

**A COMPARISON OF POSTHARVEST TECHNOLOGY IN
THE SOUTH AFRICAN SUGARCANE AND THE FRESH
PRODUCE INDUSTRY**

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PREFACE

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ABSTRACT

Postharvest deterioration of sugarcane still presents a challenge to efficient sugar recovery in many sugar-producing regions in South Africa. However, sugarcane deterioration appears to be a well published area of research. In South Africa, the implementation of policies to manage sugarcane quality after harvest is still relatively primitive when compared to the policies and checks in the fresh produce (fruits and vegetables) industry. The perishable nature of sugarcane, considering the rate and impact (monetary) of its postharvest deterioration, warrants a comparison, of quality management technology, with the fresh produce industry. A comparative analysis of postharvest quality management in sugarcane production and the mentioned horticultural produce industry is presented in this review. Biological and environmental factors that influence deterioration in the mentioned types of produce were identified and their influence described in the context of these produce. A review of postharvest quality management techniques, specifically techniques for detecting, quantifying and controlling deterioration, as a result of the identified factors, is presented. The common supply chain orientations, for these produce, were described, and the influence of these orientations on quality management is discussed. The difference in postharvest handling of fresh produce and sugarcane is shown to be the most pertinent factor that results in the major difference in postharvest quality management activities between the two industries. A critical analysis of the literature shows that a number of opportunities exist, such as in, deterioration detection technology, quality measurement, sanitation and handling practices after harvest, to significantly reduce the rate of deterioration in harvested produce. This review concludes with recommendations for potential improvements in postharvest management of sugarcane quality to increase efficiency in the value chain, based on lessons that can be learnt from fresh produce advances in this area.

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1. INTRODUCTION

Agricultural products are affected by losses in quality and quantity between harvest and consumption (Kader 1992; Lyne and Meyer, 2005; Ansorena *et al.*, 2012). These produce are living tissues, subject to changes after harvest, which may affect quality at consumption (Kader, 1992; Wills *et al.*, 2007). Consumption in the context of this document also includes points in the value chain where the harvested produce is processed, because the quality of the produce is often a limiting factor in the processing operation. The diversity in morphological structure, composition and general physiology of produce, dictates that commodity requirements and recommendations for maximum postharvest life will vary among these produce (Wills *et al.*, 2007).

According to Artés *et al.* (2009), the post-harvest life (and quality) of fresh-cut plant commodities, such as fruits and vegetables, is influenced by (a) pre-harvest factors, such as produce varieties and cultivation conditions, (b) processing factors, such as pre-cooling, trimming, peeling, disinfecting and drying, and (c) distribution conditions, such as temperature, relative humidity and atmosphere conditions. It is apparent that a number of the factors mentioned by Artés *et al.* (2009) also affect sugarcane postharvest quality. Because of these varying factors, it is recommended that these agricultural commodities are processed under highly integrated systems, where holistic consideration is given to interactions between the variety of factors in the system (Shewfelt and Prussia, 1993; Artés, 2004; Artés *et al.*, 2009).

1.1 The South African Sugar Supply Chain

The South African sugar industry is globally competitive and involves interaction between growers, who produce the sugarcane, and millers who convert the cane into raw and refined sugars, syrups, specialised sugars and a range of by-products (Martin, 2008). According to Morokolo (2011), the South African sugar industry generates an annual average direct income of ZAR 8 billion.

The sugarcane supply chain in South Africa, as depicted in Figure 1.1, consists of a number of parties involved in growing, harvesting, transporting and milling the produce (Perry and Wynne, 2004). Temporary storage of the produce *e.g.* at a transshipment zone, or as stockpiles at the mills is often practiced (Perry and Wynne, 2004; Bezuidenhout,

2010). In general, however, it is desirable to reduce the harvest-to-crush delay (HTCD) to a minimum (Solomon, 2009).

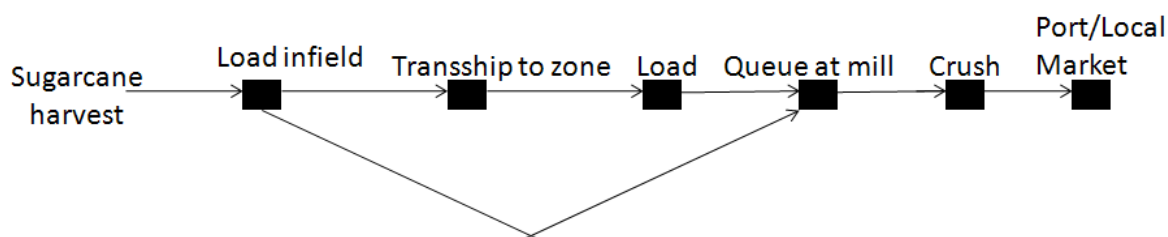


Figure 1.1 A typical South African sugarcane supply chain (adapted from Perry and Wynne, 2004).

An increase in HTCD may result in an increase in cane deterioration. According to Ravno and Purchase (2005) and Martin (2008), postharvest deterioration of cane results in estimated financial losses of ZAR 60 million per season, based on deterioration-associated sucrose losses of 1.4 to 2.2 kg per metric ton cane. This value does not include the cost of reduction in exhaustion efficiency at the mill as a result of processing poor quality cane.

An important role player in the South African sugarcane supply chain is the Cane Testing Service (CTS), which is under contract to individual Mill Group Boards (MGB) and is responsible for determining the quality of cane consignments for payment purposes (Anonymous, 2012a). CTS facilities are strategically located at the mill and have the potential to serve as check-points for sugarcane deterioration.

1.2 The South African Fresh Produce Supply Chain

In 2012 the South African fresh produce market was estimated to be worth ZAR 30 billion (Chikazunga and Paradza, 2012). The South African fresh-produce supply chain also involves a number of parties in the harvesting, transportation, storage, processing, marketing and retailing of the agricultural produce. The major difference between the sugarcane and fresh-produce supply chains is that long-term storage of fresh-produce prior to consumption is commonplace, whereas this is not the case in the sugar industry. Due to the cold storage requirement in this industry, the supply chain is often referred to as a cold chain (Ngcobo *et al.*, 2012). A simplified schematic of fruit logistics in South Africa, as described by Ortmann *et al.* (2006), is presented in Figure 1.2.

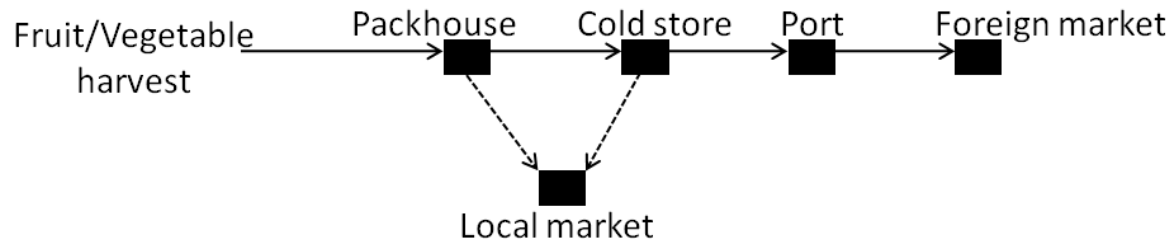


Figure 1.2 Simplified schematic of the fruit supply chain in South Africa (adapted from Ortmann *et al.*, 2006).

