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REVIEW ARTICLE

Post-harvest deterioration of sugarcane

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Abstract Sugarcane is a perishable commodity and must be processed into sugar quickly after it is harvested. Post harvest sucrose losses have been reported from many cane producing countries and linked with low sugar recovery and several problems during sugar processing. Bio deterioration is associated with the inordinate delays between harvest to milling of sugarcane and aggravated by many intrinsic and extrinsic factors causing enormous depreciation in cane tonnage as well as sugar recovery. Besides harvest-to-mill delays, other factors such as ambient temperature, humidity, cane variety, period of storage, activities of invertases, maturity status etc. are responsible for decline in sugar recovery. The activity of invertases and proliferation of acid, ethanol and polysaccharides (dextran) producing microbes play a crucial role in the loss of recoverable sugars in cane and milled juice. In addition to loss in sugar recovery, its adverse affects has been noticed in the sugar manufacturing process and sucrose quality. Efforts have been made to reduce loss in tonnage and sucrose using physico-chemical methods. These include spraying of water, bactericidal solution, use of anti-inversion and anti-bacterial formulations and pre-harvest foliar and soil application of zinc and mangnous compounds. An integrated mill sanitation program and simultaneous use of dextranase could further improve sugar recovery and minimize problems caused by dextran. The possibility of electrolyzed water (EW) fogging to reduce post harvest deterioration in field and mill yard has also been explored. Some of these methods are useful and present larger options for the industry to minimize after-harvest quality losses in the field and milling tandem.

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Introduction

The post-harvest deterioration of sugarcane is one of the most vexing problems of sugar industry and has attracted widespread attention in the recent years. The published reports indicating loss of recoverable sugar following cane harvest began to appear towards the end of the 19th century (Stubbs 1895; Weinberg, 1903; Cross and Belile, 1914, 1915). According to these authors, Went and Geerligs from Java reported deterioration of sugarcane in 1894. Early workers emphasized the importance of time lag between harvesting and milling as well as storage environment in deterioration process. Muller von Czernicki (1900) and Browne and Blouin (1907) in Java reported considerable drop in juice purity during storage of cane, however, no scientific explanation was advocated by the author. The earliest specific reference to a cane invertase role in post-harvest deterioration was made in 1907 by Browne and Blouin and later on Hall in 1913 used the term inversion to be associated with the process of cane deterioration and subsequently published another report on inversion in 1914. In 1915 Cross and Belile performed studies which established the presence of an inverting enzymes in the millable stalks and milled juice, and their they become more active during storage. These workers stated "It appeared to us possible that the inversion in the stored canes might also be due to the ferment invertase, and we therefore stored some of the juice of one of these canes with chloroform and toluene, and analyzed it after a certain time. It was found that considerable inversion had taken place. As bacteria were excluded by the antiseptics added, the inversion must have been due to a ferment, probably invertases present in the deteriorated cane". Guilbeau *et al* (1955, 1956), noticed the phenomenon of after ripening associated with the cane deterioration and advocated that increased sugar yields and profits could be gained by storing harvested cane in heaps for a period of one week or more.These workers pointed out that increased sugar content was attributed to loss in cane weight. However, in actual practice sugar content, purity of juice and tonnage showed significant decline. Somewhat similar effects were reported by Australian scientist (Egan,1971). A rapid decline in CCS and dextran formation in mechanically harvested burnt sugarcane crop were also reported from Taiwan (Hsia, 1972). Alexander(1973) in Puerto Rico concluded that no significant increase in recoverable sugar resulted as a delayed grinding response. Many researchers reviewed the work on post-harvest biotechnology of sugar crops and highlighted the importance of loss reduction technology in improving sugar productivity. (Bruijn, 1966; Salunkhe and Desai (1988), Batta and Singh, 1991; Magadum and Kadam, 1996; Eggleston *et al.,* 2001; Sharma *et al.* 2004 ; Milintawisamai *et al.* 2006; Solomon, 2000, 2002, 2004, 2006, 2009; Solomon *et al*., 1990, 1996 , 1997, 1999, 2001, 2003, 2008).

The terms *Stale cane* and *Sour Cane* are two different stages of cane deterioration after harvest . During the process of deterioration, metabolic conversion of stored sucrose takes place into less economic products (organic acids, oligo and polysaccharides, gums, ethanol) through the agency of enzymes and microbes. The stale cane according to Alexander (1973) is the aging of harvested stalks which have depleted their sucrose via continuing inversion and respiration. Whereas sour cane is microbiological deterioration of sugarcane stalks by lactic acid bacterium *Leuconostoc mesenteroides* which converts sucrose into organic acids of typical sour odor. However, both types of deterioration seem to operate simultaneously in cane and milled juice.

Industry problem

Sugarcane deterioration that detrimentally affects industrial processing is a serious economic problem for sugar industry in many cane processing countries. The postharvest sugarcane deterioration products are dependent on many factors such as method of harvesting, sugarcane injury, environmental conditions, variety, supply system, harvest to milling delays etc. Sugarcane management and harvesting methods also differ. In the prevailing supply system of raw material, cut to crush delay of 3 to 5 days is quite normal which aggravates deterioration process in the harvested cane due to inversion, respiration and formation of acids, alcohol and polysaccharides producing micro-organisms. Sucrose loss in the harvested cane and milled juice through these biochemical and microbiological agents *(Leuconostoc sp.*) has detrimental affect on sugar recovery and presently a serious economic problem to sugar mills in many cane producing countries. *Leuconostoc* infections is considered as one of the main causes of factory processing difficulties when handling deteriorated sugarcane. Economically, it may not be worthwhile to process a deteriorated cane. Not only can poor cane quality impinge on profitability, it could also trigger off many processing problems and consequently factory shutdown.

The following constraints seem to operate at farmers and factory level which lead to deterioration of cane quality. These bottlenecks in cane logistics considerably delay the milling of harvested crop and consequently impacts raw material quality, upstream processes, sugar quality and recovery .

(i) There is a general misconception amongst cane growers and cane development staff that sugarcane is a weather resilient crop and there are minimal quantitative and qualitative losses after its harvest.

(ii) Many sugar factories do not maintain a proper varietal balance (i.e. early, mid-late and late maturing varieties; ratoon, spring and autumn planted crop) and follow scientific harvesting and crushing schedule based on crop/varietal maturity. This leads to a substantial quantity of immature cane in supplies which deteriorates faster and also affect juice quality during milling process.

(iii) In developing countries, farmers practice of harvesting sugarcane crop 3 to 5 days in advance before its supply to sugar mills (as practiced in Indian sub-tropics), is very common.

(iv) Limited crushing capacity of the mills resulting into staling of cane in mill yard/cane centers (an intermediary agency between farmers and mill which manages supply of cane). Some old mills have grinding capacity of < 1000 TCD.

(v) In some places, transport of harvested cane from farmer's field/ cane centers to the sugar mills is delayed due to lack of an efficient communication network.

