Ripening and the Use of Ripeners for Better Sugarcane Management

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1. Introduction

The sugarcane crop is important because of its multiple uses: it is used around the world "in natura" for forage for animal feed or as raw material for the manufacture of brown sugar, molasses, alcoholic beverages, sugar and ethanol. Processing its waste also has great economic importance, especially for vinasse, which is transformed into organic fertilizer, and for bagasse, which is transformed into fuel. Sugarcane is grown mainly in tropical and subtropical climates across a wide region, between the 35° north and south latitudes from the equator. The ideal climate has two distinct seasons: the first is hot and humid to facilitate budding, tillering and plant growth and the second is cold and dry to promote maturation and the consequent accumulation of sucrose in stems.

Distinct from the plants grown at the beginning of commercial exploitation, there are now genetically improved varieties of sugarcane that have low levels of fiber and high concentrations of sugar, which are both responsible for high productivity. However, despite the diversity of genetic material available, the sugarcane industry still faces problems with the precocity of raw material, and it is not capable of meeting industry demand at the beginning of the season as is it during the middle of the season to produce the same amount of material required for processing. Another problem that has not been fully resolved for industrialization is flowering.

The process of flowering, an important aspect in the production of sugarcane, involves morpho-physiological alterations of the plant, which are considered highly undesirable features when accompanied by an intense pith process (the process of juice loss in the parenchyma cells of the stalk) and may modify the quality of the raw material from a technological point of view. Substantial losses in the productivity of stems and sugar are attributed to flowering during the season. The pith process in the stem begins with blooming, causing dehydration of the tissue and a consequent loss of weight in the stem; thus, it becomes very important to quantify the degree of pith processing and the possible modifications in the quality of the raw material to properly design the area to be planted for each variety and to determine the time periods most favorable for their industrialization. However, depending on the variety and environmental conditions to which it is subjected, the intensity of the process is variable, as is the intensity of the problems arising from these phenomena.

A gradual drop in temperature and reduced rainfall are crucial for the natural ripening of sugarcane. However, in many years during the ripening period, these conditions do not occur simultaneously or completely. In such situations, the use of ripeners and flowering inhibitors in the sugarcane crop is designed to increase productivity and to anticipate the harvest, thus allowing essential crop management in a modern production system.

Ripeners, defined as plant growth regulators, act by altering the morphology and physiology of the plant, which can lead to quantitative and qualitative changes in production. They may act by promoting a reduction in plant growth and enabling increases in sucrose content, early ripening and increased productivity, and they may also act on enzymes (invertases), which catalyze the accumulation of sucrose in the stalks. The use of ripeners in the sugarcane production system has provided greater flexibility in managing the harvest and is highly relevant for harvest planning. Additionally, ripeners promote the industrialization of a better quality of raw material. However, the feasibility of utilization depends on a number of factors, including climatic, technical and economic variables; feasibility especially depends on the additional responses that each variety may provide to this cultivation practice.

The number of studies involving flowering and ripeners has increased. Doses and products have been tested to achieve greater sugar productivity without causing damage to the plant or decreases in the agricultural productivity of the current year and subsequent ratoons.

The main chemicals used as ripeners include ethephon, glyphosate, trinexapac-ethyl, sulfometuron-methyl, fluazifop-p-butyl and others, such as maleic hydrazide, paraquat and imazapyr.

This chapter describes the alterations that occur in sugarcane during the process of sucrose accumulation and flowering and provides information on crop management options with the application of ripeners and chemical flowering inhibitors when climate conditions are not suitable for natural ripening.

2. Sugarcane ripening

The ripening of sugarcane is a characteristic of the plant that can be stimulated by environmental and management factors.

Fernandes (1982) defined sugarcane ripening as a physiological process that involves the synthesis of sugars in the leaves, translocation of the products formed and storage of sucrose in the stalk. According to Castro (1999), ripening is one of the most important aspects for sugarcane production; in the process of sucrose accumulation, which depends on energy, varietal characteristics are fundamental.

According to Deuber (1988), the ripening of sugarcane may be considered from three different points of view: botanical, physiological and economic. Botanically, sugarcane is ripe after the production of flowers and formation of seeds, which may give rise to new plants. Taking into account vegetative reproduction, which is the manner used by the productive sector, plants may be considered ripe much earlier in the cycle when the buds are ready and able to give rise to new plants. Physiologically, ripening is reached when the stems reach their potential sucrose storage, i.e., the point of maximum possible sucrose accumulation. In this cycle, the sugarcane reaches full botanical maturity before reaching

physiological maturity. This means that although the seeds may already be falling in panicles, the accumulation of sucrose still continues for a period of generally one to two months. Economically, from the perspective of agronomic practice, sugarcane is considered mature or able to be industrialized from the moment it possesses the minimum sucrose content (pol), which is greater than 13% of the stalk weight.

For example, in the southeastern region of Brazil, which is considered to be the largest producer of sugarcane in the world, the culture's ripening process occurs naturally from the beginning of May and reaches its climax in October. The region's climatic conditions, which include a gradual drop in temperature and a decrease in precipitation until it is completely dry in the middle of the year, are decisive in the maturation process.