In South Africa the Perishable Products Export Control Board (PPECB) is responsible for quality inspection and certification, of a variety of perishable products that are destined for export (Julius, 2009). In some instances PPECB provides quality inspection services for produce destined for local consumption (Julius, 2009; Chetty, 2010). PPECB provides a broad range of services from laboratory services measuring produce quality, to equipment certification, standards and protocol management (Julius, 2009; Chetty, 2010). Product Control for Agriculture (PROKON) is another agency that performs quality certification of fruits and vegetables, mainly for local markets in South Africa (Anonymous, 2012b).

The aim of this review is to present postharvest techniques that are common to both the South African sugar and fresh-produce industry, in an attempt to identify techniques for improving postharvest quality management in the sugar industry. This will be done by addressing the following objectives:

- a. Identifying factors, common to both the sugar and fresh produce industry, which influence postharvest deterioration,
- b. presenting an overview of how these factors are currently mitigated,
- c. identifying internal quality parameters, measured in both these industries and describing the analytical techniques used to measure these parameters, and
- d. comparing these parameters and mitigation methods, in an attempt to identify opportunities for the South African sugar industry, this is presented in Chapter 5.

2. FACTORS THAT INFLUENCE POSTHARVEST DETERIORATION OF PRODUCE

A number of factors have been identified, by various authors, as being responsible for the deterioration of produce after harvest (*e.g.* Kader, 1992; Shewfelt, 1993; Devereau *et al.*, 2002; Farrell *et al.*, 2002). According to Devereau *et al.* (2002) harvested produce may be analogous to an ecosystem. Jayas (1995) suggests that the interaction between physical, chemical and biological factors within this ecosystem leads to changes in the quality and nutritive value of agricultural products after harvest.

The postharvest deterioration of produce is influenced by produce (a) biological factors such as respiration, ethylene (C₂H₄) production (both functions of the climacteric/non-climacteric nature of the produce), transpiration; (b) by pathological breakdown from bacteria and fungi; (c) by rodents and other pests; and (d) by environmental factors such as temperature, relative humidity and atmospheric composition (Kader, 1992). In this Chapter, some of the common factors that enhance deterioration of both sugarcane and fresh produce, after harvest will be reviewed.

2.1 Respiration

According to Kader (1992), respiration is the process by which stored organic materials (carbohydrates, proteins, and fats) are broken down into simple end products with a release of energy. Oxygen (O₂) is used in this process and carbon dioxide (CO₂) is produced. A number of authors have reported on the significant impact of respiration on postharvest quality of produce (*e.g.* Kader, 1992; Brosnan and Sun, 2000; Lyne and Meyer, 2005; Campbell and Klotz, 2006; Fugate *et al.*, 2010).

The impact of respiration activity after harvest is evidenced in the depletion in food reserves of the produce, which, according to Kader (1992), results in:

- a. hastening senescence, because of the exhaustion of food reserves which provide energy for the produce,
- b. reduction in food value (in terms of energy) for the consumer,
- c. loss of flavor quality, especially sweetness, due to reduction in carbohydrate content,
- d. loss of salable dry weight and

- e. the generation of heat, this may create an optimum environment for postharvest pathogen proliferation, and also influences refrigeration and ventilation requirements.

Various studies have shown a correlation between the rate of postharvest deterioration of produce and the rate of respiration (*e.g.* Brash *et al.*, 1995; Paul *et al.*, 1997; Chen *et al.*, 2010; Fugate *et al.*, 2010). The measurement of the respiration rate of produce, under different environmental conditions, and over varying lengths of time after harvest, may provide valuable information to assist in managing (reducing) the respiration rate for maximum postharvest life (and quality).

The respiration rate of agricultural produce can be stated in terms of the rate of O₂ consumption or the CO₂ production rate (Fonseca *et al.*, 2002). The following, commonly used, methods for measuring respiration rate in agricultural produce are explained in Fonseca *et al.* (2002):

- a. the closed or static system,
- b. the flowing or flushed system and
- c. the permeable system.

In each of these non-destructive systems the gas concentration can be measured using techniques such as gas chromatography (*e.g.* Kader, 1992; Mahajan and Goswami, 2001), infra-red gas analysis (*e.g.* Glover, 1973; Kader, 1992; Watt and Cramer, 2009)

In sugarcane research, Watt and Cramer (2009) relate the respiration rate in mature internodes to the postharvest deterioration of sugarcane. A closed system is used and CO₂ released from internode 10 is measured (Watt and Cramer, 2009). Postharvest sugar loss in cane stalks is often attributed to respiration and microbiological activity, by determining the respiration rate under different environmental conditions, information on sugar loss as a result of respiration can be generated and used to facilitate in the development of techniques to reduce this rate (Watt and Cramer, 2009).

2.2 Transpiration

Agricultural produce constantly lose water to the environment (Kader, 1992; Boxall *et al.*, 2002). In both the sugar industry (*e.g.* Lyne and Meyer, 2005) and the fresh produce

industry (*e.g.* Brosnan and Sun, 2000), postharvest moisture loss has been identified as a challenge to postharvest quality. The postharvest loss of water from produce is irreplaceable and leads to both quantitative losses *e.g.* saleable weight, and qualitative losses *e.g.* wilting and shrivelling, textural quality loss *etc.* (Kader, 1992; Boxall, *et al.*, 2002; Caleb *et al.*, 2012). Moisture loss has been shown, by a number of researchers, to increase the susceptibility of harvested produce to pathogen infection (Shewfelt, 1993; Boxall *et al.*, 2002; Sharma *et al.*, 2009). The transpiration rate of agricultural commodities is often measured during research, and moisture content is measured as a quality parameter in both sugar and fresh produce supply chain (this is discussed in further detail in Chapter 4).

2.3 Physical Damage

Physical damage of harvested produce can significantly hasten deterioration (Kader, 1992; Solomon, 2009). The result of damage could be evidenced in browning of damaged tissues, acceleration of water loss, presentation of entry-site for microbial infection (Eggleston *et al.*, 2008; Solomon, 2009), stimulation of CO₂ and C₂H₄ production by the commodity (Kader, 1992). In South Africa, sugarcane burning before harvest (to facilitate manual harvesting) is a common practice and this results in physical damage and faster deterioration (Muir *et al.*, 2009). Physical damage also results in qualitative losses, especially in the fruit industry where appearance is an important factor.

2.4 Pathological Breakdown

Bacterial and fungal activity have been identified, by many researchers, as a significant issue in the postharvest deterioration of produce (Kader, 1992; Solomon *et al.*, 2000; Eggleston *et al.*, 2008; Solomon, 2009; Sharma *et al.*, 2009). Although microorganisms can infect seemingly healthy tissues, in many cases pathogen attack follows physical injury or physiological breakdown (Kader, 1992). Susceptibility to pathogen attack is enhanced by stresses such as chilling injury and sunscald (Kader, 1992).

2.5 Physiological Breakdown

A number of physiological disorders in produce can occur as a result of preharvest and postharvest conditions (Kader, 1992; Strano *et al.*, 2011). Examples such as freezing

injury, chilling injury, heating injury, bitterpit and blossom-end rot have been identified (Kader, 1992; Strano *et al.*, 2011). Bitterpit and blossom-end rot, for example, can be caused by a pre-harvest nutritional deficiency such as calcium deficiency (Kader, 1992). Storage conditions, in particular the temperature that commodities are exposed to will influence the occurrence of physiological breakdown (*i.e.* for freezing injury, chilling injury and heating injury). In the next section a brief description of environmental factors that influence deterioration is presented.

