leuconostoc spp* to thrive [12]. It is an acidophilic bacterium and desirably its growth increased when an initial medium pH of 6.0 decreased to 4.0 likely after 20 h incubation period. The *Leuconostoc* bacterium has resulted in a faster pH reduction [28]. This bacterium can cause sugarcane juice to degrade.

The (Fig. 1a) depicts the pH level changes because of delayed sugarcane crushing with different treatments. The initial fall in sugarcane juice pH occurred three days after staling and the pH decline outline variance was observed in all the treated and control sugarcane. In the control cane, 3 days after staling pH of the juice started to decline, and a sharp fall in juice pH was seen after 6 days of staling. There was a progressive drop in pH up to 6 days of staling with a sustained decrease up to 9 days of staling in canes treated with a foliar spray of 5% neem cake extract and 5% dried neem leaves extract (T_6) and a pre-harvest spray of 2%

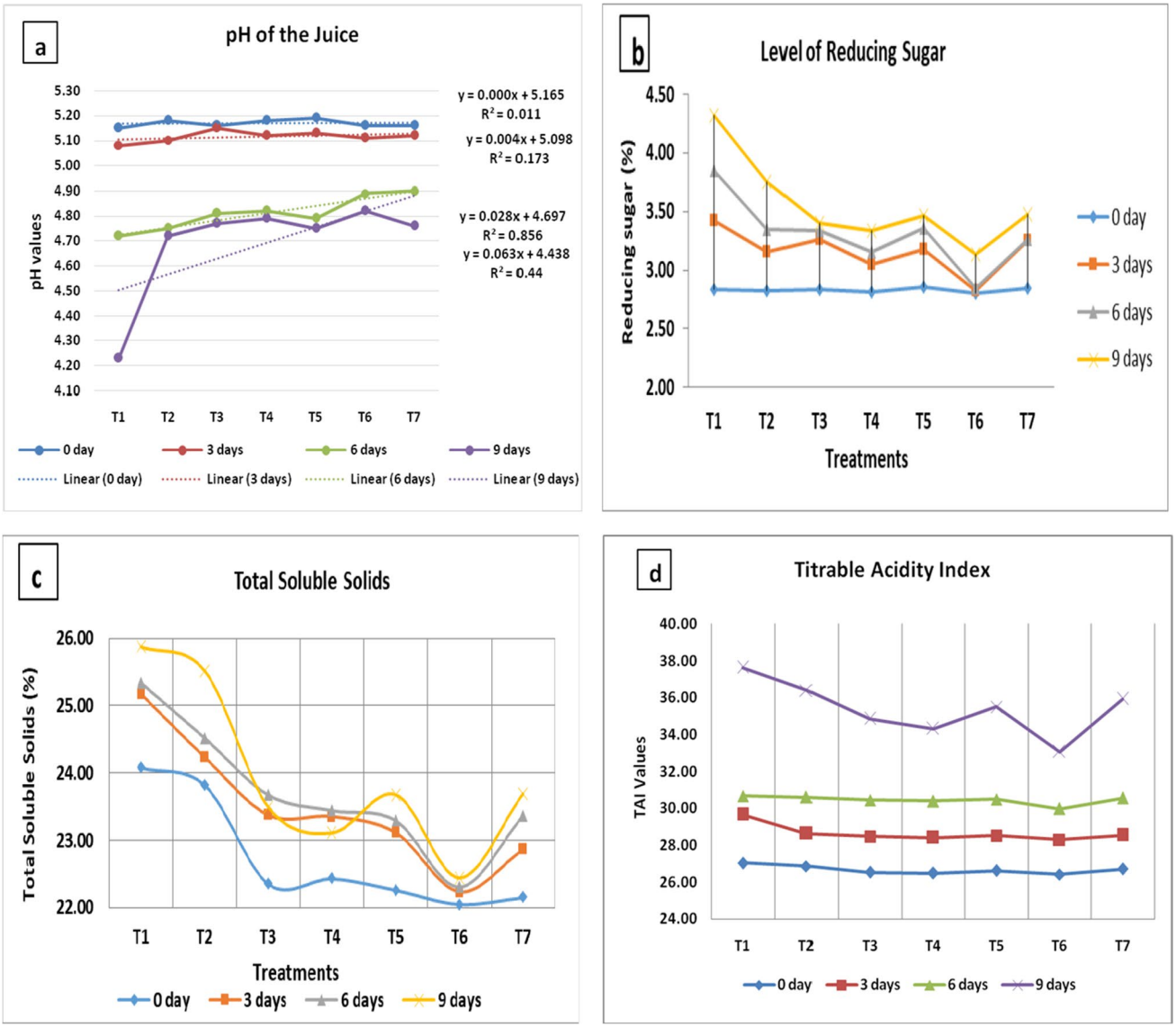

Fig. 1 Influence of SMS and organic source on post-harvest quality parameters of sugarcane at different staling periods (**a**. pH), (**b**. Reducing sugars), (**c**. Total soluble solids), (**d**. Titrable acidity index)

SMS on 3 days before harvest with foliar spray of BKC @ 2000 ppm in heaping of sugarcane (T_4). The study revealed that the control cane percentage change in pH decrease was highest (17.86%), followed by canes treated with heaping and covering with trash (8.88%), BKC (8.48%), Nisin (7.75%), SMS (7.56%) and lowest percentage change of pH reduction was observed with SMS + BKC (7.53%) and Neem extract (6.59%). This proved that the juice pH begins to drop over the progression of the harvesting process leading to increasing the juice acidity and encouraging the growth of the *Leuconostoc* bacterium. Similarly, the slight pH fall is due to the potential for small amounts of lactic acid to be produced. At the same time as 0.1% lactic acid is required to achieve about 0.1 pH level drop was earlier reported by [29].

3.2 Level of Reducing Sugars in Cane Juice

Sugar reduction is a crucial sign of cane [18]. The level of reduced sugars increases as time extends in storing canes after harvest. In all treatments, the pattern of increasing reducing sugars was consistent (Fig. 1b). In normal heaping of sugarcane (T_1) reducing sugars level was obtained to be 2.84% at 0 days although, after 9 days of staling, this was increased to 4.32% whereas in a foliar spray of 5% neem cake and 5% dried neem leaves extract in heaping of sugarcane (T_6), the level of reducing sugar was 2.80% at 0 days which raised after 9 days of harvest to 3.13% as well as a pre-harvest spray of 2% SMS + foliar spray of BKC @ 2000 ppm in heaping of sugarcane treatment (T_4), the