During ripening, sugarcane stores sucrose starting from the bottom and then in the top of the stalk. Therefore, at the beginning of the season, the lower third of the stalk has a higher sucrose content than the middle third, which has a higher content than the upper third. As ripening progresses, the sucrose content tends to equalize in the different parts of the stalk.

The increase in sucrose accumulation in the internodes of the already developed stalks is strongly influenced by environmental conditions that are unfavorable for plant growth and development. In this stage, 11 to 20 months after planting (depending on time of installation of the cane field, the period of ripening for the variety used and the country where it is being produced), there is full ripening of the sugarcane, which is observed when the harvest is properly monitored by specific technological analyses.

Varieties are classified as a function of whether they ripen in the early, mid or late stages; in other words, varieties are classed by when they reach the sucrose content suitable for industrial uses (i.e., at the beginning, middle or end of the season) without accounting for establishing the period of maximum sucrose content.

Worldwide, sugarcane generally has only one planting season; however, in Brazil, there are two distinct seasons for sugarcane planting. One-and-half-year planting, or sugarcane in 18 months, which is planted from January to early April, has a limited growth rate (zero or even negative), depending on the weather conditions from May to September. The phase of higher crop development takes place mainly from October to April, if there are good rainfall conditions, with peak growth from December to March. This is the planting period preferred by farmers. However, sugarcane planted in one-year cycle is usually planted from September to October, with its maximum development occurring between the months of November through March, which decreases after these months due to adverse weather conditions. The possibility of harvest begins in July, depending on the variety. This planting method is used for areas that are planned for the end of the harvest season.

The sugarcane ripening process has been studied in several countries. Given its relationship with agronomic experimentation, routine assessment of the stage of ripening and the cost of sugarcane based on sucrose content, it is of fundamental importance to understand the attributes in the juice and stalk, such as Brix, pol, juice purity, sugar cane fiber and reducing sugars, and the total recoverable sugars during plant development, (Caputo, 2006).

2.1 Mechanism of sucrose accumulation in sugarcane stalks

Sugarcane has the capacity to maximally use the available sunlight for photosynthesis. Each internode produces a new leaf in approximately ten days, and older leaves senesce, leaving

a constant number of eight to nine leaves per stem. The majority of incident light is intercepted by the six most apical leaves (Alexander, 1973).

According to Legendre (1975), rapid fluctuations in temperature have little effect on the photosynthetic process, within the limits of 8-34 °C. Temperatures of 17-18 °C appear to be particularly favorable for the partition of photosynthates into the interior sugar reserves and the accumulation of high levels of sucrose.

However, according to Castro (2002), low temperatures lead to a rapid decline in photosynthetic efficiency, and high levels of sugar are not retained; the low temperatures affect the development of the stalk, sugar transport and storage, leading to accumulation of sucrose in the leaves. There is an interactive effect between sunlight, temperature and different varieties of sugarcane in response to the maturation process; however, with respect to rainfall, there is apparently no association with the referred process.

According to Moore (1995), the synthesis of sucrose that occurs in the cytosol and the synthesis of starch that occurs in the chloroplast are competitive processes that are established in sugarcane leaves. The metabolic pathways of sucrose and starch synthesis have several phases in common that involve certain enzymes, but these enzymes have isozymes that have different properties and are unique to an appropriate cellular compartment. The excess of triose phosphate can be used both for the synthesis of sucrose in the cytosol and for the synthesis of starch in the chloroplast, and the conditions that promote one inhibit the other.

According to Lingle (1999), sucrose, the end product of photosynthesis, passes through the phloem before being deposited in the vacuole and finally undergoes changes within storage cells. The inversion of sucrose, interconversion and phosphorylation of glucose and fructose, synthesis of sucrose phosphate and active accumulation through the tonoplast constitute the storage process. This process is characterized by the movement of sucrose against a concentration gradient. Through the inversion of fructose and glucose, sucrose can leave the vacuole once again.

Independent of the maturity of tissues, the mechanism of active sucrose accumulation appears to be the same, but there are differences between these tissues (mature and immature) with respect to the accumulation of sucrose due to the concentration of invertase and the need for growth. The immature storage tissues are characterized by cell expansion. The sucrose accumulated in these tissues is rapidly hydrolyzed by acid vacuolar invertase, and the hexoses produced move freely to the cytoplasm to be used in the growth process. As a part of the cycle, the hexoses may also be stored again.

In mature stem tissues, where growth processes are near completion, there is a decline in the concentration of acid vacuolar invertase, and neutral invertase then becomes predominant (the enzyme is apparently situated in the cytoplasm). This enzyme, together with cell wall acid invertase, governs the active accumulation of sucrose in the vacuole. Later, in more mature tissues that exhibit sucrose levels of approximately 15 to 20%, sucrose is stored in the intercellular spaces. Thus, sucrose plays an important role in the movement of sugars, depending on the physiological condition of plants, as conditioned by the environment; this may result in passive diffusion between the intercellular space and the vacuole by translocation to areas of intense sugar metabolism.

The synthesis of sucrose promotes the enrichment of stalk internodes, while the synthesis of starch reveals the immaturity of the sugarcane plant. Young plants and the apical region of the stalk are rich in starch, as are plants that have lost apical dominance due to the effect of the application of chemical products, improper management or unfavorable environmental factors.