2.6 Environmental Factors

Environmental factors, *viz.* temperature, relative humidity and atmospheric composition, play a major role in postharvest quality. These factors influence the occurrence and rate of the biological factors of deterioration.

2.6.1 Temperature

Temperature has been determined as one of the most significant factors influencing the rate of deterioration in harvested commodities (Kader, 1992; Mashau *et al.*, 2012; Yun *et al.*, 2012). Temperature has been found to influence the emergence of many physiological disorders, determines conditions for pathogen proliferation and influences the effect of ethylene, the respiration rate, rate of moisture loss, as well as atmospheric composition in the storage environment (Kader, 1992; Caleb *et al.*, 2012). The control of temperature after harvest is therefore paramount to maintaining quality and extending storage life.

2.6.2 Relative humidity

Relative humidity, defined as the ratio of the partial vapour pressure to the saturation vapour pressure, is a measure of the quantity of moisture held by air expressed as a percentage of what the air could hold at that temperature (Golob *et al.*, 2002). Moisture (water) loss from agricultural commodities is influenced by the vapour pressure deficit (vpd) between the commodity and the surrounding atmosphere (Kader, 1992; Medina *et al.*, 2012). The vpd is influenced by both temperature and relative humidity. Controlling these two factors is therefore critical in reducing the rate of water loss from commodities, as well as microbial activity in the storage area (Boxall, 2002; Ansorena *et al.*, 2012).

2.6.3 Atmospheric composition

The concentration levels of CO₂, O₂ and other gases in the storage environment are an important determinant of postharvest quality of commodities (Kader, 1992; Mahajan *et al.*, 2007; De Santana *et al.*, 2011). As with many of the factors influencing deterioration, the influence of atmospheric composition is dependent on the commodity, cultivar, physiological age, temperature and duration of holding (Kader, 1992). For cane destined to the mill, the storage period is required to be minimal after harvest, and this might be the reason why the author was unable to find literature on the effect of atmospheric composition on harvested cane in South Africa. However, atmospheric composition is important for packaging sugarcane for fresh consumption (Solomon, 2009).

2.7 Other factors

Certain agriculture commodities *e.g.* potatoes, sweet potatoes, lettuce, peaches and strawberries are affected by light during storage (Kader, 1992; Li *et al.*, 2007; Martinez-Sanchez *et al.*, 2011). Effects such as browning in lettuce and colour development in strawberries (Martinez-Sanchez *et al.*, 2011) have been reported. The author was unable to find literature on light as a factor affecting sugarcane after harvest.

Other factors such as the application of fungicides, growth regulators and produce maturity at harvest, may have an influence on the postharvest life of agricultural commodities (Kader, 1992; Watt and Cramer, 2009). It is therefore important to know what the impact of any implemented chemical may have on the quality of the harvested produce before application. In the next Chapter an overview of the ways in which these factors are controlled is presented.

3. AN OVERVIEW OF METHODS USED TO MITIGATE THE INFLUENCE OF DETERIORATION FACTORS

A number of techniques are currently in use for reducing the influence of the various deterioration factors on produce quality after harvest. These techniques mainly focus on controlling the environmental conditions during storage, as well as preventing microbial proliferation on the commodity.

3.1 Temperature and Relative Humidity Control after Harvest

Temperature control is important during the postharvest storage of fresh produce. From the pre-cooling of the produce immediately after harvest to attaining and controlling an optimum temperature during storage (*cf.* Wills *et al.*, 2007). In South Africa's fresh produce industry, cold storage facilities are found at the ports and at various points in the fruit and vegetable supply chain (*cf.* Julius, 2009; Chetty, 2010; Cronje *et al.*, 2011; Mashau *et al.*, 2012).

Temperature is controlled in the storage area to extend postharvest life by slowing metabolic activity after harvest and by suppressing the growth of pathogens. Examples of produce that require cold storage include Hass avocados, which are often stored at a safe temperature of 5.5°C (Snowdon, 1990; Kader and Rolle, 2004; Tesfay *et al.*, 2011) and potatoes at 4°C (Kader and Rolle, 2004). Commodities that are not sensitive to chilling injury may be stored at temperatures as low as 0°C (Boxall *et al.*, 2002), for example lettuce, spinach, carrots (Kitinoja and Kader, 2004; Workneh *et al.*, 2011).

The South African sugar industry is faced with a challenge when it comes to temperature control after harvest. Because even though temperature plays a key role in sucrose loss after harvest, due to respiration and inversion (Watt and Cramer, 2009), and the harvest-to-crush delays (HTCD) in most mill areas often exceeds the recommended time for burnt cane *i.e.* 24 hours (*cf.* Solomon, 2009), the literature on storage or temperature control in harvested cane is minimal. Solomon (2009) recommends storage of cane in small heaps and constant sprinkling with water, during the HTCD, as a method of avoiding high temperatures in the cane pile. Covering of harvested cane with trash was recommended by Solomon *et al.* (2011) as a method for lowering the cane's temperature during the HTCD.

Boneta-Garcia and Lugo-Lopez (1962), suggest the storage of harvested cane in the shade as a means of keeping cool temperatures during HTCD.

The regulation of relative humidity in the storage area is also important in reducing postharvest deterioration. Relative humidity in the storage area is highly dependent on temperature and as the air temperature decreases the relative humidity increases (Kader, 1992; Boxall *et al.*, 2002). Refrigeration, in a store where moisture is added to the fans or a wet floor is maintained, is one of the ways in which a high RH store is maintained (Wills *et al.*, 2007). The South African sugar industry faces a problem of moisture loss after harvest (Lyne and Meyer, 2005). This loss could be mitigated by developing structures that enable high RH conditions, such as evaporative cooling structures (Wills *et al.*, 2007) which may not have to include refrigeration (which might be too expensive for cane storage).

3.2 Atmospheric Composition Control in the Storage Area

Atmosphere management in storage areas is regulated by the use of a variety of techniques to create types of control systems referred to as controlled atmosphere (CA), modified atmosphere (MA) and modified atmosphere packaging (MAP) (Wills *et al.*, 2007). Controlled atmosphere refers to the precise control of the storage atmosphere composition, MA refers to a situation where the atmosphere composition is a function of the packing material or storage conditions and is achieved by the physiology of the tissue (Barkai-Golan, 2001; Wills *et al.*, 2007). MAP refers to control of the storage atmosphere by selective permeability of the packing material (Wills *et al.*, 2007). In South Africa all three technologies are used. Figure 3.1 is an example of MAP used in South Africa.



Figure 3.1 An example of pumpkin stored using MAP (Anonymous, 2012c).

According to Kader (1994), MA, CA and MAP in storage can be used to supplement optimum temperature and relative humidity maintenance in fresh produce quality preservation after harvest *i.e.* during transportation and storage. In CA, MA and MAP storage the aim is to maintain a low O₂ and an increased CO₂ concentration, both of which are produce-specific (Kader, 1994). The application of CA, MA and MAP technology appears to be limited with regards to sugarcane destined for sugar production in the South African sugar industry. However, in markets where sugarcane stalks are consumed fresh, for juice, vacuum packaging (a form of MA) is used to maintain quality after harvest (Mao and Liu, 2000). This type of packaging limits the action of invertases and polyphenol oxidases (PPO) (Mao and Lin, 2000; Solomon, 2009). Figure 3.2 shows an example of packing peeled sugarcane billets for delivery to a local market in Liberia (Williams, 2011).



Figure 3.2 An example of fresh-cut sugarcane storage (Williams, 2011).