reducing sugars content was 2.81 percentage at 0 days which increased after 9 days of staling to 3.34. These all point out that there was an increase of 52.11% after a 9-day staling period in control heap canes but this increased level was quite lesser in neem extract and SMS + BKC treated canes as 11.79% and 18.86%. So, the T_6 and T_4 showed the least rate of reducing sugar increase with time of staling compared to other treatments. Gradual rises of reducing sugar decline the quality of sugarcane juice [30]. Generally, juice may become intense during the staling period because of moisture loss, which may also increase the activity of other hydrolytic enzymes. These microbial enzymes break down sucrose and convert it to reducing sugars [31]. More than 4 to 5 fold increase in reducing sugar from harvest to staling period due to redounded in a hasty transition from sucrose to reducing sugar [32]. The effects of cane heap temperature and extended period on harvested sugarcane stalks reported higher reducing sugars as a result of cane being stored at high ambient temperatures [33].

3.3 Total Soluble Solids of Cane Juice

Both sugars and non-sugars are included in the description of total soluble solids, which also indicates high reducing sugars are thought to be responsible for increased total soluble solids in stale canes. An increase in total soluble solids was seen along with the increase in cane staling. In contrast to control canes, those treated with neem extract and SMS with BKC experienced a gradual total soluble solids increase. Overall, 9 days after harvest, control canes showed a higher percentage change in total soluble solids (7.48%), followed by canes heaping and covering with trash (7.14%). This study implies that after 9 days of harvest, canes treated with neem extract (1.77%) and a combination of SMS + BKC (3.03%) experienced the least increase in total soluble solids. The total soluble solids values in each sample of cane juice that received a different treatment were plotted against time in days shown in (Fig. 1c). Results are confirmed by the study reports of [34, 35]