In the elongation phase, assimilates are employed in the construction of the structure of internodes. Thus, the loss rate of assimilates is greater than the utilization rate because glucose, fructose and sucrose begin to be accumulated during this phase. Acid invertase and sucrose synthase reach their maximum activities in this process, demonstrating their association with this phase. Water content is negatively correlated with the activity of sucrose phosphate synthase, and the latter is positively correlated with sucrose content (Lingle, 1999).

2.2 The role of enzymes in ripening

Sucrose is accumulated in the stalks against a concentration gradient; the energy required for this process is provided by respiration. It has been established that increased sucrose content is accompanied by a continuous cycle of degradation and synthesis during the accumulation of sucrose in the reserve tissues (Vorster & Botha, 1999; Rohwer & Botha, 2001).

Many enzymes govern the primary metabolism of sucrose. Invertases have a key role in the partition of photosynthates between storage and growth, in which sucrose is broken down into glucose and fructose. These enzymes are classified by solubility, cellular location and optimum pH. The best-characterized isoforms are the acid invertases that occur in the apoplastic space, both free-form and bound to the cell wall. The soluble isoforms are predominantly present in the vacuole.

The activity of soluble acid invertase can be high or low, respectively, under favorable or unfavorable growth conditions (e.g., water stress, short photoperiod, low temperatures and application of ripeners).

Neutral or alkaline invertase occurs in the cytosol and still requires better characterization.

Sucrose-phosphate synthase (SPS) is considered to be the main regulatory enzyme in the pathway of sucrose synthesis. It synthesizes sucrose-6-phosphate, which is dephosphorylated by the action of the sucrose-phosphate phosphatase enzyme. Sucrose synthase (SuSy) can break down sucrose, generating UDP-glucose and fructose; it can also catalyze the reverse reaction, synthesis. In vivo, SuSy acts preferentially in the direction of the breakdown of sucrose.

According to Zhu et al. (1997), increasing the concentration of sucrose in individual sugarcane internodes is correlated with a decrease in soluble acid invertase activity during ripening.

The roles of soluble acid and neutral invertases (SAI and NI, respectively) and acid invertase are linked to cell wall mobilization, utilization and accumulation of sucrose in different varieties of sugarcane. The difference between sucrose concentrations in some genotypes is correlated with the difference between the activities of sucrose-phosphate synthase and soluble acid invertase enzymes. Ebrahim et al. (1998) and Lingle (1999) showed in their

studies that both the activity of SPS and the difference between SPS and soluble acid invertase is correlated with the concentration of sucrose in developing internodes. Botha & Black (2000) demonstrated a positive correlation between SPS activity and the rate of sucrose accumulation and a highly significant correlation between SPS activity and sucrose content.

Environmental conditions can greatly influence the activity of invertase. Terauchi et al. (2000) reported that the activity of SAI decreased in cold conditions. The highest activity of SPS and the lowest activity of SAI probably resulted in an increase in the concentration of sucrose in the winter, at low temperatures, suggesting that the activity of SPS is one of the factors involved in the control of sucrose accumulation in sugarcane. Leite et al. (2009) observed an increase in SAI activity through the use of chemical ripeners under high precipitation, a condition favorable for sugarcane plant development. However, when subjected to decreases in temperature and precipitation, which are favorable conditions for natural ripening, the application of chemical ripeners resulted in elevated NI activity.

Lingle (1997) suggested that the activity of SAI was responsible for controlling growth in sugarcane plants. It was observed that the total concentration of sugar and sucrose increased while the activity of SAI decreased during the maturation of internodes, leading to the conclusion that this enzyme suppresses the accumulation of sugar.

The NI activity and sucrose content in mature internodes are closely related. Vacuolar SAI allows the accumulation and effective storage of sucrose when it is nearly absent (Suzuki, 1983). Rose and Botha (2000) also found a significant correlation between sucrose content and the level of NI.

Plant growth regulators promote distinct and significant alterations in the enzymatic activities of acid and neutral invertases (Leite et al., 2009, Siqueira, 2009).

2.3 Climatic factors that affect ripening

Sugarcane productivity is most influenced by climate (Barbieri, 1993; Keating et al., 1999).

Alexander (1973) mentioned that sugarcane plants slow their growth rate to accumulate more sugar under specific conditions involving both temperature and soil moisture content. The author also reported that the physiological ripening process limits the rate of plant growth without affecting the photosynthetic process, such that there is a greater balance of products that are photosynthesized and transformed into sugars for storage in plant tissues. Under these conditions, climate is defined as the major determinant of the restrictions imposed by the physical environment, which are represented by the interaction of climate factors that influence the soil and plant, such as the harvest season, the programmed number of plant cycles and the choice of crop varieties.

Air temperature plays a key role in sugarcane ripening: temperature is responsible for slowing the growth rate, leading to the accumulation of more sugar. Glover (1972) noted that low temperatures increased the sucrose content in stalks.

Sugarcane growth is also governed by genetic makeup and the environment. In general, the conditions of all seasons affect the development of sugarcane, and the success of the culture is intrinsically linked to environmental conditions favorable for its development.

Because ripening is the inverse of growth (Alexander, 1973), the method of negative-degree days is used to correlate ripening and temperature, corresponding to the area between the base temperature and the daily minimum temperature (Scarpari & Beauclair, 2004).