(vi) In years of excess production, milling season is extended during summer months when ambient temperature is high (>40^{o}C). This leads to a quick decline in sugar content due to inversion and respiration.

(vii) Many undesirable practices such as uprooting, burning and de-topping of cane are prevalent in many countries.

(viii) Supply of cane with high extraneous matter (EM) in countries where farmers are paid on the basis of cane weight.

(ix) Absence or lack of understanding regarding cane and mill sanitation program and use of low quality biocides and application of inadequate quantity during milling process.

There are two areas of post-harvest quality losses leading to low sugar recovery.

(a) *Primary Losses:* Sucrose inversion process following harvesting of sugarcane and subsequent delays in delivery of cane to the sugar factory,

(b) *Secondary Losses*: Factory losses due to inversion, dextran, alcohol and acid formation in the extracted juice incident to inefficient and unhygienic processing.

Due to these factors, in most cases, field losses in sugarcane quality considerably exceed factory losses borne by the processor. The following causes are often attributed to post-harvest cane staling at the farmer's field/mill yard and in the milling tandem.

(a) Nature of varieties grown in the area (rind hardness, wax content) and their inversion behavior.

(b) Moisture and original condition of cane, maturity status of the crop.

(c) Pre-harvest practices such as late application of N, burning and severity of fire, de-topping, etc.

(d) Atmospheric conditions at the time of harvest and storage, viz., temperature, humidity, and rainfall.

(e) Methods of harvesting viz., hand cut or mechanically harvested.

(f) Green or burnt cane harvesting ,size of billets (short/ long green, short/long burnt).

(g) Storage methods (open storage or in piles, size of the piles) and duration.

(h) Time lag between harvesting to milling or cut-to-crush delays .

(i) Sanitary conditions outside (cane yard) and inside the mill as well as efficiency of processing,

(j) Physical condition of cane i.e. number of bruises, presence of mud, loading and transport methods etc.

(k) Crop history viz., incidence of pests and diseases; factors affecting growth and quality of crop viz., saline, alkaline, drought, water-logging, frost, stand-over cane, extremes of temperatures and excessive use of compost made from dunder/ vinasse.

Factors responsible for cane deterioration

1. Sugarcane varieties : Sugarcane varieties play a crucial role in sugar recovery, depending upon the climate and management practices followed (Lauritzen and Balch, 1948). A very big difference in susceptibility to post-harvest deterioration has been noticed which is important in countries where there are prolonged harvest-to-milling delay. Sugarcane varieties, in addition to their inversion behavior may also have an effect on its susceptibility to *Leuconostoc* infection (Ahmad and Khan, 1988; Balusamy *et al*., 1990; Dendsay *et al*., 1992; Chiranjivi Rao, 1993; Uppal and Sharma, 1999; Solomon *et al*. 1997; 1999, 2001, 2003; Uppal *et al*., 2000, Larrahondo *et al*., 2002; Sugarcane varieties have been evaluated for their post harvest performance under tropical and subtropical climate (Raja Rajeshwari *et al*, 2006; Siddhant *et al*. 2008). The fibrous varieties show higher reduction in sucrose compared to less fibrous type. A large number of factors such as ambient temperature, humidity, nature of variety, period of storage, activities of soluble invertases in cane, maturity status etc. are responsible for this difference.

2. Crop maturity : The fully mature cane will not deteriorate as rapidly as either immature or over mature cane. This deterioration is relatively faster in hot weather. Cane maturity is a major factor governing the rate of inversion in harvested cane. As maturation level increased the extent of deterioration slackened.

3. Green and burnt cane: Extensive literature on this aspect shows that full green cane are less susceptible to post-harvest deterioration as compared to the chopped /burned cane (Boneta-Gareia and Lugo-Lopez, 1962; Turner and Rojas, 1963; Young, 1963; Foster, 1969; Foster *et al.*, 1977a & b; Foster and Ivin,1981; Sang *et al*., 1986; Chiranjivi Rao 1989). The effect of cane burning on dextran production has been studied in detail by many workers. Available reports show that burnt chopped cane deteriorates faster as compared to green chopped cane. Delaying the harvesting of burned standing cane or supply of burned harvested cane could lead to a marked loss in the yield of sugar (Samules and Gayere, 1967; Amin *et al*., 1971; Ivin and Foster,1977; Cox and Sahadeo,1992; Eggleston *et al.*, 2001).

4. Environmental factors : Weather has profound influence on cane deterioration, higher the temperature and humidity, and wetter the weather, the greater is the deterioration (Solomon *et al*., 1997; 2006; Uppal and Sharma,1999; Uppal *et al*, 2000). Deleterious effects of high temperature (> 40^{o}C) and low atmospheric humidity (25-35%) on juice quality have been reported by many workers. A recent study from sub-tropical India show that the loss in CCS was 0.35, 1.0 and 1.32 units per day during early (winter crushing) , mid-season (Spring) and late-crushing periods (summer crushing), respectively. The wetness is especially detrimental in mechanically harvested crop and it was reiterated that, if possible, harvesting operations should be suspended during rainy weather (Wold, 1946). Rainfall *per se* does not affect deterioration or dextran formation but the muddy field conditions created by heavy rain do. Muddy cane favors multiplication of polysaccharide producing bacteria such as *Leuconostoc* sp. which live in soil and so are held in close contact with sugarcane tissues. Beside, these bacteria prefer an anaerobic environment and multiply rapidly when air is blocked by mud. The effect of ambient temperature on cane deterioration is well known. Higher night time temperature triggers off dextran production in stored cane. These observations support that environment play a major role in quality decline after harvest, however variety factor also influences deterioration process, but to a certain extent.

5. Mechanical harvesting : The introduction of mechanized harvesting and subsequent chopping of green burnt cane leads to loss of quality and dextran formation, a deterrent in processing. The mechanical harvesting with consequent delay in delivery of cane to sugar factory continues to be one of the major problems affecting factory efficiency and sugar quality. Egan (1968) reported that post-harvest losses in crop harvested by chopper harvester in Queensland (Australia) represented 6 to 11 per cent of the original CCS present, as compared to a loss of 1 to 2 per cent in the stored whole cane. Egan (1971) found that size of the billet was most crucial in post-harvest deterioration. A study by Singh and Solomon (2003) showed that billets, in general, recorded significantly higher decline in recoverable sugar, purity and juice pH. Dextran and reducing sugars contents were also significantly higher in billets as compared to whole cane after 7 days of staling. The mechanical harvesting of burnt or unburnt cane has been shown to reduce cane quality *vis-à-vis* sugar recovery in many countries (Egan, 1963, 1968,1971; Irvine and Legendre, 1973; Larrahando, 2005; Larrahando *et al.,* 2002, 2006). In mechanically harvested sugarcane with high trash content, drop in purity, sucrose and phosphate content was reported (Larrahondo, 2005) with increased dextran levels. A recent study by Solomon *et al.* (2008) with sugarcane billets during late-milling period indicated over 1.0 unit decline in CCS per day whereas, in conventionally harvested whole-stalk green cane it was relatively less.