3.4 Titrable Acidity Index (TAI) in Cane Juice

The titrable acidity index (TAI) is also one of the indicators to supervise the sugarcane post-harvest deterioration. Acid-producing bacteria led to poorer juice pH and an increase in sugarcane juice acidity [36]. Progress of acidity is based on acids produced in the harvested sugarcane storage. In this experiment, After 9 days of harvest, all the treatment canes showed an increasing tendency in titrable acidity index due to an increase in the pattern of TAI differences between both control and treated canes (Fig. 1d). TAI of untreated canes or control increased gradually up to 6 days after staling before increasing sharply up to 9 days after sugarcane staling. The 9 days after harvest, a steady TAI increase was noticed in the cane that had been treated with a foliar spray containing 5% neem cake and neem leaf extract (T6) followed by the combined application of SMS with BKC in heaping of sugarcane (T4). Both these treatments had the lowest rate of TAI increase throughout staling. It claimed the juice pH value decreases while being stored or delayed during transportation of canes, increasing juice acidity. The intermingled levels of high acidity and low pH may be known for the formation of acids, which may be related to the development and propagation of the microbes particularly where the oxygen is limited [12, 22]. Acidity to be involved in sugarcane deterioration [37] and to have a positive correlation with *Leuconostoc* bacterial activity.

3.5 Invertase Activity in Cane Juice

Invertase activities dependable post-harvest sucrose losses in sugarcane. Commonly, immature internodes have extensively higher invertase activity. Over time after harvest, increased invertase activity lowers the amount of recoverable sugars because it activates the invertase enzyme [38], which lowers milling efficiency.

From three days to nine days after staling, invertase activity in harvested canes increased in both control and treated canes (Table 1). After 9 days of harvest, the control canes had the greatest increase in invertase activity value from 20.15 to 43.12 µmol sucrose hydrolyzed/mg/protein/hr with a percentage change of 114%. While the canes treated with a foliar spray of 5% neem cake extract and 5% dried neem leaf extract (T6) had the least increase in invertase activity value from 20.18 to 32.15 µmol sucrose hydrolyzed/mg/protein/hr with a percentage change of 59.32%. This is followed by a pre-harvest spray of 2% SMS + foliar spray of BKC @ 2000 ppm in heaping of sugarcane treatment (T4) with invertase activity value from 20.60 to 34.76 µmol sucrose hydrolyzed/mg/protein/hr with percentage change of 68.74%. Cane tissue loses its specificity once it has been harvested due to the invertase activity. After the cane is harvested, invertase activities play a role in sucrose degradation, which reduces sugar yield and recovery [39, 40]. Invertase activities have been observed to become active shortly after cane harvest for several rationales, *Leuconostoc* development is one of them in harvested canes because this organism is capable of reversing sucrose into fructose and glucose.

3.6 Sucrose Content in Cane Juice

The critical issue of post-harvest sucrose losses in sugarcane must be addressed by farmers and sugar millers. Farmers lose a lot of sucrose when they leave cut canes in the fields for a

Table 1 Influence of sodium metasilicate and organic source on invertase activity and sucrose content of sugarcane at different staling periods

Treatments	Invertase activity (µmol sucrose hydrolysed/mg/protein/hr)				Sucrose content (%)			
	0 days	3 days	6 days	9 days	0 days	3 days	6 days	9 days
Tr.1- Heaping of sugarcane (control)	20.15	28.25	32.85	43.12	18.48	17.83	17.02	15.21
Tr.2- Heaping and covering with trash	20.21	26.57	34.25	42.10	18.74	18.38	17.82	16.06
Tr.3- Sodium metasilicate (Pre-harvest spray)	20.25	28.06	36.54	38.08	19.52	19.09	18.62	17.57
Tr.4- Sodium metasilicate (Pre-harvest spray) + foliar spray of benzalkonium chloride	20.60	28.25	30.78	34.76	19.7	19.46	18.97	18.23
Tr.5- Foliar spray of benzalkonium chloride (Anti-inversion and Anti-bacterial)	20.36	28.56	36.32	39.25	19.24	18.89	18.33	17.04
Tr.6- Foliar spray of neem cake + dried neem leaves extract	20.18	26.57	28.59	32.15	20.11	20.08	19.66	18.62
Tr.7- Foliar spray of Nisin (Lactobacterical)	21.56	28.23	31.56	42.45	19.25	18.62	18.21	17.00
SEd	0.46	0.39	0.61	0.51	0.34	0.33	0.26	0.44
CD ($p=0.05$)	1.00	0.85	1.34	1.11	0.73	0.72	0.56	0.96

few days [41]. Additionally, microbes influence post-harvest sucrose losses. When they invade the harvested canes, they alter the quality parameters. Due to the mature internodes with high sugar content when bacteria enter the harvested stalk through cuts they flourish there [42]. A significant factor in the deterioration of sucrose has been identified as *Leuconostoc* bacterium invasion in harvested sugarcane.