3.3 Sanitation and Control of Pathological Breakdown

Biological deterioration as a result of microbial action is often enhanced by poor sanitary conditions during handling, in the storage area as well as during processing. These conditions often lead to poor quality produce and inefficient extraction of desired qualities during processing (Artés *et al.*, 2009; Solomon, 2009). Artés and Allende (2005) propose that the important considerations for the production of safe fresh-cut produce include screening materials entering the processing chain, suppressing microbial growth, reducing the microbial load during processing and preventing post-processing contamination.

To maintain the quality and safety of fresh-cut commodities, a number of sanitation strategies are used in various agro-industries, such as, antimicrobial solutions (Solomon *et al.*, 2006; Artés *et al.*, 2009), O₃, UV-C light, intense light pulses and MAP under super-atmospheric O₂ (Artés *et al.*, 2009), these are noted in Table 3.1, for a detailed description of the strategies please refer to Artés *et al.* (2009).

Table 3.1 Sanitation strategies used for preventing microbial contamination of agricultural commodities (Adapted from Artés *et al.*, 2009)

Strategy	Example	Physical appearance	Examples of identified organisms affected	Further references
Antimicrobial Solutions	Peroxyacetic acid, Chlorine dioxide, Hydrogen peroxide, citric acid, ascorbic acid, calcium, electrolyzed water, steamer jet-injection, biocontrol	Liquid	<i>E. coli</i> , <i>L. monocytogenes</i> , <i>Enterobacter sakazakii</i>	Kulkarni and Warne, 2004, Solomon <i>et al.</i> , 2011, Rodgers <i>et al.</i> , 2004, Rico <i>et al.</i> , 2008
UV-C radiation, intense light pulses			<i>Pseudomonas aeruginosa</i> , <i>S. typhimurium</i> , <i>L. monocytogenes</i> , <i>S. enteric</i> , psychrotrophic, coliform bacteria and yeast	Erkan <i>et al.</i> , 2001, Allende <i>et al.</i> , 2006
Ozone		Ozonated water	<i>S. typhimurium</i> , <i>E. coli</i> , <i>L. mesenteroides</i> , <i>S. aureus</i> , <i>R. stolonifer</i>	Aguayo <i>et al.</i> , 2006, Zhang <i>et al.</i> , 2005
Superatmospheric Oxygen		Gas	<i>C. lambica</i> , retards growth of anaerobes, <i>Enterobacteriaceae</i>	Escalona <i>et al.</i> , 2007, Zheng <i>et al.</i> , 2008

In a study of quality at a sugarcane factory, Antier (1996) emphasises that microorganisms which enter the factory in great numbers *e.g.* mesophilic microbes, are not necessarily those that will multiply most in the factory, which in some cases maybe thermophilic microorganisms. To optimize sanitation programs, it is therefore important to instate a strategy that can reduce the population of the different microorganisms that present a threat to quality at different stages in the supply chain after harvest. Antier (1996), Solomon (2009) and Solomon *et al.* (2011), emphasise the importance of clean mills and an integrated mill sanitation (IMS) program (application of both chemical and physical treatments), to facilitate the reduction in biological losses of sucrose at the mill.

The use of antimicrobial solutions appears to be common to both the sugar and fresh produce industry (Kulkarni and Warne, 2004; Artés *et al.*, 2009; Solomon, 2009; Solomon *et al.*, 2011), for example, sucroguard[®] (Kularni and Warne, 2004) has been used in South Africa and is applied to the cut-ends of sugarcane stalk after harvest. This has been

reported to reduce invert sugars as well as the microbial count. In India, Singh *et al.* (2008) used glutaraldehyde and benzalkonium chloride solutions to reduce postharvest microbial and physico-chemical changes, which cause sucrose loss. The application of essential oil coatings on citrus has also been recommended for postharvest quality management, and serves as a replacement for synthetic fungicides (du Plooy *et al.*, 2009).

Solomon (2009) recommends the use of electrolysed water (EW) fogging, to reduce purity decline and sucrose loss in sugarcane, both in the field (after harvest) and in the mill. This method has, reportedly, been used for disinfection of vegetables such as cabbage, spinach and lettuce (Wang *et al.*, 2004). Ozonated water, which has been shown to increase shelf-life of grapes and tomatoes (Artés *et al.*, 2009) appears to be ideal for sugarcane due to its effect on *L. mesenteroides*, a predominant microorganism in postharvest deterioration of sugarcane. However, the requirement for high purity water (Artés *et al.*, 2009), may be a financial deterrent when attempting to apply this treatment on harvested cane at a large-scale. Ozone can also be applied in gaseous phase, this is for continuous or cyclic exposure. The cost of setting up a system for applying ozone, either in liquid or gaseous form to harvested cane, may impede the implementation of such a system (*cf.* Suslow, 2004), particularly due to the fragmented nature of the sugarcane supply chain in South Africa as well as the relatively low value density of the produce in this industry.

In both the sugar and fresh produce industry in South Africa, there are a number of parameters that are used to measure quality after harvest. In the next section these parameters will be identified and how they are quantified will be described.

4. QUALITY PARAMETERS IN THE FRUIT, VEGETABLES AND SUGARCANE INDUSTRIES AND THEIR MEASUREMENT IN THE SOUTH AFRICAN CONTEXT

The detection and measurement of deterioration after harvest may be based on some of the parameters which are currently used by the fresh produce and sugarcane industries to determine commodity quality. The quality parameters may differ according to commercially desired attributes in the produce. In this chapter an attempt has been made to identify routinely measured quality parameters that may be of importance to both the sugar industry and the fruit and vegetable industry.

4.1 Quantitative Measures of Sugarcane Quality Parameters

In the South African sugar industry, the important sugarcane quality parameters are; sucrose, total soluble solids (TSS, measured as °Brix), moisture content, non-sucrose and fibre (Schaffler *et al.*, 2003). Other indicators that have been suggested as indicators of deterioration include ethanol, dextran, and mannitol (*cf.* Lionnet, 1986; Eggleston, 2008). The Recoverable Value (RV, expressed as a percent of cane mass), as described by Equation 1, is used as a basis for payment by the miller to growers (Groom, 1999).

$$RV = S - dN - cF \quad \text{Equation (1)}$$

where S = sucrose

N = non-sucrose

F = fibre

d = relative value of sucrose from which each unit of non-sucrose diverts from sugar production to molasses

c = the loss of sucrose from sugar production per unit of fibre.

The coefficients c and d are calculated each season (in 2012, $c = 0.02$ and $d = 0.4$ (Anonymous, 2012a)).

4.1.1 Pol, TSS, nonpol, fibre, moisture

Cane Testing Service (CTS) routinely samples and analyses individual cane consignments using the Direct Analysis of Cane (DAC) system (*cf.* Schoonees-Muir *et al.*, 2009), to determine pol (an estimation of sucrose), TSS, moisture and fibre content. These values are

required for the calculation of RV and to facilitate factory process control (Love, 2002; Martin, 2008; Anonymous, 2012a). An estimate of sucrose content, referred to as pol, in mixed juice, is measured in the factory by a method known as polarimetry which represents an indirect measure of the sucrose content (*cf.* Schoonees, 2003). A polarimeter is used to quantify the amount of sucrose in a sample, by determining the angle of rotation of polarized light in the sample solution.