6. Effect of biotic and abiotic stress : In biotic and abiotic stress affected canes the process of deterioration sets in before the harvest which leads to steep loss in quality if cut-to-crush delay is more. In stress affected crop, major physiological and chemical alterations have been noticed which are conducive to further deterioration of cane quality. Frozen cane and frost-induced deteriortion is sometimes a serious matter in Louisiona, Florida, Argentina, and other regions situated on the northern and southern periphery of the sugarcane World. Freeze-deteriorated cane can cause problems in processing and sometimes leads to a factory shut-down. Temperatures below 22^{o} F kill all above-ground parts of commercial varieties, showed significant harmful changes in juice quality i.e. sucrose content, purity, sugar yield, pH, acidity and dextran concentration. (Eggleston and Legendre, 2003; Eggleston *et al*., 2004; Legendre *et al*. 2007).

7. Sugarcane transport-loading system and its impact on sugar losses : The cane transport system comprises of man, bullock carts, camel carts, canals to highly mechanized road and rail cars and is a major factor governing quality of harvested cane. The time factor during transport, storage conditions, degree of damage from loading equipment and size and shape of transport containers are important factors in regulating cane quality. Transport of fresh cane in small storage containers is less prone to deterioration. Grab loaders, chains, slings, push-pile rakes, etc. can mutilate cane which is aggravated by mud and high temperature. These canes are likely to develop massive population of *Leuconostoc* , especially if left for a longer time. Studies carried out in Louisiana, where cane is burned prior to harvest, clearly showed that cane cut late in the day(billet cane) and left overnight in the trucks for early morning delivery is a good breeding ground for *Leuconostoc* bacteria and dextran production. The same factors are important in the Cane centers and mill yard i.e. temperature, cane conditions and size of the cane piles. The cleanliness and hygiene in the yard is therefore an important factor and that "First cane in should be first cane out". In India, cane supplied by the animal driven carts is usually considered fresh and of better quality. On the other hand, cane supplies routed through intermediate cane agencies are usually of sub-optimal quality (Solomon *et al*., 1997).

Magnitude of post-harvest sucrose losses

Studies have conclusively proved that the cut-to-crush interval and external temperature are most important factors which determines the rate of sucrose loss through inversion, organic acids, dextran and polysaccharides formation and respiration. Hughes (1956) reported sugar losses as high as 35 per cent at the Hawaiian Commercial and Sugar Factory Ltd., Punnene, Maui, during the period 1929 to 1953 mainly due to staling. These losses were expected to increase upto 50 per cent if the management of crop and its subsequent processing was not done on scientific lines. Many studies have reported quality losses from delayed grinding of sugarcane crop varied from a minimum of 12 per cent to as high as 50 per cent of the recoverable sugar from fresh cane after it was held for 14 days (Guilbeau 1955, 1956). According to Egan (1968), for normal weather conditions, some of the heaviest losses (in CCS) reported are 4 per cent in Dominican Republic, 5 per cent in Mexico, 7 per cent in Argentina and 8 per cent in India. Studies conducted by Chiranjivi Rao (1989) have shown 2% loss in sugar recovery when cut-to-crush period exceeds 72 h. Burcer *et al.* (2004) reported 1.5 per cent loss in sugar/day due to delayed milling. Studies undertaken by Solomon (2008) in India have shown over 1.0 unit loss in pol% cane from harvest to milling stage. On an average, Indian sugar mills lose about 5 to 10 kilogram sugar per ton of cane ground. These losses further shoot up when crushing is extended in summer months. The enormous amount of sugar lost during post-harvest operations point out the futility of increasing sugar production in field level if sugar is not proportionately recovered in the factory.

Economic implications of cane staling

The deterioration of cane after harvest has serious socio-economic consequences affecting farmers, millers, refiners, exporters and consumers. The post-harvest deterioration of sugarcane mainly affects cane growers and millers. A rapid loss of moisture from the harvested cane affects the growers due to reduction in cane tonnage. The sugar industry loses money due to low recovery from the deteriorated cane. Besides, many undesirable compounds are formed as a result of bacterial growth, and chemical reactions which impede sugar processing. The low quality sugar produced from deteriorated cane adversely affect consumers and exporters.

Cane growers: The deterioration in cane quality due to cut-to -crush delay affect cane growers as well as sugar industry. Loss of moisture from the harvested cane affect the growers due to reduction in cane weight, as payment is made on weight basis. Solomon (1997)observed weight loss between 7 to 10 percent under sub-tropical conditions within 72 hours after harvest. This delay in supply of harvested cane to sugar factory could lead to major economic loss to cane growers. As per the prevailing State Advised Prices (SAP) in north-India, loss to growers may exceed US$ 2 per tonne cane.

Sugar industry: The impact of processing deteriorated cane is enormous and has debilitating effects on sugar industry. Above and beyond loss in sugar recovery, it impacts machinery, process and quality of the final product-sucrose.

The sugar industry loses money due to low recovery from deteriorated cane. A sugar mill (capacity 5000 ton cane per day) crushing 72 h stale cane may lose around US$ 6000 per day on account of low sucrose recovery. These losses may further escalate depending upon the variety, cut-to-crush delay and ambient temperatures. In addition, many undesirable compounds formed during cane deterioration due to chemical and microbial activity entail sugar processing difficult and also render the sugar manufacturing uneconomical.

Biochemical basis of post-harvest sugar loss

The deterioration of harvested cane is primarily a biochemical process which aggravates with the passage of time. This is followed by bacterial invasion through the cut ends or damaged sites of stalk. The time lag between harvesting and milling is therefore, of crucial importance to achieve maximum sugar recovery. Early experiments of Rizk and Normand (1968, 1969) demonstrated the presence of acid and neutral invertase in cane stalk and both the enzymes has the tendency to increase after harvest. Alexander (1973) elucidated the critical role of sugarcane invertases in post-harvest sucrose loss, and emphasized that all invertases present in cane lose their tissue specificity once the stalk is ground and the enzymes are released into the milled juice. Solomon *et al* (1990) noticed increase in the activity of both acid and neutral invertase after 72 hours of storage of cane with a corresponding rise in the level of invert sugars. The CCS drop after this period becomes quite significant, due to increase in acid invertase activity. This change in invertase activity in harvested cane is also associated with the loss of moisture from cane. The behavior of endogenous invertase varies with the variety, storage conditions and the external temperature. The highest activity was recorded during late-crushing period when the ambient temperature exceeds 40^{o}C. Besides invertases, presence of amylase, acid phosphatase, carboxymethy cellulase and fructose 1,6 di phosphatase in deteriorated cane were also reported (Das and Prabhu,1988). These studies have indicated that many hydrolytic enzymes gets activated during storage of cane, which are responsible for decline in its quality. These enzyme(s) in harvested cane play a major role in the loss of sucrose and during subsequent milling and upstream processes. Batta and Singh (1991) and Uppal et al (2008) observed that the activity of acid invertase (pH 5.4) was lower than that of neutral invertase (pH 7.1) in fresh cane. Activities of both the enzymes increased during storage and pattern of both enzymes remained unaltered during post-harvest period. Mao and Wang (2006) studied the sucrose metabolism in sugarcane stalks during storage and also recorded increase in invertase activity after harvest.