Since the 1940s, studies have shown that the variety of plant plays an important role in the ripening process because the different varieties have different ripening times, even when subjected to the same soil and climatic factors.

Sugar production (assimilation) is governed mainly by solar energy in the form of light and heat, while the use of sugars (dissimilation) depends largely on moisture and growth. The balance between production and use is reflected in the sucrose content of sugarcane. To ripen, the stalk must suffer growth retardation; low temperatures and moderate drought, among other factors, are effective agents for accelerating ripening. In tropical regions, moisture is essential for ripening, while in the subtropical regions, suitable minimum temperatures are essential.

2.4 Flowering of sugarcane

Sugarcane flowering (Fig. 1) has been regarded as harmful to the process of sucrose accumulation, as it is commonly accepted that the formation of flowers drains a considerable amount of sucrose. Substantial losses in sugarcane productivity and sucrose content at harvest are attributed to flowering.

Another aspect refers to the phenomenon of the pith process (Fig. 2) related to the flowering and ripening of sugarcane, which occurs in some varieties and is characterized by the drying of the interior of the stalk from the top. The pith process leads to a loss of moisture in the tissue, with a consequent reduction of the juice stock and an increase in the fiber content of the stalk. Thus, although the concentration of sucrose in the stalk is increased, it is difficult to extract and involves the loss of stalk weight and, consequently, a reduction in the final yield.

Fig. 1. Flowering of sugarcane.

Quantification of the degree of the pith process and the possible changes in the quality of the raw material may provide critical data to the design of the area to be planted for each variety and the best time periods for industrial use. The intensity of the flowering process and its consequences for the quality of raw materials vary with the variety and climate. Therefore, reducing the amount of juice is the main factor that is affected by flowering.

Fig. 2. Different grades of pith process in sugarcane. From the left to the right, intense pith to no pith.

The flowering process occurs simultaneously with the ripening process. Araldi et al. (2010) reported that the factors that influence flowering are the sensitivity of the variety to flowering, minimum age of the plant (varieties that are very sensitive to flowering may be induced at six months), photoperiod (optimum is approximately 12.5 hours) and light intensity, temperature (small variations in temperature can cause significant changes in flowering), humidity (humid and cloudy days favor flowering, which is less common in hot, dry regions), altitude (lower altitudes favor flowering), chemical products (various hormonal chemical products decrease flowering, which is of great practical interest) and fertilization (excess nitrogen can hinder or prevent flowering).

Sugarcane flowers during short days. In the Southern Hemisphere, the differentiation of the flower bud occurs from February to April, and the emergence of panicles occurs from April to July. In the Northern Hemisphere, these factors occur between July and August and from September to November, respectively.

Each variety has its particular length-of-day period, within which floral initiation can occur, as other factors, such as stage of development and nutritional aspects, are favorable. In some varieties, this time is broad, giving rise to abundant blooming for a considerable period; however, there are varieties that flower only during a short period with a precise day length.

For the latitudes of the State of São Paulo (Brazil), the most suitable period for the application of ripening chemicals is between the second half of February and the first half of

March (i.e., during the induction period, to inhibit flowering and to speed ripening). In Guatemala, because of the particular climatic conditions, two applications of products are necessary: ethephon is applied to inhibit flowering and is applied between July and August; then, another application of ripener products is administered to ripen the sugarcane in October.

Research studies involving different sugarcane varieties with flowering habits emphasize that the pith process accompanies flowering, with behavioral differences between varieties for certain technological characteristics (Caputo et al., 2007). Differences in terms of Brix, pol, purity and fiber were observed between the different regions of the stalk compared to the state of the culture (not flowered, in flower, flowered) (Leite et al., 2010).

For the sugarcane agribusiness, flowering is considered to be a waste of the plant's energy, which also ceases the development of the stalk after differentiation of the buds. During flowering, the supply of carbohydrates to the roots decreases to very low levels. In a study of nutrient solutions, it was observed that the roots excrete nitrogenated and potassiated substances into solution during flowering. Various studies have revealed that there is a reduction in the photosynthetic rate during the period of rapid hydrolysis of organic reserves.

With respect to the hormones linked to flowering, auxin, the plant growth hormone, is diminished at the time of flowering. In stalks that bloom, the upper internodes contain the highest fiber content. The percentage of fiber in the top six internodes is 14% higher in flowered sugarcane than in sugarcane that has not flowered.

2.5 Plant growth regulators and inhibitors

Plant growth regulators are synthetic substances applied exogenously that have actions similar to known groups of hormones (auxins, gibberellins, cytokinins, retarders, inhibitors and ethylene), while plant hormones are organic, non-nutrient, naturally occurring compounds produced by the plant at low concentrations (10^{-4} M), which promote, inhibit or modify physiological and morphological processes of the plant. Growth inhibitors are natural or synthetic substances that have the capacity to inhibit the growth of the sub-apical meristem.

Currently, most planted areas have already reached a stage that requires high technical skill to achieve economically satisfactory yields. These cultures no longer exhibit nutritional or water limitations and are adequately protected with pesticides. Under these conditions, advanced technology has led to the use of growth regulators, which can often be highly rewarding.