The determination of non-pol content in the sugarcane is calculated as the difference between °Brix%cane and pol%cane. It is therefore important to measure the total soluble solids (°Brix) content of the sugarcane. In the South African sugar industry, the °Brix content is measured by the use of a refractometer (MacGillivray and Graham, 1969). Purity is another parameter determined from the °Brix and is measured as the ratio of pol%cane to °Brix%cane. In South Africa, the determination of fibre%cane is done indirectly from the °Brix and moisture of prepared cane samples (*cf.* SASTA, 2009). Direct determination involves the weighing of cane samples before after drying, and this is performed rarely (Engelke, 2002).

The value of the change in mass of the sample, when weighed after drying, is assumed to be the moisture content of the cane, this is calculated by Equation 2. The RV%cane for individual consignments is then calculated from the adjusted DAC values upon direct determination of sucrose values obtained from gas chromatography tests (Walford *et al.*, 2004).

$$\text{Moisture \%} = \frac{(\text{Initial weight} - \text{Dried weight})}{\text{Initial weight}} \times 100 \quad \text{Equation (2)}$$

The presence (and concentration) of either ethanol, dextran, mannitol and/or lactic acid has been suggested as an indicator of sugarcane deterioration, but these products are not routinely tested for in sugarcane consignments at South African sugar mills. In Figure 4.1 a summarized description of the process of sugarcane quality determination, at sugar factories (mills) is presented. It is apparent from Figure 4.1, that deterioration indicators have not been incorporated into the process for determining quality for payment purposes.

Near Infra-Red (NIR) spectroscopy, is another technique that is gaining popularity as a rapid measure of sugarcane quality parameters in South Africa. This technology has been shown to be able to measure a number of cane quality parameters such as sucrose, fibre,

°Brix, glucose, fructose, ethanol, lactic acid (*cf.* Meyer and Wood, 1988; Schaffler *et al.*, 1993; Edye and Clarke, 1996; Meyer, 1997; Naidoo and Simpson, 2011). The detection of volatile organic compounds (VOC), such as ethanol, produced during deterioration, may also be performed using e-nose technology (Naidoo, 2003; Wilson and Baietto, 2009). Although not used commercially in the sugar industry, this artificial olfaction technology is currently used in quality control in a variety of food industries (Wilson and Baietto, 2009).

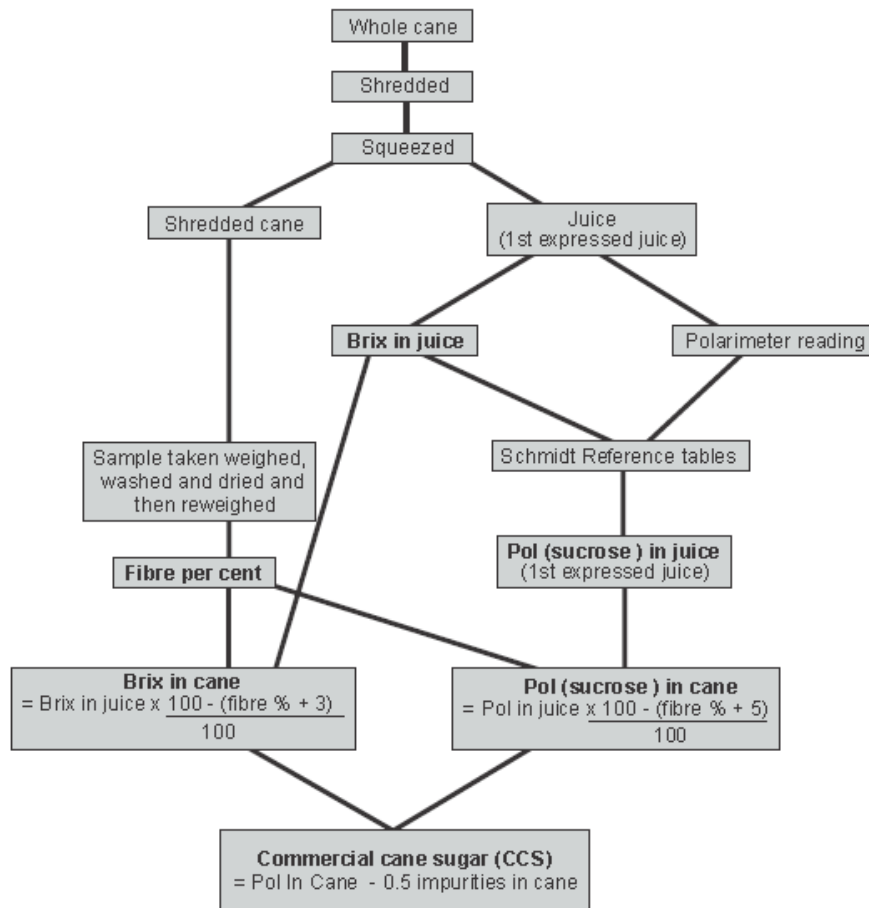


Figure 4.1 A process path diagram of sugarcane quality determination at the mill (Engelke, 2002).

According to Martin (2008), DAC methodologies are considered time-consuming and cannot be performed prior to the corresponding cane consignment being crushed. This time lag hinders the ability to objectively analyse cane quality before allowing the consignment into the factory (Lionnet and Gooch, 2002). Near Infra-Red (NIR) spectroscopy has therefore been used in recent times, as a faster alternative, to measure cane quality parameters (Naidoo and Simpson, 2011). The DAC methodologies are still popular, with most sugar factories in South Africa.

4.2 Quantitative Measures of Fresh Produce (Fruit and Vegetables) Quality Parameters

Quality measures in the fruit and vegetable industry differ slightly from the sugar industry, because, with the exception of produce destined for processing industries, fresh produce is delivered to a market that demands more detailed specifications with regards to the product desired. However, a number of the quality measures used in the sugar industry, such as sucrose, TSS, and deterioration indicators such as ethanol, are also used extensively in the fresh produce industry in South Africa (Swanepoel *et al.*, 2007; OECD, 2009). In addition pH appears to be an important indicator of produce quality, and is measured after harvest (Swanepoel *et al.*, 2007). Instrumental measurements are preferred to sensory evaluations in research and commercial contexts, because they provide a common, and less subjective, language among researchers, industry and consumers (Abott, 1999).

In this section some techniques for measuring internal quality in fruits and vegetables will be described. According to OECD (2009) the internal quality of fruit is defined as: “the degree measured with objective criteria, to which a commodity has reached a sufficient stage of development such as to enable its quality, after harvesting and postharvest handling to be acceptable to the final consumer.”

4.2.1 TSS, titratable acidity, determination of juice content, moisture content, dry matter content

Sugar is the main component of Total Soluble Solids (TSS) in fruit and vegetables (James and Ngarmsak, 2011). The measurement of TSS provides a reasonable indicator of sugar levels or sweetness (James and Ngarmsak, 2011). The measurement of TSS, as °Brix, in the fresh produce industry is similar to the sugar industry. This is performed using a refractometer or a hydrometer (*cf.* OECD, 2009). Sampling and sample preparation vary according to the commodity of interest (*cf.* OECD, 2009) and this method of measuring TSS represents a destructive measurement of quality.

The sugar acid ratio is used in the fresh produce industry as a measure of commercial and organoleptic quality (OECD, 2009). Acidity is therefore measured after harvest to calculate this ratio and hence determine quality of the produce (James and Ngarmsak, 2011). Acidity

can be measured by titrating a known volume of fruit juice with 0.1N NaOH to an end-point of pH=8.2 as indicated by phenolphthalein indicator or by using a pH meter (*cf.* Mitcham *et al.*, 1996; Abott, 1999; OECD, 2009; James and Ngarmsak, 2011). The methods described for determining pH are destructive. Sampling and sample preparation differs according to commodity (*cf.* OECD, 2009).