Singh *et al*. (2008) studied the magnitude of post-harvest sucrose losses and its relationship with acid invertase and dextransucrase enzymes during late milling season. There was a significant relationship between reduction in commercial cane sugar (CCS) and increase in the activities of these enzymes.

Microbiological aspects of cane deterioration

Egan reported that *Leuconostoc mesenteroides* is the principal cause of deterioration of harvested cane (Egan, 1965 a, b). The microbes infect cane wherever the stalk is damaged or cut. It rapidly colonizes the damaged tissue which is followed by lowering the sucrose content, juice purity and pH. The titrable acidity increases markedly within two days after infection. The loss in CCS becomes apparent in chopped cane compared to whole stalk (Egan, 1968; Tilbury, 1969). Microorganism such as *Leuconostoc* and some acid producing rods are found in the interior of cane stalk immediately after cutting. Infection is found heavier if the cane is harvested in the early morning, before the extruded juice is dried off. It has been advocated that the sites for microbial multiplication such as extruded juice globules, growth cracks and protected areas beneath sheath provide sufficient and congenial place for microbial multiplication (Beavan and Bond, 1971). Massive infection is found up to six inches from the cut ends after about one and half hours storage. Organisms such as yeasts, *Leuconostoc, Xanthomonas* and *Aerobacter* the last three being producer of mucoid material such as dextran are present at cut ends or damaged sites. Presence of *Penicillium, Actinomyces* and acid producing *Streptomyces* was also recorded on harvested cane (Kulkarni and Kulkarni,1987).

The deterioration due to microorganism is also known as biodeterioration and caused by mainly *Leuconostoc* sp. (*L. mesenteroides* and *L. dextranicum)*. These organisms form nodular colonies after multiplication, under favorable conditions, by converting sucrose into polysaccharides, such as dextran. The microorganism is a facultative anaerobe and reproduces rapidly under anaerobic conditions, such as mud coated canes and cane stored in large piles with poor ventilation. The sucrose to dextran reaction is catalyzed by enzyme dextransucrase or exogenous invertase. Dextransucrase catalyses the transfer of glucose moiety of sucrose to the primer for the formation of dextran, a long chain polysaccharide.The glucose and fructose are converted to organic acids and mannitol by the enzymes secreted by bacterium.

In addition to the entry of many external microbes, sugarcane stalks contains an endophytic microbial flora viz., *Acetobacter, Enterobacter, Pseudomonas, Aeromonas, Vibrio, Bacillus* and lactic acid group which increased several folds during staling and also responsible for deterioration of juice quality. The heterotrophic bacterial population inside the parenchymatous tissues of the fresh and stale canes varied from 1.5 x 105 to 7 x106 cfu g^{-1} to 9 x 105 to 7 x106 cfu g^{-1} tissue, respectively. Deterioration is triggered off by endogenous invertase as well as invertase of bacterial origin followed by the production of secondary metabolites such as organic acid, dextran, gum and alcohol. Furthermore, very high bacterial population in stale cane, needs to be brought down considerably to minimize sugar losses (Suman *et al*., 2000). Saeng-on and Daengsubha (1984) reported that *Streptococcus* sp. was the major population and showed highest activity in decomposing the sucrose in sugarcane juice. In addition, *Lactobacillus fermentum, Leuconostoc mesenteroides* and *Lactobacillus cellobiosus* were also found some what predominant and showed decomposing activity in the juice. It is well known that deteriorated sugarcane detrimentally affects processing in the factory, due to high dextran content.

Origin of dextran in sugarcane

The problems caused due to bacterial polysaccharides such as dextran in sugar manufacture are not new, and sugar technologists were aware of it probably since the time sugar extraction and processing came into existence. Several excellent reviews of dextran and polysaccharide production in sugarcane are available, highlighting their role in sugar manufacturing process (Imrie and Tilbury, 1972; Coll *et al*, 1978; Bose and Singh, 1981; Roberts *et al*, 1983; Shaw 1984; Atkins and McCowage, 1984; Kitchen,1988; Sharma *et al,* 1994; Clarke,1997; Hylton,1997; Cuddihy and Day 1999; Cerutti *et al* 2000; Rauh, *et al*. 2001; Abdel-Rahman *et al*. 2007).The origin of dextran in cane could be attributed to the following factors:

(i) Time lag between harvesting and milling
(ii) Size of cane piles and storage conditions
(iii) Size of the billet,
(iv) Varietal characteristics, cane husbandry & harvesting practices,
(v) Ambient temperature and humidity,
(vi) Rainfall and mud
(vii) Degree of pre-harvest burning and delay between burning and harvesting,
(viii) Poor sanitary conditions inside the mill house,

Dextran formation and sucrose losses

Dextrans are commonly produced in sugar process streams by bacteria of the genera *Lactobacillus, Leuconostoc* and *Streptococcus.* The principal cause of deterioration is the presence of *Leuconostoc* bacteria while the subsequent deterioration of cane depends on the time lag between harvesting and milling retention of juice in the tank as well as atmospheric temperature and humidity. The sucrose losses as a result of dextran formation is approximately 1.9 times the dextran formed. Clarke *et al.* (1980) calculated the loss of sucrose and acid produced due to dextran formation. It was pointed out that for every 0.1 per cent of dextran produced represents sucrose loss of 0.04 per cent.

Besides its adverse effect on sucrose recovery, presence of dextran and other undesirable polysaccharides in raw sugar are adversely affecting the export potential of many sugar producing countries. Many sugar refiners in USA have been penalizing all sugars high in dextran which obviously enters the factory with deteriorated cane. Thus the problem of post-harvest cane deterioration has become more alarming in countries where economy is largely dependent on the export of sugar.

Effect of cane deterioration on milling process

The stale cane undergo further deterioration in quality during subsequent milling operations i.e., cane preparation, juice extraction and clarification stage. The harvested sugarcane stalks delivered to the mills contain a large number of bacteria which further multiplies if time lag between harvesting and milling is more. The soil coming along with the cane is also full of bacteria. During milling process, high population of bacteria are passed on into the extracted juice. The microbes thus entering the juice starts their activity under favorable conditions of temperature and pH. The conditions become worse when the disease or pest infected cane is ground in the Mills. The activity, survival and growth of micro-organism is at its peak when the temperature levels are between 30^{o}C to 40^{o}C and go in dormant condition when the temperature exceed 95^{o}C. The activity of microbes is considerably reduced when the juice is heated and sent to clarifiers and remains in dormant condition in the muds and clarified juice. The muds, pass through the filter station and the filtrates are re-circulated to the mixed juice, where these microbes readily become active.