In this context, the use of chemical ripeners in sugarcane, also defined as growth regulators, stands out as an important tool for management. These products are applied to speed the ripening process, promote improvements in the quality of the raw material to be processed, optimize the agribusiness and economic results and aid in the planning of the harvest, as natural ripening in early season can be deficient, even in early varieties.

The ripener paralyzes development, which induces the translocation and storage of sugars, and confers resistance to lodging, which facilitates cutting and reduces losses in the field

and the amount of foreign matter transported to the industry. When applied, the ripener is absorbed by the plant and acts by selectively reducing the level of active gibberellin, inducing the plant to temporary reduce its growth rate without affecting the process of photosynthesis and integrity of the apical bud.

Factors such as the period of application of chemical products, doses, the genetic characteristics of the variety and the harvest season of the raw materials are factors that can influence the efficiency of chemical flowering inhibitors and sugarcane ripeners.

2.6 Utilization of chemical ripeners

The physiology of sugarcane ripening has been studied for more than 30 years. Natural ripening in early harvest may be poor, even in early varieties. In this context, the use of chemical ripeners stands out as an important tool (Dalley & Richard Junior, 2010). Due to the areas cultivated with sugar cane are extensive, the application of these products is normally done with agricultural aircraft (Fig. 3), but helicopters can also be used for this purpose (Fig. 4).

Fig. 3. Aerial application of ripener using an agricultural aircraft.

Among the chemical products used as ripeners, those that stand out include ethephon (Ethrel, ZAZ and Arvest), a growth regulator; sulfometuron methyl (Curavial), a plant growth regulator from the sulfonylurea chemical group; glyphosate (Roundup, etc.), a growth inhibitor that can cause destruction of the apical bud of the plant and induce lateral growth (which is detrimental to the quality of the raw material); and ethyl-trinexapac (Moddus), which reduces the level of gibberellin without affecting photosynthesis and the integrity of the bud. Other chemicals include fluazifop-p-butyl (Fusilade), maleic hydrazide, paraquat and imazapyr.

Fig. 4. Aerial application of ripener using a helicopter.

2.6.1 Ethephon

Ethephon (2-chloroethylphosphonic acid), a chemical from the ethylene-forming group, is a plant growth regulator with systemic properties. Highly soluble in water, it is stable in aqueous solution with a pH <3.5 and releases ethylene at higher pH levels. It is sensitive to ultraviolet radiation and is stable up to 75 °C. Ethephon penetrates plant tissues and is progressively translocated, and it then decomposes into ethylene, affecting the growth process (Tomlin, 1994). Its use is justified because the chemical inhibits flowering in sugarcane and increases tillering.

These products that release of ethylene tend to form phosphonic acid. They are maintained at a stable pH of less than or equal to 3.5 (acidic) and lose this stability upon contact with the plant tissue, at which point the pH moves closer to neutrality, releasing gaseous ethylene (C_2H_4).

Regarding commercial products, although they have the same phosphonic acid and the technical name of ethephon, they may differ in the pH needed to maintain the stability of the formulation, may include surfactants or other chemical agents and may have concentrations of the active ingredient ranging from 240 g L^{-1} to 720 g L^{-1}. Thus, the application rate can vary from 0.67 to 2 L ha^{-1} of commercial product. Castro et al. (2001) reported that different brands of the chemical available on the market did not differ significantly from each other in their capacities to increase the pol% of sugarcane after treatments. Table 1 provides a brief summary of ethephon.

Ethephon has yielded improvements in the technological quality in areas that do not have flowering, and when blooms are present, there is improvement in the production of

sugarcane. However, Gururaj Rao et al. (1996) found distinct responses for different varieties of sugarcane when considering production.

For Caputo et al. (2007), ethephon was able to inhibit flowering and to significantly reduce the pith processes of sugarcane varieties, though the magnitude of this reduction varied. Still, it improved the sucrose content in stalks and did not impair the productivity of stalks and sugar.

Studies on the effects of ethephon on sugarcane ripening and productivity emphasized that the product was effective in promoting ripening and increasing sucrose content, allowing the harvest to be anticipated by at least 21 days with a significant reduction in the pith process of the stalk.

With the use of ethephon, an elevated sucrose content from sugarcane has been measured at the beginning of the season, both in experimental and commercial areas. Upon the application of ethephon, there is a temporary shutdown of vegetative growth at the apical meristem. As a result, the produced sugar is stored, resulting in the elevation of the sugar content in the stalks. This change persists for 60 to 90 days, depending on the variety, which is considered to be a long utilization period for the treated cane field. The sugarcane stalks that receive ethephon application always have one or two shorter internodes than normal, indicating that those represent the places of growth at the time of application. As growth intensifies, the sucrose content is reduced, reaching a level that would normally have with no application (i.e., in the middle of the cycle). Samples taken from this period rarely show an economic benefit to the application of ethephon. One of the advantages of its implementation, aside from inhibiting flowering, is to significantly reduce the phenomenon of the pith process, generally resulting in stalks that are denser and that contain greater levels of sucrose.

Another advantage observed with the use of ethephon as a ripener is that it does not damage the sprouting of next sugarcane ratoon; in some cases, a beneficial effect is observed, with increased tillering at the beginning of sprouting after cutting. Silva et al. (2007) observed a stimulating effect on the emergence of tillering up to six months after cutting, although the responses were dependent on the variety.