The cane juice quality of sucrose content decreases with the time between harvest and staling period increases (Table 1). Based on staling period, sucrose declined most in control canes and reached 15.1% after 9 days of staling with a percentage change of 17.69% which is followed by canes treated with heaping and covering with trash (14.30%), Nisin (11.69%), BKC (11.43%) and SMS (9.99%). The lowest percentage change of sucrose content was observed with SMS + BKC (7.46%) and neem extract (7.41%) which were comparable to each other. In harvested stale canes, the rate of respiration increases quickly, leading to an increase in reducing sugars and deprivation in sucrose condensation. Stacked sugarcane significantly influences the deterioration of sucrose due to the release of carbon dioxide during respiration which increases temperature and accelerates deterioration. The reduced sucrose content was more as staling period increased [32] and delays in the cut-to-crush process caused the cane to dry out too much and cause a significant reversal of sucrose due to respiration [33].

3.7 Single Sugarcane Weight

The single cane weight of sugarcane at different staling periods is presented in (Table 2). All the treatments applied on harvested sugarcanes exhibited better results in comparison to control canes from the time of harvest until 9 days after staling. In control, the highest percentage change of single cane weight from 0 to 9 days after a staling period with 40.95%. Among the treatments, foliar spray of 5% neem

Table 2 Influence of sodium metasilicate and organic source on single cane weight and commercial cane sugars at different staling periods

Treatments	Single sugarcane weight (g)				Commercial cane sugars (%)			
	0 days	3 days	6 days	9 days	0 days	3 days	6 days	9 days
Tr.1- Heaping of sugarcane (control)	1.05	0.81	0.74	0.62	12.86	12.09	10.86	9.08
Tr.2- Heaping and covering with trash	1.52	1.31	1.28	0.95	13.02	12.56	11.50	9.95
Tr.3- Sodium metasilicate (Pre-harvest spray)	2.01	1.65	1.54	1.45	14.25	13.29	12.37	11.81
Tr.4- Sodium metasilicate (Pre-harvest spray) + foliar spray of benzalkonium chloride	2.00	1.7	1.64	1.53	14.38	13.50	12.63	12.46
Tr.5- Foliar spray of benzalkonium chloride (Anti-inversion and Anti-bacterial)	1.97	1.66	1.56	1.42	14.05	12.78	12.04	11.53
Tr.6- Foliar spray of neem cake + dried neem leaves extract	2.03	1.76	1.68	1.58	14.68	13.97	13.77	13.08
Tr.7- Foliar spray of Nisin (Lactobacterical)	1.79	1.35	1.3	1.23	13.68	12.66	11.87	11.00
SEd	0.04	0.03	0.03	0.03	0.36	0.37	0.34	0.32
CD ($p=0.05$)	0.09	0.06	0.05	0.05	0.72	0.74	0.69	0.64

cake extract and 5% dried neem leaves extract (T_6) and a pre-harvest spray of 2% SMS on 3 days before harvest with foliar spray of BKC @ 2000 ppm in heaping of sugarcane (T_4) treated cane showed a marginal difference in decreasing pattern after 6 days of staling. The least percentage change of 22.17% and 23.50% was obtained in the T6 and T4 treatments, respectively after 9 days of staling were comparable will aid in reducing cane weight loss because the staling period is directly related to loss in cane moisture content. The cane growers may suffer significant financial losses if the gap between cutting and milling widens. The rate of moisture loss in sugarcane is influenced by cane storage time and technique [43].