Diluted juice has been found to favor the growth of micro-organism and hence the imbibition water entering the last mill speeds up their multiplication. An increase in temperature by 1°C brings about ten fold increase in the activity, maximum at 30-40°C. Alkaline condition (pH 8.0) greatly favors the production of dextran in juice.

Post-harvest deterioration and sugar processing

The field origins of dextran showed that *Leuconostoc* can enter sugarcane storage tissue before harvest when cane is physically damaged (cracks, lodging) while undamaged standing cane is free of internal contamination with *Leuconsotoc.* Also, over burning of cane removes the protective surface wax, causing cracks in the rind and cooks the underlying storage tissue, causing stalks to collapse and juice to ooze, providing a feast for *Leuconostoc.* Sound, whole-stalk cane seldom shows elevated dextran content; but burned or frozen whole-stalk cane will deteriorate more rapidly (Eggleston *et al.*, 2004) with the superimposed field mechanization. The organism *Leuconostoc mesenteroides* feeds on sucrose in dilute solutions in neutral or slightly acid pH at temperature under 60 °C and therefore, grow freely on exposed sugarcane tissue, cane juice and syrups of low brix. The microorganism reproduces rapidly under anaerobic condition, for example in mud coated cane and in cane kept in large piles with little circulation of air.

Cane juice is a rich medium which contains about 15-18% sucrose 0.5 % reducing sugars and adequate amounts of organic nitrogen and mineral salts for microbial growth, its pH ranges from 5.0 to 5.5 making it selective for acidophilic microorganisms especially, yeasts and lactic acid bacteria. In a typical cane sugar factory, juice is extracted from the stalks by crushing them in a series or three or five roller mills. The collected juice is then limed to pH 8 and heated to boiling in the clarification process which effectively kills all vegetative cells. The time interval between crushing and clarification is approximately 15-20 minutes, but the level of microbial contamination of the juice is usually extremely high, typical viable counts being 10^8-10^9 cells/ml juice. The microbial population increases tremendously if there are unscheduled stoppage and no biocides are used during milling. Nearly all microbes are eliminated during liming and sulphitation, however, due to fluctuation in temperature as a result of frequent stoppage, certain thermophilic bacteria have the tendency to multiply. It has been known that a major loss of sugar occurs due to inversion of sucrose in the raw sugar cane juice and other types of degradation of the juices caused by bacterial activities, enzymes and other biological factors. These losses may run from about 0.5% up to as much as 4 to 5% of the total sugar entering the factory. Of this sucrose loss, about 13% is due to chemical inversion, 25% is due to the activity of cell free enzymes and about 62% is eaten up by the microorganism present in juice and mills.

The poor mill sanitation and lack of an effective biocide hampers the processing efficiency and reduces sucrose recovery in the following ways :

(i) Direct loss of sucrose by native invertase (plant origin), especially when immature/ stale cane is processed,

(ii) Sucrose loss through metabolic products formation (dextran, polysaccharides, ethanol, acid, etc.)

(iii) Microorganisms growing in the cane juice consume sucrose present in it. The rate of sucrose destruction by microorganisms varies with species.

Under normal milling conditions sugar loss is estimated to be around 2.0 to 2.5 kg of sucrose per ton of cane ground between crusher juice and mixed juice depending on the factory conditions in some well managed sugar factories these losses are 1.0 kg sugar per ton of cane ground.

In sugar industry, formation of post-harvest metabolic products of microbial origin have special importance because of their effect on sucrose recovery and processing operations (Ravelo *et al*. 1991). Some important metabolites of microbial origin have been mentioned below and can be used as indicator of cane deterioration.

(a) Organic acids : Organic acids such as lactic acid, acetic acid and butyric acid produced by microorganisms leads to loss of sucrose and lowering of juice pH. For each gram of acid produced about 2.77 g (*L. mesenteroides*) and 11.09 g (*E. coli*) sucrose is degraded. Juice containing excess acid requires extra lime addition to neutralize acidity. The reaction between acids and lime results in heavy scale formation in juice heaters, thus decreasing heating efficiency. The titrable acidity index (TAI) is therefore a valuable indicator of deterioration (Gupta and Lal, 1984).

(b) Ethanol : Large population of yeast is invariably present in juice which not only favors the acid but also ethanol production at the expense of sucrose. In South Africa, ethanol accumulation is used as an indicator of sugar loss in cane extracts and as an indicator of burn-to-crush delay. It is 2-3 times higher for burned cane as compared to unburned cane (Cox and Sahadeo, 1992)

(c) Dextran: Sucrose is biologically converted to dextran by *L. mesenteroides,* which produces an enzyme dextransucrase. The enzyme causes polymerization of dextrose into a polysaccharide, called dextran with a molecular weight of 15,000 to 2,000,000 or more. Dextran is a gummy substance and impedes sugar processing and quality of sucrose. Dextran estimation (Haze, dip stick, ASI enzymatic, MCA methods) in cane or juice serves as a valuable indicator of deterioration (Sarkar and Day, 1986; Clarke *et al*., 1987; Roberts *et al*., 1983; Saska *et al*. 2002; Kim *et al*., 2001; Rauh *et al*., 2001).

(d) Oligosaccharides: The accumulation of oligosaccharides during post-harvest period is also indicative of enzymatic, bacterial activity. The kestoses (1-6-and neo-kestoses) were found to be the main oligosacchrides formed. Eggleston (2002) reported higher kestoses levels in harvested stored cane under different harvesting conditions.

(e) Mannitol: The rate of mannitol formation from the reduction of fructose by enzyme from *Leuconostoc* was much higher than associated with other oligosaccharides or ethanol. Mannitol formation was therefore considered as one of the most reliable indicator of cane deterioration (Eggleston,2002; Eggleston and Harper 2006; Eggleston *et al*., 2005).

Sources of microbial contamination

The origin of the contaminating organisms has been traced to the soil adhering to cane stalk and leaves. Small number of organisms are detected on the surface of green and burnt cane, but not inside the stalk. The cut ends of cane stalk become infected with the *Leuconostoc* at the time of harvest by contact with contaminated cane cutter's machetes, soil and the epiphytic flora of the plant. The infection of *Leuconostoc* rapidly penetrates the stalk and colonizes the tissue. The organisms multiply rapidly in harvested cane and exhibit a characteristic exponential growth curve, attaining maximum count of 10^7-10^{8-} cells/ml within 3 to 4 days after harvest, followed by a slight decline.

During milling, most of the microorganisms from cane stalks washed off into the extracted juice where microbial development occurs immediately because juice provides a natural and highly nutritive environment, rich in both organic and inorganic nutrients. In addition, juice becomes aerated as it falls from the mills. As the juice passes through the milling tandem it is stopped in the regions of stagnation or low speed and the microorganisms in it find conditions favorable for their growth. A continuous supply of fresh nutrients is received and simultaneously, the metabolic products are incorporated into the juice stream. Microorganisms utilize sucrose and other sugars present in the juice as a source of energy while delivering a variety of metabolic products such as organic acids, reducing sugars, ethanol and polymers with long and complex chains. These metabolic products of microorganisms can cause various troubles in further processes of sugar manufacturing. It is generally accepted that loss in recoverable sugar occurs only in between first and last mill, but in reality, deterioration in quality starts from field itself, soon after harvesting and condition is aggravated in tandem due to presence of nutrients, aeration and dynamic state of juice. The following sites provides breeding ground for sucrose destroying micro-organisms.