2.6.2 Sulfometuron-methyl

Products of the sulfonylurea chemical group are characterized as potent inhibitors of plant growth, affecting both growth and cell division without interfering directly with mitosis and DNA synthesis. Sulfonylureas inhibit the synthesis of branched-chain amino acids, such as valine, leucine and isoleucine, through the action on the ALS enzyme (acetolactate synthase), which undergoes inhibition of its activity, preventing the synthesis of amino acids from the substrate pyruvate alpha-ketobutyrate. They apparently do not directly block the action of growth promoters (auxins, gibberellins and cytokinins) but strongly stimulate ethylene production due to the stressing effect caused by phytotoxicity. Sulfonylurea molecules originating from foliar or root absorption may be neutral, highly permeable and susceptible to transport in the phloem upon reaching the middle of the cell wall. In alkaline medium, the molecules dissociate in the anionic form, become fixed and systemically move by mass flow through the phloem. These molecules exhibit systemic action, acting in the meristematic regions, affecting growth and inhibiting cell division after absorption by plant leaves. Paralyzed development of the apical meristem causes a reduction in the internodes

formed at the time of application. Then, sucrose is stored in the stalk in place of the production of new leaves, which results in a reduction in the rate of the pith process.

The recommended dose of the product to hasten ripening of sugarcane is 15 g ha^{-1} of the active ingredient or 20 g ha^{-1} of commercial product. After application, the treated area can be harvested in 25 to 45 days. Table 1 shows the general characteristics of sulfometuron-methyl.

Studies have reported that sulfometuron-methyl, regarding its potential ripening effect in sugarcane varieties, causes no damage to sugarcane production (t ha^{-1}) or the agronomic characteristics of the culture (Silva et al., 2007, Leite et al., 2010). This product does not cause the death of apical buds, and the internodes formed after application resume their normal growth, which allows the culture conditions to be harvested for a longer period. If the harvest of the treated area is late, it does not result in loss or damage to the crop.

The results show consistency in the increase of sugarcane pol, Brix and the reduction index of the pith process (Caputo et al., 2007). Castro et al. (1996) found that the rate of the pith process was reduced from 50 to 60% with the application of sulfometuron-methyl. When sulfometuron-methyl was administered there was an increase of 1.26 in the pol, and ripening occurred 21 days earlier; in addition, treatment induced a decrease in reducing sugars (Caputo et al., 2007, 2008).

The product, when applied to different sugarcane varieties, allows for an improvement in the technological quality of sugarcane: it has a significant determined response regarding gains in pol, increases in purity and reduced organic acid content in the juice and offers a greater possibility for producing higher quality sugar (Fernandes et al., 2002). Organic acids and other undesirable constituents, such as polysaccharides (starches), are responsible for increasing the viscosity of sugar solutions and honey, are precursors to the formation of color (e.g., the ratios of amino acids and reducing sugars) and reduce the exhaustibility of molasses due to the relationship of reducing sugars and ash.

Several studies have identified the influence of the variety on the responses to sulfometuron-methyl (Fernandes et al., 2002, Caputo et al., 2007, 2008). The chemical also does not promote detrimental effects on the sprouting of ratoons following application; although an increase in tillering has been observed up to 180 days after the onset of budding, this condition is not reflected in increased productivity (Silva et al. 2007).

2.6.3 Trinexapac-ethyl

Trinexapac-ethyl belongs to the cyclohexanedione chemical group and induces a greater accumulation of sucrose in stalks, facilitating the planning and agro-industrial utilization of sugarcane. This growth regulator inhibits the synthesis of active forms of gibberellic acid, a hormone involved in growth and cell division, which leads to a decrease in plant development and, thus, an accumulation of sucrose.

The recommended dose to promote ripening is between 200 and 300 g ha^{-1} or between 0.8 to 1.2 L pc ha^{-1}. It is recommended that the treated area be harvested between 35 and 55 days after application. This and other information regarding trinexapac-ethyl is provided in Table 1.

After application, this product is predominantly absorbed by the leaves and shoots and is translocated to areas of meristematic activity, where it inhibits the elongation of internodes. A shortening of internodes has been observed in different sugarcane varieties, negatively

influencing the development of the stalks while improving the technological quality and providing gains of theoretical recoverable sugar in relation to the production of stalks. The suppressive effect on apical elongation leads to formation of shorter internodes, but it does not influence final stalk productivity levels. Still, it is possible to reduce the levels of reducing sugars while also observing increases in Brix concentrations and an increase in juice purity. Other advantages of this product are the control of flowering and the absence of injury in ratoon tillering.

In studies employing trinexapac-ethyl, there were increases in the productivity of sugar and the margin of agricultural contribution, resulting in the improvement of technological quality; additionally, the natural ripening process was anticipated compared to untreated plants (Leite et al., 2008, 2009, 2011).

2.6.4 Glyphosate

Glyphosate (N-glycine phosphonomethyl) is currently one of the most popular herbicides in agriculture because of the efficient control it exercises on weeds and its low acute toxicity.

