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Strategies for Enhancing Sugarcane Yields by Harnessing the Power of Ripening and the Use of Ripeners in Sugarcane cultivation

Ajeet Kumar, Sunita Kumari Meena, S.K. Sinha, A.K. Singh

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Ajeet Kumar, Sunita Kumari Meena, S.K. Sinha, A.K. Singh. Strategies for Enhancing Sugarcane Yields by Harnessing the Power of Ripening and the Use of Ripeners in Sugarcane cultivation. Sustainable sugarcane production and utilization: Issues and Initiatives, RPCAU, Pusa, Oct 2023, Pusa (Samastipur)-848125, India. pp.185-196. <hal-04881488>

HAL Id: hal-04881488

<https://hal.science/hal-04881488v1>

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SOUVENIR CUM EDITED BOOK

Sustainable Sugarcane Production and Utilization: Issues and Initiatives

Editors: Navnit Kumar, A.K. Singh, D.N. Kamat, Anil Kumar,
Md. Minnatullah, Ajeet Kumar, S.N. Singh, C.K. Jha and Anupam Amitabh



Annual Group Meet - 2023

All India Coordinated Research Project on Sugarcane
(October 26 – 27, 2023)

Organized by:

Dr. Rajendra Prasad Central Agricultural University

Sugarcane Research Institute

Pusa (Samastipur)- 848125, Bihar

and

ICAR-Indian Institute of Sugarcane Research

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Patron

Dr. P.S. Pandey, Vice-Chancellor, RPCAU, Pusa

Organizing Chairman

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Publication Year : 2023

ISBN No. : 978-81-966957-2-9

Technical Assistance

Sri Rajesh Kumar, Sr. Technician, SRI, RPCAU, Pusa

Citation

Kumar, N., Singh, A.K., Kamat, D.N., Kumar, A., Minnatullah, Md., Kumar, A., Singh, S.N., Jha, C.K., Amitabh, A. (2023). Sustainable Sugarcane Production and Utilization : Issues and Initiatives (Souvenir-cum-Edited Book). SRI, RPCAU, Pusa-848 125 (Bihar), India, Pp. 1-256.

Printed by : K. G. Enterprises, Mahendru, Patna-6

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Strategies for Enhancing Sugarcane Yields by Harnessing the Power of Ripening and the Use of Ripeners in Sugarcane cultivation

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Abstract

Sugarcane is a significant crop with a multitude of applications, from animal feed and alcoholic beverages to the production of sugar, ethanol, and other products. Its growth primarily occurs in tropical and subtropical climates, with two crucial seasons dictating its development and sucrose accumulation. While genetically improved sugarcane varieties now exist, with higher sugar concentrations and lower fiber levels, challenges still persist in the industry, particularly concerning flowering and the associated pith process, which affects the quality of the raw material. The ripening of sugarcane, a process that peaks between May and October, is influenced by environmental and management factors. This involves the synthesis of sugars in the leaves, their transportation, and the eventual storage of sucrose in the stalk. The sugarcane variety, along with its planting cycle, also impacts the ripening process. Sugarcane's photosynthetic efficiency is influenced by environmental factors such as temperature, sunlight, and rainfall. The accumulation of sucrose in sugarcane stalks is an intricate mechanism. The photosynthetic process, affected by fluctuating temperatures, is key to this accumulation. Understanding the balance between the synthesis of sucrose and starch is vital as they play different roles in the sugarcane plant. Enzymes play a central role in ripening. For instance, invertases regulate the breakdown of sucrose, while Sucrose-Phosphate Synthase (SPS) and Sucrose Synthase (SuSy) play pivotal roles in sucrose synthesis and breakdown respectively. The activities of these enzymes can be influenced by environmental conditions and are crucial for the successful growth and productivity of sugarcane. To manage and enhance productivity, ripeners and chemical flowering inhibitors are often used. These substances, while affecting the sugarcane's morphology and physiology, are employed to improve sucrose content, enable early ripening, and enhance overall yields. The decision to use ripeners depends on various factors including climatic and economic variables. As the sugarcane industry evolves, understanding these processes and managing them effectively will be pivotal to its success.