- Recycling of wash water which carries a sizeable number of microorganism
- Across the mill, juice collecting troughs under the mill are prime areas for *Leuconostoc* multiplication.
- Areas behind juice screens also harbor dextran producing microorganisms.
- All screens are major source of bacterial infection.
- Dilute juice tanks, because it receives contaminated juices.
- Pipe lines and valves holding unlimed juice.

The cane juice contains sucrose, nitrogenous compound and many growth factors which hasten the process of microbial multiplication. If the growth of these microbes continue, as a result of poor mill sanitation and absence of an effective biocide, sucrose depletion become very fast leading to decline in recovery.

Adverse impact of dextran on sugar processing

The loss of sucrose after harvests is the greatest source of revenue loss catalyzed by inversion and dextran formation. The detrimental effects of dextran formation on sugar processing and recovery have been summerized by many researchers (Tilbury, 1971; Well and James, 1976; Hylton, 1997).

(a) Reduction in sucrose recovery, losses are exorbitant during late-milling.

(b) Formation of more reducing sugars and increased molasses purity.

(c) Formation of soluble polysaccharides (dextran) in milled juice due to multiplication of *Leuconostoc.* sp. which leads to processing and sanitation problems. The increased viscosity lowers heat exchange rate and therefore, causes lower evaporator efficiency and slow crystal growth.

(d) Slow crystallization, poor clarification and slow mud-settling rate. Dextran impedes clarification by acting as neutral or uncharged colloids and blocking aggregation of charged particles (Satinder Kaur and Kaler, 2007).

(e) Excess nucleation formation of elongated crystals of sucrose which affects its marketability .

(f) Increase in gum content leading to high viscosity of syrups, massecuites.

(g) Increased in organic acids leading to scaling problem, requiring more heating time during evaporation.

(h) Erroneous pol reading in sugar factory due to presence of dextran. Chemical control become distorted as dextran affects the Pol in varying degree from juice through syrups to sugar.

(i) The loss of time and capacity in process involving a loss of steam, especially in the factories having power co-generation projects.

(j) Dextran also creates multiple problems in sugar refinery such as Pol distortion, loss in affineation and slowing of filtration, etc. Studies carried out at Sugar Processing Research Institute, USA (Clarke, 1997) pointed out problems in products such as soft brown sugar elongated crystals, which do not pack into the assigned containers and cloudiness in cordial and liquors.

(k) Dextran poses numerous problems in sugar refinery due to its viscous nature and remains in the sugar crystal which are morphologically abnormal. The elongated crystals prevalent in remelt sugar create the grater increase in cost factor in the refining situation.

A. Strategies to minimize post-harvest sucrose losses in sugarcane : Field losses

Research efforts to assess the extent of cane deterioration and contain its progress at the field and factory have met with only partial success. Some of the useful parameters to asses juice quality of cane arriving at the factory, are dextran, gum, oligosaccharides, ethanol, mannitol, reducing sugars, titrable acidity, invertase content, juice viscosity, purity drop, etc. Based on these indicators, quality of cane supplied to the mills could be assessed, however, sucrose loss in the harvested cane could be minimized by using methods described below.

(1) There is no substitute for better communication, quick and efficient transport to minimize post-harvest losses. The harvested cane must be brought to mill and processed as quickly as possible. The factory management must ensure that fresh cane is supplied regularly and all indents should be placed accordingly. Solomon *et al.* (2004) have advocated following milling schedule for harvested cane/billets for Indian sugar factories:

Full green cane:	Milled within 48 h (early season)
	Milled within 24 h(late-season)
Burnt full cane	Milled within 24 h
Billets (green/burnt)	Milled within 12 h

(2) The harvested cane before crushing should be made free from trash, leaves and roots etc. For late-milling season (high ambient temperature) , varieties with high rind hardness/ fiber along with high wax content should be preferred. This will reduce considerable moisture and sugar loss from cane.

(3) Soil content of cane is also one of the factors influencing not only cane deterioration but also causes process difficulties, such as cane preparation, milling, clarification and is a source of millions of microbes that can grow in juice. Soil particles are directly responsible for damage of hammer, knives, conveyer, juice screens, pipes and many other parts of the processing unit. It is therefore, important that processing of muddy cane should be avoided.

(4) It has been observed that topped cane deteriorates faster than cane with the crown of leaves attached. In case of any anticipated delay in crushing, topping should be avoided.

(5) Maturity of cane is a major factor in the inversion and subsequent reduction of stored sucrose. As maturation level increases the extent of sucrose loss is minimized. Harvesting of immature or over mature cane should be avoided to cut down post-harvest sugar losses. It is necessary that maturity-wise harvesting should be implemented, especially in the low recovery areas.

(6) In order to cut down post-harvest sugar losses, it is important to identify sugarcane varieties with high sucrose content and less inclined to post-harvest inversion (both biochemical and microbiological). These varieties should also be screened for rind hardness, wax content, etc.

(7) The transport and storage of cane also affect the process of dextran formation i.e. degree of damage from loading equipments, size and shape of container, etc. Excessive mechanization viz., grab loader, chains and slings tend to bruise cane.

(8) In case of unavoidable delay in crushing, the harvested cane should be stored in small heaps with minimum ground contact and sprinkled with a solution of bactericide and covered with a thick layer of trash. This method has been found to suppress the activation of invertases. The cane piles should be stacked in such a way so as to facilitate proper ventilation.

(9) The cleanliness in the cane yard is of utmost importance. The management should ensure that *first cane in should be first cane out*, this will avoid piling up of stale/ deteriorated cane.

(10) Pre-harvest application of chemicals: Many preventive methods developed earlier could not be scaled up into

commercial venture due to poor efficacy of chemicals and operational difficulties under field conditions. These methods include treatment of cane with bactericidal chemicals, gamma irradiation from ^{60}Co and pre-harvest spray of divalent cations such as Zn^{++}, Cu^{++}, Co^{++} and Ba^{++}. Pre-harvest foliar application of Zn++ (@ 1000 mg/l) showed appreciable improvement in juice quality in stale cane. Inhibitory effect of Mn^{++} on cane invertases has also been reported(Solomon *et al*.,1990; Batta *et al*.,2007).

(11) A study conducted by Tomar and Malik (2004) has indicated that basal application of zinc sulphate (25 $kgha^{-1}$) reduced the pace of post harvest deterioration of sugarcane. Recent studies conducted at the Indian Institute of Sugarcane Research, Lucknow have shown that pre-harvest soil application of zinc sulphate and manganous sulphate @ 25 kg/ha six weeks prior to harvest improved sucrose content in sugarcane and minimized post-harvest sucrose losses.