The juice content of fruit, such as citrus and mango, is also an important parameter for measuring quality (Jha *et al.*, 2010). The process involves extracting as much juice as possible from the commodity and filtering this juice into a beaker (*cf.* OECD, 2009). To calculate the juice content Equation 3 is used.

$$\text{Juice percentage} = \frac{\text{Total weight of juice (g)} - \text{Beaker weight (g)}}{\text{Total weight of fruit}} \times 100 \quad \text{Equation (3)}$$

Dry matter (DM) content is also an important indicator of quality after harvest in certain fresh produce commodities such as kiwifruit, avocado, mango, apple and swiss chard (McGlone and Kawano, 1998; Clark *et al.*, 2004; Daiss *et al.*, 2008; OECD, 2009). The technique that appears to be popular for measuring dry matter content, involves measuring the mass of a sample of the commodity before and after oven-drying (*cf.* Devereau *et al.*, 2002; OECD, 2009). Equation 4, from OECD (2009), shows how the DM content is calculated.

$$\text{DM percentage} = \frac{(C-A)}{(B-A)} \times 100 \quad \text{Equation (4)}$$

where A = mass of the container

B = total mass of fresh sample + container

C = total mass of dry sample + container

The DM content is a useful indicator, because dry matter is dominated by a large carbohydrate component *i.e.* sugar and starch, which is converted to sugar on ripening and harvest (McGlone and Kawano, 1998; Clark *et al.*, 2004). Therefore, DM content is an indicator of potential or actual sugar level in the fruit (Clark *et al.*, 2004).

Another important internal measure of quality after harvest in fresh produce is the determination of moisture content. A direct method of measuring moisture in fruit and vegetables is the oven-drying method (refer to Equation 2) (Devereau *et al.*, 2002). Indirect

methods, also known as secondary methods, of measuring moisture content in agricultural commodities were developed to overcome the time-consuming nature of standard methods (*cf.* Devereau *et al.*, 2002; Jha *et al.*, 2011). These methods involve the use of specialised moisture meters to measure electrical properties of the commodity, which vary with moisture content and hence provide indirect measurements of moisture content (Devereau *et al.*, 2002; Jha *et al.*, 2011). Moisture meters have been used in the citrus (Fito *et al.*, 2004) and grain industries (Jha *et al.*, 2011). Another secondary technique, which is more accurate, but more capital-intensive, for measuring moisture, is Near Infra-Red spectroscopy (Devereau *et al.*, 2002; Nicolai *et al.*, 2007; Lin and Ying, 2009).

Determining moisture content is of particular importance in dried fruit *e.g.* dried apples, pears, apricots, and grains (Devereau *et al.*, 2002; Wittuhn *et al.*, 2005; OECD, 2009). Table 4.1 presents a summary of the discussed quality parameters.

Table 4.1 Comparison of internal quality parameters in the sugar and fresh produce industry

Internal Quality Parameter	Technique	Sugar Industry	Fresh Produce Industry
Pol/Sucrose	Polarimetry, High Performance Liquid Chromatography, NIR*	✓	✓
Total Soluble Solids (°Brix)	Refractometry, NIR*	✓	✓
Fibre	Oven Drying, NIR*	✓	✓
Moisture	Oven Drying, Moisture Meters*, NIR*	Not routine	✓
Dry Matter	Oven Drying	Not routine	✓
Volatile Organic Compounds (Ethanol <i>etc.</i>)	HPLC, E-nose*	Not routine	✓
Acidity	Titrateable Acidity, pH meter	Not routine	✓
Juice percentage	Determining mass of Juice as percentage of the fruit mass	Not performed	✓

*Non-Destructive technique.

5. DISCUSSION AND CONCLUSION

The research in postharvest technology appears to generate more advances from the fresh produce industry when compared to the sugar industry. The requirements for quality from the fresh produce industry also appear to be more stringent and with more parameters, *viz.* external quality parameters such as visual appearance, in addition to the internal quality parameters such as sucrose content and sugar/acid ratio. The majority of sugarcane grown in South Africa is destined for mill processing and therefore only internal parameters such as sucrose content, fibre and moisture content. are considered important in this industry.

Despite the frequent harvest to crush delays (HTCDs) in the South African sugarcane supply chain, the literature on strategies implemented in the country to minimise deterioration during this delay period is still limited. Most literature that indicate advances in this area appear to point towards research conducted in the Indian sugar industry.

The South African fresh produce industry shows significant advances in storage technology *viz.* controlled atmosphere and modified atmosphere storage, as well as modified atmosphere packaging. This may primarily be due to the supply chain orientation of the fresh produce industry, which is designed to accommodate extended storage periods and long distance transportation of produce to consumer destinations. In the sugarcane industry, storage recommendations include techniques such as covering harvested cane with trash and sprinkling water periodically to maintain cool temperatures during the HTCD.

In South Africa, the literature primarily shows attempts to identify chemical (or biochemical) indicators of deteriorated sugarcane and using these indicators as a basis for accepting or rejecting cane at the mill. Indicators such as ethanol, lactic acid and dextran have been used. However, recent advances in the industry have called the reliability of these indicators into question. Ethanol is also measured as an indicator of deterioration in citrus fruit. General indicators, such as total acidity, might prove useful to the sugar industry rather than focussing on particular acids, which may vary with the deterioration mechanism. It may also be important for these indicators to be included in routine quality measurements of sugarcane at the mill.

Sanitation appears to be a concern in both agricultural sectors. Antimicrobial solutions are currently in use to minimise deterioration after harvest for sugarcane and in a variety of fruit. Integrated sanitation strategies suppress proliferation of the diverse range of microorganisms that are responsible for produce deterioration after harvest. Electrolysed water fogging of the cane in stockpiles is a technique that might prevent/reduce microbial action (Solomon *et al.*, 2000; Solomon, 2009). The number of strategies that can be implemented in the sugarcane supply chain is limited by the costly nature of some of the treatments such as UV radiation and intense light pulses.

Ideally, non-destructive measurement techniques would provide a rapid and accurate determination of quality. One such measurement is the indirect measurement of moisture content, based on the dielectric properties of the commodity. This technique, common for measuring moisture in grains during storage, has gained popularity in the citrus and apple industry (Devereau *et al.*, 2002). Since moisture is an important parameter to the sugar industry, this non-destructive technique may prove useful to rapidly determine moisture content in cane stalks before processing. The use of infra-red thermography (IR) has proven useful in monitoring moisture content in citrus (Fito *et al.*, 2004), however the application of this may be limited in sugarcane.

The use of artificial olfaction may prove useful in detecting volatile organic compounds produced during deterioration. In the South African sugar industry the major limitation to using this technology appears to be an inability to quantify these compounds, in addition to detecting them. In the future, with an integration of quantification ability, the e-nose could serve as a potentially powerful detector of deteriorated cane at the mill. Overall, Near Infra-Red Spectroscopy (NIRS) seems to be the most accurate technique available in South Africa to measure quality. With the incorporation of deterioration indicators in routine NIRS analysis of cane consignments, then postharvest quality management may be improved.

The differences between the sugar and fresh produce supply chain, dictate the parameters that are important for each chain. The end product is often different with the sugarcane stalk not being visible to the consumer whereas most fruit and vegetables must be visually appealing to the consumer. However, it is important to compare internal quality parameters between the two industries, and advances in one industry may be applied to the other if possible and economically feasible.