Glyphosate's mechanism of action is quite unique: it is the only herbicide capable of specifically inhibiting the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), which catalyzes the condensation of shikimic acid and phosphate pyruvate, thus preventing the synthesis of three essential amino acids – tryptophan, phenylalanine and tyrosine (Zablotowicz & Reddy, 2004).

Glyphosate is treated as a systemic, non-selective and broad-spectrum herbicide that translocates via the symplast. Its absorption is facilitated by transport proteins of phosphate groups that are present in the membrane. Inhibition of EPSPS leads to accumulation of high levels of shikimate in the vacuoles, which is exacerbated by the loss of feedback control and the unregulated flow of carbon in the pathway. According to Kruse et al. (2000), approximately 35% of dry plant mass is represented by derivatives of the shikimate pathway, and 20% of the carbon fixed by photosynthesis follows this metabolic pathway.

As a ripener, glyphosate has been fairly consistent and effective in speeding sugarcane ripening (Dalley & Richard Junior, 2010) because of two principal reasons:

1. It inhibits sugarcane growth or reduces it by killing the apical bud, or it inhibits the synthesis of indole acetic acid (IAA). Inhibition of stem elongation may also be related to the capacity of auxin to promote ethylene synthesis by increasing the activity of ACC (1-aminocyclopropane-1-carboxylic acid) synthase (Liang et al., 1992). The increase in ethylene may stimulate the senescence process and germination of lateral buds, and the hormonal balance between IAA and ethylene may also lead to the inhibition of stem elongation.
2. It causes stress in sugarcane by inhibiting the synthesis of essential amino acids and proteins. EPSPS is encoded in the nucleus and performs its role in the chloroplast, catalyzing the binding of the compounds shikimate-3-phosphate and phosphoenolpyruvate to produce enolpyruvylshikimate-3-phosphate and inorganic phosphate.

As a ripener, the effective dose of glyphosate varies widely around the world, ranging from applications of 144 to 864 g ha^{-1}; this has been due mainly to climatic conditions. In Brazil,

the dose is between 144 and 240 g ha^{-1} (i.e., from 0.3 to 0.5 L pc ha^{-1}). However, in Guatemala, due to excessive rainfall and high temperatures, which are conditions not conducive to ripening, doses between 0.9 and 1.8 L pc ha^{-1} have been used. Table 1 provides general information on glyphosate.

Results from studies have identified glyphosate as a technical and economical alternative that allows for more flexibility in the harvest period and for managing of the behaviors of different varieties. In the literature, studies have often shown that the application of glyphosate promoted the improvement of the quality of raw material for industry use, increases in sugarcane pol, reduction of the pith process and fiber, reduced juice loss, and reduction in the average number of internodes per stem and in the weight of sugarcane produced.

Studies have also shown that the use of glyphosate as a ripener for sugarcane has promoted increases in recoverable sugar content and sugar production. For distinct varieties of sugarcane, different responses to glyphosate as a ripener have been reported regarding flowering, industrial yield, stalk moisture, Brix, pol and purity.

There are minor differences between the different formulations of glyphosate applied to sugarcane cultures; however, all formulations promoted increases in sucrose content and sugar production compared to controls (Villegas et al., 1993; Bennett & Montes, 2003; Viator et al., 2003).

Fig. 5. Sugarcane stem with side shoots after application of glyphosate.

Some studies have reported two negative effects of glyphosate as a ripener for sugarcane. The first is the elevated rate of side shoots on stems after application (Fig. 5), which leads to lower raw material quality. The second is the detrimental effect on sprouting ratoons after

harvest from treated areas, with a reduction of tillers per meter (Fig. 6), which would lead to lower productivity in the next harvest (Leite & Crusciol, 2008). For this reason, glyphosate has been widely used in areas that will be used for the implementation of a new cane field. However, there are also reports that glyphosate did not cause any detrimental effects on sugarcane quality and productivity (Viana et al., 2008). Due to the strong influences that factors such as dose, variety and climatic conditions have on the effectiveness of the product, this issue merits further study.

Fig. 6. Detrimental effect on sprouting ratoons after harvest from glyphosate treated areas.

The Table 1 shows a summary of the main characteristics of ripener glyphosate.

2.6.5 Fluazifop-p-butyl, maleic hydrazide, paraquat and imazapyr

There are other products that have been or are currently being used as sugarcane ripeners. These are mainly herbicides, which when used in lower doses, have a stressing action on the plant, promoting ripening. However, with the production of new growth-regulating molecules specific for promoting ripening, these herbicides have been losing importance as ripeners in the management of sugarcane.

Fluazifop-p-butyl is a systemic graminicide herbicide that translocates apoplastically, focusing on the growing points of plants and causing death. However, it may also be used as a ripener in sugarcane when applied at lower doses (from 0.1 to 0.3 L ha^{-1}). It is rapidly absorbed in the leaf and causes necrosis; due to its herbicidal action, it kills the apical bud. Therefore, sugarcane should be harvested between 4-6 weeks after application; there is a risk of loss in quality of raw material if this period is exceeded. This product inhibits