(12) Post-harvest application of chemicals: Several disinfectants and chemicals have been tried in recent past but their practical use has been restricted by the availability, high cost and sometimes environmental problems. A study from Australia has shown that deterioration could be controlled by dipping stalks in formaldehyde solution. Further studies have shown that continual spraying of the chopper harvester blade and dipping cane stalks in bactericide did not prevent infection. Desai *et al,* (1985) noticed that spraying of harvested cane with benzoic acid (100 ppm) and formaldehyde (100 ppm) significantly retarded post harvest losses. Many bactericide such as formaldehyde, Polycide, Bactrinol-100, BD Mill sanitizer, DBAC, IFOPOL, DNDT, ABF, Actin-ID, potassium permanganate and sodium metasilicate, Tsunami-100, Kcide 800, Sucroguard, Perla soap solution (1%) etc. have been recommended to check deterioration of cane and milled juice. Spraying of a solution containing allyl isothiocyanate could minimize sucrose loss in the harvested cane (US Patent 3975204).Studies conducted by Coote (1984) have shown that bactericides applied directly to the knives on mechanical harvesters or continuous loader is beneficial. Further work by the same author has suggested that biocides applied in the field can eliminate up to 40 % of dextran in juice.

(13) Vacuum packaging with preservative treatment could effectively inhibit the activities of invertases and PPO, and significantly reduce sucrose degradation and acid accumulation. Peeling and cutting stimulated the increase of respiration rate of sugarcane by 8.43 times. The shorter the sugarcane section, the more the respiration rate increased. Peeled sugarcane, combined with the application of preservative and vacuum packaging, could be stored for 20 days at 0° C (Mao and Liu, 2000)

(14) Combined application of anti-bacterial and anti-inversion chemicals: Solomon *et al* (2006) reported efficacy of a few chemical formulations containing antibacterial (quaternary ammonium compounds/ thiocarbamates), anti-inversion chemicals (sodium metasilicate/sodium lauryl sulphate) in minimizing post-harvest sucrose losses in sugarcane. The aqueous formulation(s) are sprayed over freshly harvested cane (whole stalk and billets) followed by covering the treated cane with a thick layer of dried cane leaves (trash). Formulation containing benzalkonium chloride (BKC) + sodium meta silicate (SMS) was found to be most effective and improved sugar recovery by over 0.5 units. This method reduces the loss of sucrose from harvested cane up to a period of one week, irrespective of temperature and variety (Fig. 1 & 2).

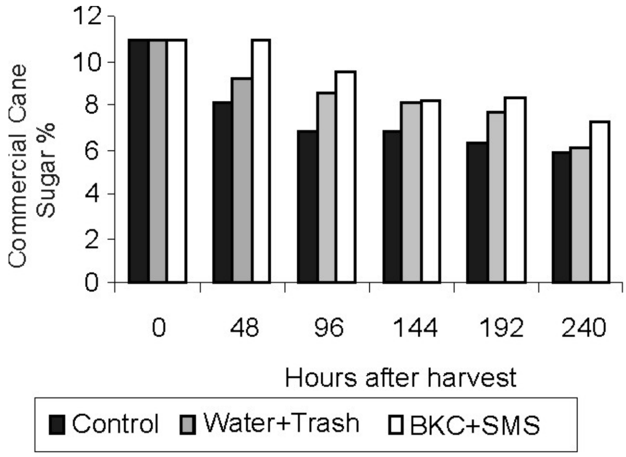

Fig 1. Effect of combined application of an anti-inversion (sodium metasilicate) and anti-bacterial (benzalkonium chloride) formulation on CCS during storage

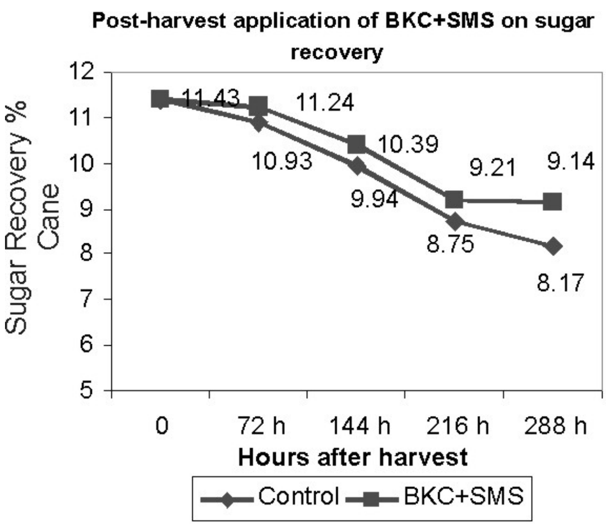

Fig. 2 Effect of application of a chemical formulation (BKC+SMS) on sugar recovery % cane in a sugar mill.

Application of aqueous formulation containing BKC+SMS minimizes post-harvest deterioration of sugarcane which is left in the field or at the cane centers. The synergistic action of anti-bacterial and anti-inversion chemicals reduces sucrose loss after harvest and during subsequent storage even at high ambient temperature. The increment in sugar recovery % cane after treatment may vary between 0.3-0.5 units (Fig. 4 B). This is a useful technology for the sugar mills where harvest-to-mill delays are long and sugar recovery is stumpy (Solomon *et al.*, 2006, 2007, 2008).

15. Use of electrolyzed water (EW) : The concept of electrolyzing saline to create a disinfectant is appealing because the basic materials, saline and electricity, are cheap and the end product (water) is not damaging to the environment. EW appear to work as an anti-infective agent by denaturing proteins in the membrane of single-cell organisms. Differential pressures inside and outside the weakened cell wall cause it to burst .The main products are hypochlorous acid and free chlorine radicals. This disinfectant is generated at the point of use by passing a saline solution over titanium-coated electrodes at 9 amps. The product generated has a pH of 5.0-6.5 and an oxidation reduction potential of >950 mV. The solution has been shown to be non-toxic to biological tissues. The antimicrobial activity of EW has been tested against bacteria, mycobacterium, viruses, fungi, and spores. Use of EW in sugar beet processing has been reported. Its effect on post-harvest storage quality of sugarcane showed relatively lesser reduction in quality as compared to untreated cane. The invert sugars formation in EW treated cane was also reduced.

B. Control of biological losses of sucrose during processing

The deteriorated or stale cane during milling process releases excessive amount of hydrolytic enzymes (viz.,invertase and dextransucrase), organic acids, polysaccharides, dextran etc.and favors rapid multiplication of many bacteria (*Leuconostoc* sp.), leading to phenomenal loss in recoverable sugar. These biological losses could be minimized by :

- Regular mill sanitation program or integrated mill sanitation program (Solomon *et al.*, 2000).
- Control of secondary losses of sucrose in juice (dextran, acids, alcohols, invert sugars) by addition of broad spectrum biocides.
- Removal of dextran by using dextranase enzyme

Mill Sanitation and sucrose losses

It is now established that clean milling operation will ensure minimum destruction of sucrose and better processing efficiency. However, it is the endeavor of each mill to minimize these losses through addition of appropriate chemicals or biocides. It is known that when sanitation at the mills is not proper the losses of sucrose could exceed 2.5 kg per ton cane milled more. In a clean factory following complete sanitation norms, the losses due to microbes could be appreciably reduced. However, complete elimination of micro-organism from cane/mill is almost impossible. The importance of an "Integrated Mill Sanitation (IMS) program encompassing judicious combination of various physical and chemical method, was emphasized by Solomon *et al,* (2000).