3.8 Commercial Cane Sugars

When analyzing post-harvest sugarcane losses, commercial cane sugars are crucial because they show how much cane sugar is commercially available. The study revealed that a decrease in commercial cane sugar content was seen in all treatments with different staling periods. After 10 days of harvest, control canes show a sharp decline in commercial cane sugars, whereas in treatments of foliar spray of 5% neem cake extract and 5% dried neem leaves extract (T_6) and pre-harvest spray of 2% SMS on 3 days before harvest with foliar spray of BKC @ 2000 ppm in heaping of sugarcane (T_4) showed a gradual decline. With the reduction in time after harvest, there was a higher reduction in commercial cane sugars in control canes with values of 12.86% to 9.08% during 0 to 9 days after the staling period of cane. The lowest decline of commercial cane sugars was obtained in a foliar spray of 5% neem cake extract and 5% dried neem leaves extract (T_6) and a pre-harvest spray of 2% SMS on 3 days before harvest with foliar spray of BKC @ 2000 ppm in heaping of sugarcane (T_4) with values of 14.68% to 13.08% and 14.38% to 12.46% during 0 to 9 days after harvesting time of cane, respectively.

The highest reduction percentage change of commercial cane sugars was showed by control canes (29.39%) which is followed by canes treated with heaping and covering with trash (23.58%), Nisin (19.59%), BKC (17.94%), SMS (17.12%). The lowest commercial cane sugars reduction percentage change was observed with neem extract (10.90%) which is significantly comparable with the SMS + BKC (13.35%). Commercial cane sugar reduction is correlated with the reduction of sucrose and cane weight [6, 44]. The nature of neem products possesses antimicrobial effectiveness especially higher antibacterial activity capacity [45, 46]. Similarly, the potent antibacterial effect of silicon components for gram-positive and gram-negative bacterial pathogens [47] by creating oxidative injury to its membrane led to bacterial dead [48–51]. These specific characteristics of neem products and SMS component helps to reduce the spoilage of sugarcane quality parameters during an extended period of staling for milling and provided higher commercial cane sugars recovery compared to all other treatments.

3.9 Identification of *Leuconostoc spp.*

Cane juice samples that were plated in *Leuconostoc*-specific media resulted in colonies that were shiny, smooth, and clear. They were found to be gram-positive. In studies on pH (pH levels 4.0 to 7.0); profuse colonies were discovered in pH 7, while pH 4.0 showed no growth. It was clear from the carbohydrate fermentation profile with various carbon sources that the bacteria cultivated after 24 to 48-h incubation used glucose, maltose, sucrose, fructose, and dextrose as carbon sources and released oxygen. However, they didn't use starch. All of these characteristics supported Bergey's

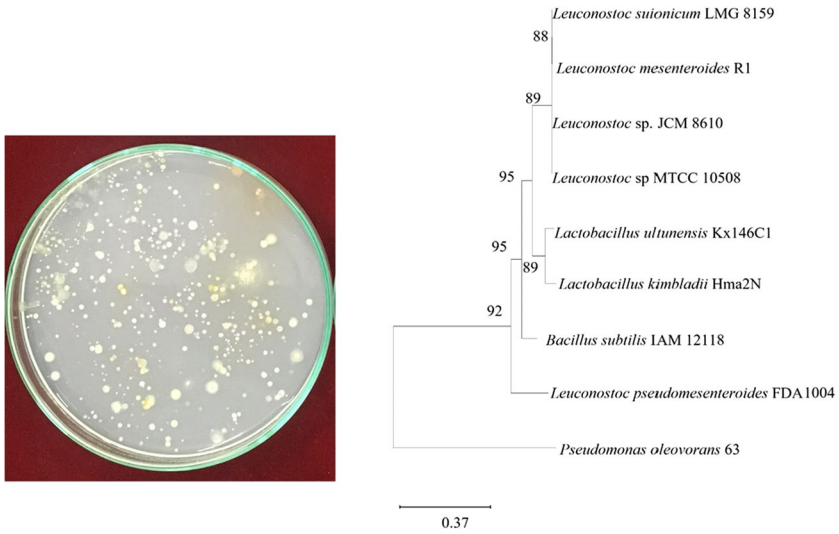

Fig. 2 *Leuconostoc* colony and their species identification by rDNA sequencing method

manual assertion that *Leuconostoc spp*. was present in sugarcane juice. The isolated strains' identification as *Leuconostoc mesenteroides* R1 was further supported by molecular testing, and they were given the accession number. The phylogenetic connections to other *Leuconostoc sp.* were shown in (Fig. 2).