Product	Ethephon	Trinexapac-ethyl	Sulfometuron-methyl	Glyphosate
Active Ingredient	2-chloroethylphosphonic acid	4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxo-cyclohexane carboxylic acid ethyl-ester	Methyl-2-[[[[(4,6-dimethyl-2-pyrimidinyl)-amino]carbonyl]amino]sulfonyl]benzoate	N-phosphono methyl glycine
Chemical Group	Phosphonic Acid	Cyclohexanedione	Sulfonylurea	Glycine
Concentration	240-720 g L^{-1}	250 g L^{-1}	750 g kg^{-1}	360 g L^{-1} (e.a.)
Formulation	CS	CE	GRDA	CS
Toxicity Class	II	III	III	IV
Vapor Pressure	1×10^{-7}	1.6×10^{-5}	5.4×10^{-16}	1.8×10^{-7}
Solubility (ppm)	1239	10.2	10	10000
Mode of Action	Liberates Ethylene	Inhibits Gibberellin	Inhibits ALS	Inhibits EPSPS
Dosage (L or kg ha^{-1})	0.67-2.0	0.8-1.2	0.020	0.3 – 1.8
Precipitation after Application	6 hours	1 hours	6 hours	6 hours
Harvest (daa)	45 – 90	35 – 55	25 – 45	25 – 35
Lateral Budding	Yes	Yes	Yes	Yes
Inhibition of Flowering	Yes	Yes	Yes	No
Stopped Growth	Yes	Yes	Yes	Yes
Death of the Apical Bud	Yes	No	No	Yes
Varietal Response	Most	All	All	All
Period of Use	Beginning of the cycle	All	All	All
Rooting	Yes (20%)	Yes (30%)	No	No
Germination/Tillering	Favorable	Favorable	Indifferent	Unfavorable
Sprouting of the Ratoon	Favorable	Favorable	Indifferent	Unfavorable

Table 1. Characteristics of the principal ripeners utilized in sugarcane.

flowering and restricts the volume of the parenchyma without juice (i.e., it decreases the pith process). No negative effect on subsequent ratoon sprouting has been reported, unlike for glyphosate.

Maleic hydrazide (1,2-dihydro-3,6-pyridazinedione) is a plant growth inhibitor that is considered to be a possible ripening agent for sugarcane. This regulator causes a loss of apical dominance in plants. Some monocots showed an increase in sugar content when treated with this ripener. Castro et al. (1985) verified that the application of maleic hydrazide promoted the accumulation of sucrose, though there was a reduction in sugarcane growth. The authors concluded that there was a direct relationship between an increase of the applied dose and an inhibitory effect on plant growth.

Imazapyr is a non-selective systemic herbicide that is absorbed by the leaves and roots. It is rapidly translocated in the xylem and phloem to meristematic regions, where it accumulates. Imazapyr blocks the synthesis of branched-chain amino acids (i.e., valine, leucine and isoleucine) through the inhibition of acetolactate synthase (ALS), which interrupts protein synthesis and leads to interference in DNA synthesis and cell growth. Both effects decrease sugarcane development. Carbohydrates synthesized during photosynthesis after the application of imazapyr are temporarily not used for plant growth; thus, they accumulate in the stalk and increase in concentration. This effect is related to the ripening process because the amount of hydrolysis of sucrose is less than its accumulation in the stem. Lavanholi et al. (2002) observed an increased sugarcane pol with the application of imazapyr, but the authors emphasized that the product did not control flowering.

The application of paraquat, an inhibitor of photosystem I, may or may not affect the quality of industrial stems. Its effect is dose-related when it is used as a desiccant in sugarcane. According to Christoffoletti et al. (1993), the use of paraquat has improved the quality of burn of the cane fields and has yielded raw material with fewer impurities for industrial use. It should be noted that the practice of burning sugarcane fields before harvest is a technique that is being abolished in sugarcane-producing countries, especially in Brazil.

3. Conclusion

A supply of raw material of sufficient technological quality to provide economic extraction is one of the greatest needs of the sugarcane industry. For ripening to occur, sugarcane growth must be slowed to accumulate more sucrose. Despite the diversity of genetic material, problems continue to be encountered in the process of providing the sugar industry with raw material throughout the harvest period that contain high levels of sucrose. Sugarcane flowering is also seen as detrimental to the quality of the raw material. Therefore, the application of ripeners and flowering inhibitors is a highly utilized agricultural technique to improve the technological quality of the raw material. The feasibility of using ripeners in the sugarcane production system depends on a number of factors, including climatic, technical and economic variables, and particularly the additional responses that each variety can provide in the practice of this cultivation. Therefore, the producer should consider these factors to find the product that provides the best agricultural, industrial and economic yield.

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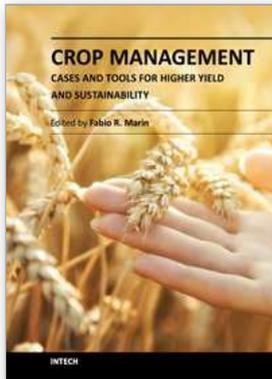
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Agricultural production is related to physical constrains, which may not always be overcomed by technology. However, under the same conditions, it is possible to see well-managed farms consistently making greater profits than similarly structured, neighboring farms. For each abiotical condition, it is well-known there is a difference between the potential and observed yields, which is usually high and often could be reduced through more appropriate management techniques. In this book, we have a selection of agricultural problems encountered in different regions of the world which were addressed using creative solution, offering new approaches for well-known techniques and new tools for old problems.

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