6. PROJECT PROPOSAL

This study proposes the development of quality indicators for the determination of the degree of deterioration in sugarcane. An attempt to generate a robust test, which can be used to determine the levels of deterioration, with confidence, inexpensively and quickly enough to allow objective analysis of delivered consignments prior to crushing will be made.

6.1 Rationale

Cane deterioration remains one of the most important supply chain efficiency leverage points in the South African sugar industry. Deteriorated cane severely affects milling efficiency and sugar quality. However, deteriorated cane may also point to incorrect infield and logistical operations, which eventually drains profits from the industry's bottom line (Ravno and Purchase, 2005; Martin 2008). This is why, over many years, researchers have been trying to establish a measure of deterioration severity. (*e.g.* Wood, 1976; Lionnet, 1986; Bacci and Guichard 1994; Lyne and Meyer, 2005; Eggleston and Harper, 2006; Eggleston *et al.*, 2008; Petit *et al.*, 2009). Recent studies have identified e-nose technology as a method with the potential of detecting deterioration products (Marti *et al.*, 2005; Wilson and Baietto, 2009), and also on-line ethanol detection as a technique for identifying deteriorated cane (Loubser *et al.*, 2003; Loubser and Gooch, 2005). To date, however, cane deterioration remains a relatively free-agent when it comes to benchmarking, economics and supply chain management, and the lack of the inclusion of a deterioration parameter in the cane payment formula (Martin, 2008) may not incentivise stakeholders to improve operations.

The financial losses associated with sugarcane deterioration (Ravno and Purchase, 2005) warrant a study into innovative methods to quantify deterioration. Such methods, if incorporated appropriately into the industry, may serve as an incentive to stakeholders in the industry to improve operations in a manner that may potentially reduce the level of deterioration of cane consignments. Improvement in cane quality management has the potential to increase the revenue generated by the entire supply chain (Ravno and Purchase, 2005; Martin, 2008).

6.2 Aim and Objectives

The aim of this project is to derive innovative measures and statistics that would detect the degree of sugarcane deterioration, upon delivery at the mill, with relative ease. This aim will be achieved by addressing the following objectives:

1. Perform statistical analyses on CTS data to confirm and further refine quality control based indicators that were discovered during the author's MSc study (Sibomana *et al.*, 2011),
2. Perform laboratory analyses (microbiological, biochemical and physical) on green and burnt sugarcane (N31 and N12 varieties), in an attempt to determine any trends in constituent changes after harvest. Analyses will be performed on cane that has been stored in a manner that simulates field conditions after harvest,
3. Use the information from the laboratory analyses to develop a test that can be performed at mill laboratories to signal cane deterioration of delivered consignments.

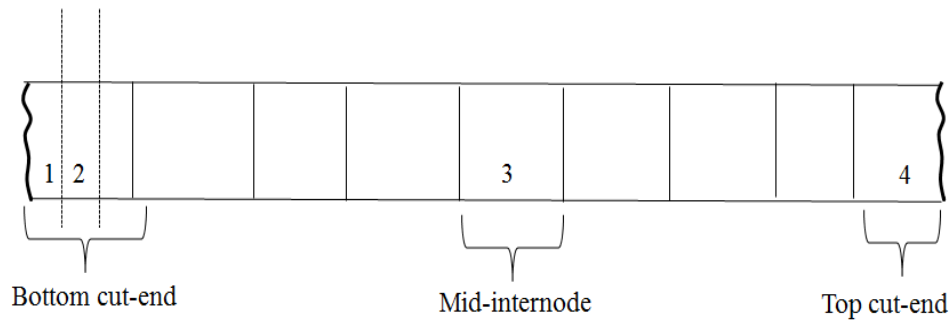
6.3 Methodology

The CTS quality data for 2011/2012 season at Umfolozi mill will be analysed using quality control charts (Shewhart, 1931) and a non-parametric statistical analysis, *viz.* Mann-Whitney test (Noether, 1991). The quality control charts (QCCs) will be used to identify days of the week when the cane delivered is of an inferior quality compared to the rest of the week's deliveries. The Mann-Whitney test will then be used to determine whether the days identified by the QCCs are, statistically significantly different from the 'good' quality days. Non-parametric statistical analyses will be performed, to compare sample groups, in the CTS quality data. Mann-Whitney statistics will only be performed on a sample of growers determined, by Pareto analysis (Evans and Lindsay, 2008; Montgomery, 2009), to contribute 80% of the total cane delivered to Umfolozi mill during this season. Mann-Whitney tests may therefore allow the evaluation of individual grow performance with regards to quality.

6.3.1 Sample production and preparation

The laboratory analyses will consist of microbiological, biochemical and physical tests on harvested cane. Two varieties of sugarcane will be harvested *viz.* N12 and N31, with the former being the most widely grown in the rain-fed regions of the South African sugar industry (Anonymous, 2006) and the latter being popular in the Midlands region of KwaZulu-Natal (Anonymous, 2006). These two varieties are also quite different in terms of quality (Anonymous, 2006). Green (unburnt) sugarcane will be harvested in October 2012 and this will constitute the summer trial. Burnt cane will be harvested in May 2013 and will constitute the winter trial. In July 2013, both green and burnt cane will be harvested and this will attempt to compare both green and burnt cane in winter conditions. In harvesting the cane, an attempt will be made to cut the stalk at the lowest point so as to be able to sample the most mature internodes in the stalks.

Assuming that cane deterioration is a function of time and progresses gradually from the exposed cut-ends of the stalk, all tests will be performed in an internode-specific manner to take this into consideration. On each sampling date, cane stalks will be cut such that internodes at the bottom cut-end, the middle and the top cut-end are separately used for the analysis of each parameter. An illustration of this is presented in Figure 6.1. Apart from Near Infra-Red spectroscopy (NIRS) analysis, which requires substantial mass for operation, 5 stalks of each variety will be analysed on each sample date.



Key:

1: 1st Bit

2: 2nd Bit

3: Mid-internode

4: Top-internode

For each test 3cm segments of cane stalk were used

i.e. 3cm of 1, 2, 3 and 4

Figure 6.1 Illustration of how each cane stalk will be sampled for laboratory analysis.

6.3.2 Sample storage

In an attempt to simulate field conditions after harvest, the cane will be stored in tied bundles of 5, and laid in an open field at University of KwaZulu-Natal, Pietermaritzburg campus. The storage area is close to a meteorological site where weather data, such as temperature and humidity, is constantly recorded. As a result, this project will have access to data on the environmental conditions of the stored cane throughout the storage period. The cane will be stored for 9 days after harvest, and will be tested on day 1, 3, 5, 7, 9.

The average HTCD in South Africa, as recorded in 2007-2008 milling season, was 71 hours (van den Berg *et al.*, 2008). However, this study will attempt to document changes in the cane for a longer period after harvest, which might provide data for understanding what might happen in extreme HTCDs.

6.3.3 Experimental assays

The harvested cane will be subjected to microbiological assays, to determine total populations of microorganisms in the cane after harvest and identify predominant microorganisms during storage period. Population determinations will be done by standard plate counts using Tryptone Soy Agar (TSA) as the substrate medium (Martin, 2008;

Margesin *et al.*, 2011). This procedure will be performed to determine populations of aerobic bacteria in the cane samples over the 9-day storage period. According to Eggleston *et al.* (2008), bacteria such as *Lactobacilli* and *Leuconostoc mesenteroides* are the most common, microbial, agents of cane deterioration in the area. On each sample date, tissue samples from the different stalk internodes will be suspended in Ringer's solution and serial dilutions will be performed. 0.1mL of each dilution will then be spread-plated (Isaac and Jennings, 1995) onto TSA plates in triplicates and incubated at 28°C for 48 hours after which colony counts will be performed (Martin, 2008).