4 Conclusion

Post-harvest losses are a subject to consider and realize because the decrease in quality of cane juice like sucrose content over the period following cane harvest leads to low sugar recovery and reduces mills financial prudence. The research study demonstrated was revealed that foliar spray of treated cane with 5% neem cake extract and 5% dried neem leaf extract produced the best results in reducing post-harvest losses when compared to control and other treatments tried in this experiment. Because it had a dual effect on *Leuconostoc spp*. inhibition and sucrose inversion process control by acquiring more antibacterial action ability. So, neem extract act as a low-cost source to diminish post-harvest losses in sugarcane. On the other hand, considering chemical component treatments, the neem extract treatment was comparable with a pre-harvest spray of 2% sodium meta silicate 3 days before harvest with a foliar spray of benzalkonium chloride of 2000 ppm in heaping of sugarcane due to effective antibacterial consequence of silicon-based constituent. This is finally reflected in post-harvest quality management of sugarcane with different staling periods.

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Data Availability All relevant data are within the research paper.

Declarations

Ethics Approval Not applicable.

Consent to Participate Consent was obtained from every researcher who participated in the experiment.

Consent for Publication The authors have given permission for this research paper to be published in the journal.

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References

1. Upadhyay TK (2021) A study of area, production and productivity of sugarcane in India and Uttar Pradesh. Int J Multi Discip Educ Res 10(1):59–65
2. Solomon S (2009) Post-harvest deterioration of sugarcane. Sugar Tech 11:109–123
3. Foster DH, Inkerman PA, Neil KE (1980) Studies on cane deterioration in Australia. Proc.17th Congress ISSCT 3:2204–2220
4. Singh P, Arya N, Tiwari P, Suman A, Rai RK, Shrivastava AK, Solomon S (2008) J Agric Food Chem 56(16):7176–7183. https://doi.org/10.1021/jf801394j
5. Solomon S (2002) Post-harvest cane deterioration and its milling consequences. Sugar Tech 2:1–18
6. Misra V, Solomon S, Shrivastava AK, Shukla SP, Ansari MI (2016) Post-harvest sugarcane deterioration: *Leuconostoc*and its effect. J Funct Environ Bot 6:1–7
7. Solomon S, Banerji R, Shrivastava AK, Singh P, Singh I, Verma MCP, Prajapati SA (2006) Post-harvest deterioration of sugarcane and chemical methods to minimize sucrose losses. Sugar Tech 8(1):74–78
8. Singh P, Solomon S, Prajapati CP, Kumar S, Misra V, Chandra A (2014) Dynamics of deterioration of fresh and stale juice in relation to expression of invertases and growth of *Leuconostoc sp*., Proceedings of green technologies for sustainable growth of sugar and integrated industries in developing countries, Nanning, PR China 120–124
9. Krishnankumar T, Thamilselvi C, Devadas CT (2013) Effect of delayed extraction and storage on quality of sugarcane. Afr J Agric Res 8:930–935
10. Solomon S, Singh P (2009) Efficacy of electrolysed water to minimize post-harvest sucrose losses in sugarcane. Sugar Tech 11:228–230
11. Bruijn J (1966) Deterioration of sugarcane after harvesting part 1, changes in juice composition. Int Sugar J 68:331–334
12. Misra V, Solomon S, Ansari MI (2016) Impact of drought on post-harvest quality of sugarcane crop. Adv Life Sci 5:9496–9505
13. Kim B, Robyt JF (1995) Production selection and characterization of mutants of *Leuconostoc mesenteroides* B742 constitutive of dextransucrase. Enzyme Microbiol Technol 17:689–695
14. Misra V, Solomon S, Singh P, PrajapatiCP AnsariMI (2016) Effect of water logging on post-harvest sugarcane deterioration. Agrica 5:119–132
15. McCleskey CS, Faville LW, Barnett RO (1947) Characteristics of Leuconostoc mesenteroidesfrom cane juice. J Bacteriol 54:697–708
16. Misra V, Mall AK, Pathak AD, Solomon S, Kishor R (2017) Microorganisms affecting post-harvest sucrose losses in sugarcane. Int J Curr Microbiol App Sci 6:2554–2566
17. Singh P, Solomon S, Prajapati CP, Kumar S, Misra V, Chandra A (2016) Deterioration of fresh and stale cane juice at high ambient temperature in relation to expression of invertases and the growth of *Leuconostoc sp*. Agrica 4:79–85
18. Misra V, Solomon S, Hashem A, Abd-Allah EF, Al-Arjani AF, Mall AK, Prajapati CP, Ansari MI (2020) Minimization of post-harvest sucrose losses in drought affected sugarcane using chemical formulation. Saudi J Biol Sci 27:309–317
19. Huang SX, Hou DZ, Qi PX, Wei YJ, Wang Q, Liang YP, Chen S (2019) Efficacy of neutral electrolyzed water for reducing *Leuconostoc mesenteroides* in sugarcane mixed juice. Sugar Tech 21:986–994
20. Zohra RR, Waseem S, Aman A, Siddiqui A, Kazmi SK, Zohra RR (2019) Dextran production by microbial biotransformation of sugarcane waste. FUUAST J Biol 9:87–94