Biocides used in controlling sugar losses

The deterionated cane brings to the mill a high population of viable microorganisms and most of them are washed off into the extracted juice and affect upstream process by direct destruction of sucrose or converting it to other products. This is further aggravated if there are unscheduled stoppage. Studies carried out by Chen and Chou(1993) reported that during a one hour delay of processing , sugar loss is around 7.7 kg/tcg. In order to minimize the sugar losses in milling tandem and during subsequent processing, it is imperative to use effective biocides at proper place and in required doses. The best place for using the biocide is first and last mill and the imbibition-maceration water. It is important that biocide usage be controlled and monitored for its effectiveness from the point of view of both cost and residue. The use of various biocides and their efficacy has been reviewed by Chen and Chou(1993). Some important biocidal agents which are used in sugar industry are halogen compounds, ammonium bifluoride, formaldehyde, quaternary ammonium compounds (QUAT) and thiocarbamates.

Solomon *et al,* (2003) and Solomon (2004) reported that continous mist spraying of an organosulpher based formulation on chopped/prepared cane by a power operated sprayer improved sugar recovery in a sugar mill receiving consignments of burnt deteriorated cane. This treatment resulted in significant drop in invert sugars, acidity and dextran from primary to mixed juice stage and improved sugar recovery by 0.5 units (Fig 3 & 4).

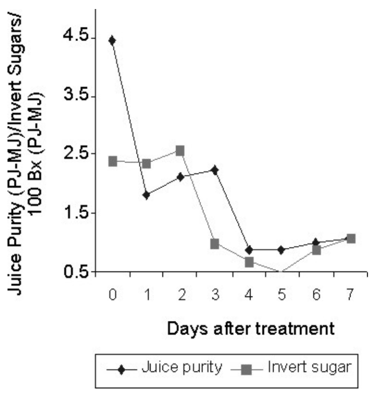

Fig. 3. Change in juice purity and inverse sugar from primary to mix juice after application of an organosulpher based formulation

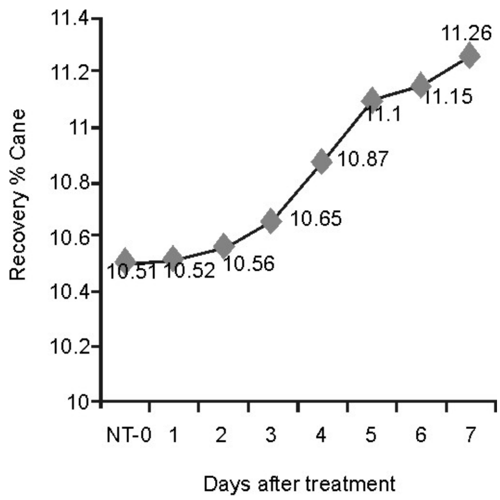

Fig. 4 Increase in recovery percent cane after application of an organosulpher based formulation during milling of cane (Sakhti Sugars Ltd., Dhenkanal, Orissa-India).

Economic benefits of using biocides in sugar industry

Chen and Rauh(1990) presented an economic evaluation of using biocides in mill tandem. Using conservative numbers from various studies around the world, they showed that each 0.1% increase in dextran in juice would result in the loss of 8.8 Lbs sugar per ton of raw sugar produced. Assuming 88% recovery, a factory crushing 10,000 tons cane per day would recover 3.87 tons additional sugar per day. By practicing good mill sanitation with biocide treatment, additional sucrose recovery of 1.0-8.0 kg per ton cane ground could be achieved. A trial done at McBride Sugar Company with Midland Laboratories, PCS 6001, (Carbamate based biocide) resulted in 0..82 per cent increase in sugar recovery equivalent to saving of about US$111,000 per year (Onna and Hashimoto, 1989).

C. Removal of dextran by dextranase enzyme

Control of dextran already present in juice extracted from deteriorated cane may be accompanied by using *dextranase* enzymes. Some excellent reviews on enzyme used in the removal of dextran is provided by Inkerman and Riddell (1976), Inkerman (1980), Inkerman *et al* .,1983 and Destefano (1988) who were the major worker in developing the use of dextranase in sugar factories.A thermostable dextranase which exhibited maximum activity at 80-85^{o}C was also reported (Wynter *et al*., 1997). Dextranase can be used economically to alleviate many of the production problems associated with dextran. With dextranase usage, elongation of grain ceases, boiling times are shortened, boiling house operations becomes smooth and filterability of the sugar produced is improved. Madhu and Prabhu 1984; Edye *et al*, 1996, 1997; Efraín Rodríguez Jiménez , 2005). The application and optimization of commercial dextranases in US sugar industry was highlighted by Eggleston and Monge (2004) and Egglestion *et al* (2007).

Management of post-harvest quality loss: Futuristic research approaches

(1) Field control of *Leuconostoc* bacterium offers an excellent scope to minimize dextran formation after harvest. Developing a suitable package of nutrients containing appropriate amount of Zn,Mn and Mg is an interesting area of research in containing field population of dextran producing bacteria and minimizing inversion losses after harvest.

(2) There is an ardent need to screen commercial varieties for their ability to withstand post-harvest stress, especially, to resist moisture loss, inversion and dextran formation. All varieties, especially those released for commercial cultivation must be screened for their post-harvest quality during early through late crushing periods (low and high temperature).

(3) In order to sustain profitability, it is imperative that sugar mills keep the post-harvest profile of each variety being grown in their area.

(4)A more realistic possibility is to develop a cheap and effective field biocide or deterioration inhibitor, which may be able to control the growth and multiplication of *Leuconostoc* sp. as well as has the ability to minimize inversion losses.

(5)A strong chemical formulation with broad spectrum anti-microbial activity and inversion inhibition will find extensive use in the field/ milling tandem to minimize biological losses of sucrose.

(6)Efficacy of electrolyzed (EW) water fogging on harvested cane/ prepared cane juice needs to be further investigated. This will greatly reduce the use of hazardous sanitation chemicals in sugar industry.

(7) The dextranase system developed in Australia, seems to be effective in removing dextran however, a thermo tolerant dextranase active at high brix may be more useful for sugar industry. Genetic engineering studies related to overproduction of dextranase from fungal sources need greater attention.

(8) Constitutive production of fungal dextranase from *Penicillium sp.* and bacteriocin treatment of cane juice to remove dextran from process juice, should be attempted.

(9) Development of an anti-sense technology which reduces invertase activity soon after harvest of cane could be useful to minimize post harvest sucrose losses.

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