Morphological characteristics of colonies, and Gram-staining results (Isaac and Jennings, 1995; Brock, 1999) of common colonies, will be noted and compared to known microorganisms, such as *Leuconostoc mesenteroides* which is a Gram-positive bacteria, by referring to literature (*e.g.* Garrity, 2001). Further, biochemical identification tests will be performed testing the ability of the microorganisms to utilise different carbohydrates (*cf.* Bell *et al.*, 2005). Those that test positive for utilization of sucrose, which is shown by the production of an acid in the test media noted by the change in colour of an indicator solution (Isaac and Jennings, 1995), may then be further identified by MALDI-TOF mass spectrometry (*cf.* Maier *et al.*, 2006). MALDI-TOF mass spectrometry is a technique that can be used for rapid identification of microorganisms. This technique involves the generation of mass spectra from selected colonies, which are smeared onto a MALDI target plate, which is then overlaid with a MALDI matrix. This MALDI plate is then placed in the spectrometer and the generated mass spectra are compared to a reference database using a Biotyper™ software (Maier *et al.*, 2006; Iilina *et al.*, 2009).

The total soluble solids (°Brix), sucrose, fructose, moisture content and ethanol content of the internodes of interest will be determined each experimental day, by Near Infra-Red spectroscopy (NIR) (Naidoo and Simpson, 2011), at SASRI. The cane samples will be shredded and cane will be placed in a container, which is then scanned by an NIR spectrometer. An example of equipment used to shred cane and a shredded cane sample, is presented in Figure 6.2. For each sample date, 15 stalks of each variety will be analysed as 1 sample *i.e.* 15 stalks will be cut into the sections as described in Figure 6.1 and each section scanned as 1 sample. The NIR spectrometer at SASRI is calibrated for wet cane tissue analysis.

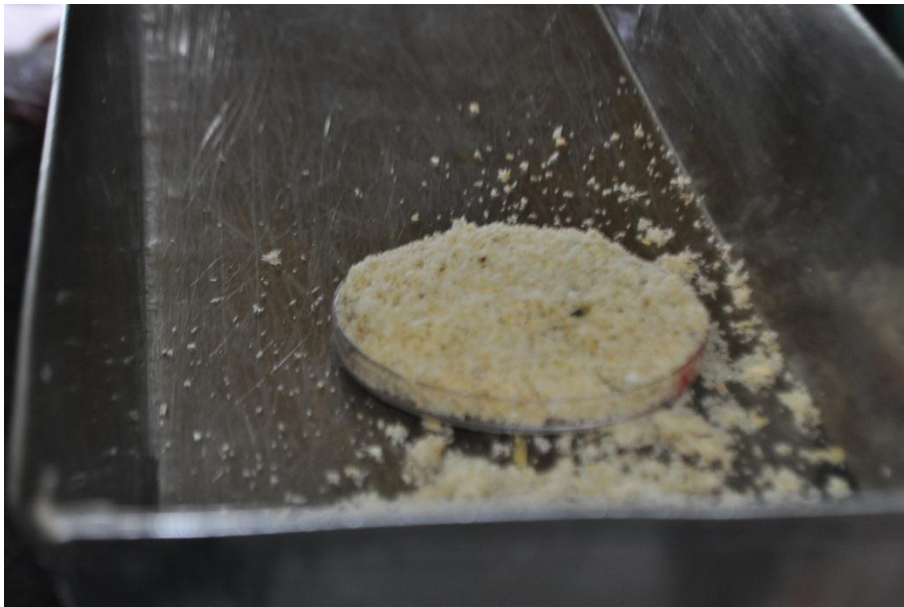
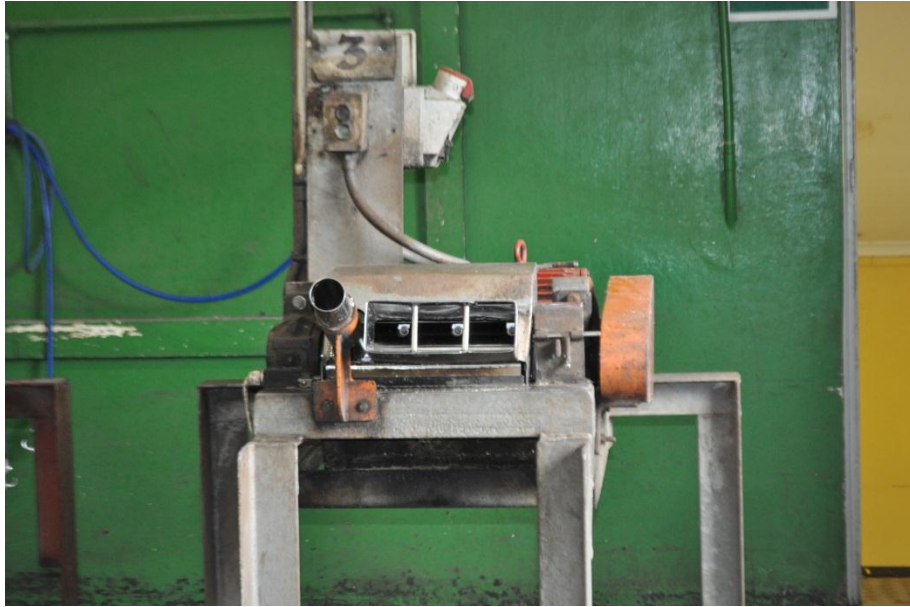


Figure 6.2 An example of a cane shredder and shredded cane sample.

The respiration rate of the specified internodes will be determined by Infra-Red Gas Analysis (IRGA) (Watt and Cramer, 2009). The production of lactic acid will also be tested using an enzymatic bioanalysis/food analysis kit from R-Biopharm (Roche, Mannheim) (Martin, 2008). The pH of juice from the specified internodes will also be measured during the storage period. pH will be measured by the use of a pH meter.

In addition to these biochemical analyses, internodes will be cut and placed in a dye solution over a period of 24 hours to measure the ability of dye solution to diffuse through the internode and determine whether this property can be related to moisture loss over time. Change in diameter between node and internode will also be monitored during storage period.

The information derived from these analyses will facilitate the generation of a number of parameters that can be used as indicators of time delay after harvest. This may have potential to signal deterioration at the mill.

6.4 Resources Required

The necessary resources for this project include:

- a. lab space, equipment & consumables
- b. transportation to and from SASRI laboratories in Durban, KwaZulu-Natal
- c. storage space for harvested sugarcane, and
- d. office, computing equipment and stationery.

Funding required for these resources has been secured through SASRI and a UKZN doctoral research grant.

6.5 Workplan

Table 6.1 Work plan

ACTIVITIES (July 2012-December 2013)	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Literature review	■	■	■															
Further statistical analysis of CTS data	■	■	■															
Experimental trial 1 (summer data, green cane)				■	■	■												
Data analysis and results write-up						■	■	■	■									
Experimental trial 2 (winter data, burnt cane)										■	■							
Data analysis and Results write-up												■	■	■				
Experimental trial 3 (both green & burnt cane, winter data)												■	■	■	■			
Results analysis and completion of write up															■	■	■	■

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