21. Cuddihy JA, Rauh JS, Porro ME (1998) Improving sugar recovery with sugar process chemicals. http://www.midlandresearchlabsinc.com. Accessed 8 Jul 2004
22. Sharma KP, Batta SK, Singh R (1994) Studies on minimizing dextran problems in sugarcane under subtropical conditions. Trop Agricult (Trinidad) 71:119–122
23. Tilbury RH (1975) Occurrence and effects of lactic acid bacteria in the sugar industry. In: Carr JG, Cutting CV, Whiting GC (eds) Whiting lactic acid bacteria in beverages and foods. Academic Press, London, pp 103–128
24. Holt JG, Krieg NR, Sneath PH, Staley JT, Williams ST (1994) Bergey's Manual of determinative bacteriology, 9th edn. William & Wilkins, Baltimor, pp 541–529
25. Nelson N (1944) A photometric adaption of Somogyi method for determination of reducing sugar. J Biol Chem 153:375–380
26. Hatch MD, Glasziou KT (1963) Sugar-accumulation cycle in sugarcane. II. Relationship of invertase activity to sugar content and growth rate in storage tissue of plants grown in controlled environments. Plant Physiol 38:34
27. Roe JH, Papadopoulos NM (1954) The determination of fructose6-phosphate and fructose 1, 6 diphosphate. J Biol Chem 210:703
28. Robert H, Gabriel V, Lefebvre D, Rabier P, Vayssier Y, Faucher CF (2006) Study of the behaviour of Lactobacillus plantarum and Leuconostoc starters during – A complete wheat sourdough bread making process. Lebensmittel -Wissenschaft und-Technologie 39(3):256–265. https://doi.org/10.1016/j.lwt.2005.01.013
29. Vermeiren L, Devlieghere F, De Graef V, Debevere J (2005) In vitro and in situ growth characteristics and behaviour of spoilage organisms associated with anaerobically stored cooked meat products. J Appl Microbiol 98:33–42
30. Xiao Z, Liao X, Guo S (2017) Analysis of sugarcane juice quality indexes. J Food Qual. Article ID 1746982, https://doi.org/10.1155/2017/1746982.
31. Chandra A, Roopendra K, Singh P, Jain R, Prajapati CP, Solomon S (2014) Time-course expression of soluble acid invertase (SAI) gene mirroring post-harvest cane quality deterioration: effective treatments cause reduction of SAI gene expression. Curr Sci 107:184–186
32. Rakkiyappan P, Shekinah DE, Gopalasundaram P, Mathew MD, Asokan S (2009) Post-harvest deterioration of sugarcane with special reference to quality loss. Sugar Tech 11(2):167–170
33. Lontom W, Kosittrakun M, Weerathaworn P (2009) Impact of storage temperature and duration on sucrose catabolism in harvested sugarcane stalks. Sugar Tech 11:146–153. https://doi.org/10.1007/s12355-009-0022-8
34. Bhatia S, Jyoti SK, Uppal KS, Thind SK, Batta (2009) Post-harvest quality deterioration in sugarcane under different environmental conditions. Sugar Tech 11(2):154–160
35. Saxena P, Srivastava RP, Sharma ML (2010) Impact of cut to crush delay and bio-chemical changes in sugarcane. Aust J Crop Sci 4:692–699
36. Khan MT, Yasmeen S, Khan IA (2020) Comparative analysis of sugarcane genotypes for post-harvest deterioration under natural conditions. Pak J Bot 52:4
37 Eggleston G, Huet JM (2012) The measurement of mannitol in beet sugar factories to monitor deterioration and processing problems. Zuckerindustrie Sugar Industry 137(1):33–39
38. Mao L, Que F, Wang G (2006) Sugar metabolism and involvement of enzymes in sugarcane (Saccharum officinarum L.) stems during storage. Food Chem 98:338–342
39. Shivalingamurthy SG, Anangi R, Kalaipandian S, Glassop D, King GF, Rae AL (2018) Identification and Functional Characterization of Sugarcane Invertase Inhibitor (ShINH1): A Potential Candidate for Reducing Pre- and Post-harvest Loss of Sucrose in Sugarcane. Front Plant Sci 9:598. https://doi.org/10.3389/fpls.2018.00598
40. Devi K, Prathima GR, Manimekalai R, Lakshmi K, Selvi A (2019) Gene expression profiling in sugarcane genotypes during drought stress and rehydration. Sugar Tech 21(5):717–733
41. Mukunda Rao M, Vijaya Kumar M, Sambasiva Rao CH, Balaji-Naik R, Sekhar D (2008) Sugarcane quality deterioration between harvest and crushing period under Telangana region of Andhra Pradesh. Coop Sugar 39(12):19–21
42. Solomon S, Singh P, Shrivastava AK, Singh P, Chandra A, Jain R, Prajapati CP (2011) Physico-chemical method of preserving sucrose in harvested sugarcane at high ambient temperature in a sub-tropical climate. Sugar Tech 13(1):60–67
43. Uppal SK, Bhatia S, Thind KS (2008) Pre milling cane preparation for high sugar recovery and reduction of post harvest losses in sugarcane. Sugar Tech 10:346–349. https://doi.org/10.1007/s12355-008-0061-6
44. Misra V, Mall AK, Solomon S, Ansari MI (2022) Post-harvest biology and recent advances of storage technologies in sugarcane. Biotechnol Rep (Amst) 33:e00705. https://doi.org/10.1016/j.btre.2022.e00705
45. Mohammed HA, Omer AA (2015) Antibacterial activity of Azadirachta indica (Neem) leaf extract against bacterial pathogens in Sudan. Am J Res Com 3(5):246–251
46. Yilleng TM, Samuel NY, Stephen D, Akande JA, Agendeh ZM, Madaki LA (2020) Biosynthesis of copper and iron nanoparticles using Neem (Azadirachta indica) leaf extract and their antibacterial activity. J Appl Sci Environ Manag 24(11):1987–1991
47 Luthfiah A, Deawati Y, Firdaus ML, Rahayu I, Eddy DR (2021) Silica from natural sources: a review on the extraction and potential application as a supporting photocatalytic material for antibacterial activity. Sci Technol Indonesia 6(3):144–155. https://doi.org/10.26554/sti.2021.6.3.144-155
48. Smirnov NA, Kudryashov SI, Nastulyavichus AA, Rudenko AA, Saraeva IN, Tolordava ER, Gonchukov SA, Romanova YM, Ionin AA, Zayarny DA (2018) Antibacterial properties of silicon nanoparticles. Laser Phys Lett 15(10):5602. https://doi.org/10.1088/1612-202X/aad853
49. Tian B, Liu Y (2020) Antibacterial applications and safety issues of silica-based materials: a review. Int J Appl Ceram Technol 18(2):289–301
50. Anitha R, Vanitha K, Tamilselvi C, Jeyakumar P, Vijayalakshmi D, Yuvaraj M, Nageswari R, Dhanushkodi V, Cyriac J (2023) Potential applications of silicate solubilizing bacteria and potassium silicate on sugarcane crop under drought condition. SILICON. https://doi.org/10.1007/s12633-023-02534-z
51. Gupta AP, Nigam N (1982) Formation of non-sucrose compounds in sugarcane on storage during post-harvest period. Maharashtra Sugar 7(3):51–64