1. Introduction

The sugarcane is important crop because of its multiple uses: it is used around the world 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. 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, there

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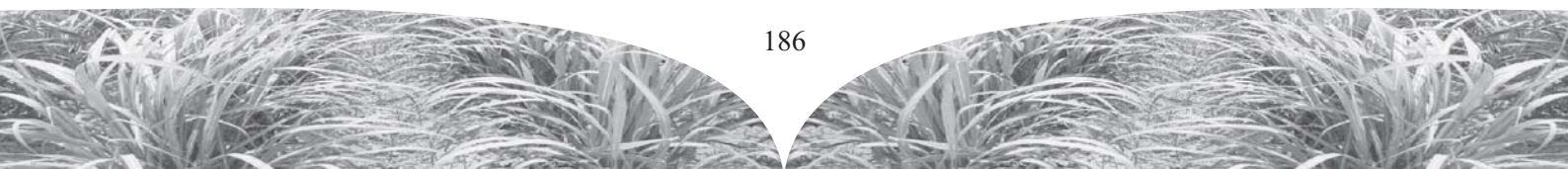


are now genetically improved varieties of sugarcane that have low levels of fiber and high concentrations of sugar, which are both responsible for high productivity. However, despite the diversity of genetic material available, the sugarcane industry still faces problems with the precocity of raw material and it is not capable of meeting industry demand. Another problem that has not been fully resolved is flowering. The flowering in sugarcane, involves *morpho-physiological alterations*, 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. 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. However, depending on the variety and environmental conditions, the intensity of the pith process is variable. A gradual drop in temperature and reduced rainfall are crucial for the natural ripening of sugarcane. However, many times during the ripening period, these conditions do not occur simultaneously. In such situations, the use of ripeners and flowering inhibitors in the sugarcane is designed to increase productivity and to anticipate the harvest.

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 *invertases* enzymes, which catalyze the accumulation of sucrose in the stalks. The feasibility of use of ripeners depends on a number of factors, including climatic, technical and economic variables. 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.

2. Sugarcane ripening

The ripening of sugarcane is stimulated by environmental and management factors. 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. Ripening is one of the most important aspects for sugarcane production; in the process of sucrose accumulation, which depends on energy and varietal characteristics. Physiologically, ripening is reached when the stems reach at the point of maximum possible sucrose accumulation. Economically, from the perspective of agronomic practice, sugarcane is considered mature from the moment it possesses the minimum sucrose content (pol), which is greater than 13% of the stalk weight. The ripening process occurs naturally from the *beginning of May and reaches its climax in October*. 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 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. Varieties are classified as a function of whether they ripen in the early, mid or late stages. The 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). There are two distinct seasons for sugarcane planting. 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. 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.

3. 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. 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 favorable for the partition of photosynthates into the interior sugar reserves and the accumulation of high levels of sucrose. However, 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, 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. 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, inter conversion 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. In mature stem tissues, 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; 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. 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

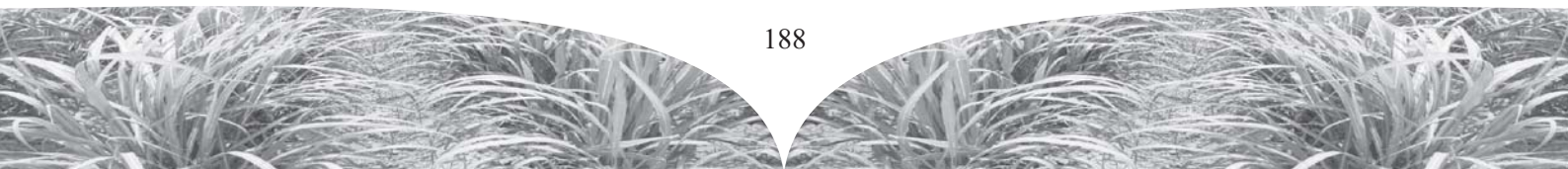


factors. In the elongation phase, assimilates are employed in the construction of the structure of internodes. Thus, the loss rate of assimilates is greater than the utilization rate because glucose, fructose and sucrose begin to be accumulated during this phase. Acid invertase and sucrose synthase reach 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.

4. 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. Many enzymes govern the primary metabolism of sucrose. *Invertases* play 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 apoplasmic space, both free-form and bound to the cell wall. The soluble isoforms are dominantly 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. *Sucrose-Phosphate Synthase (SPS)* is considered to be the main 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 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 invertase and neutral invertase (*SAI* and *NI*, respectively) and acid invertase are linked to cell wall mobilization, utilization and accumulation of sucrose in 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 and 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 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. The activity of SAI is responsible for controlling growth in sugarcane. 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.

5. Climatic factors that affect ripening

Sugarcane productivity is most influenced by climate. The sugarcane plants slow their growth rate to accumulate more sugar under specific conditions of temperature and soil moisture. 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 major determinant of the restrictions imposed by the environment. 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 in stalks. Sugarcane growth is also governed by genetic makeup and the environment. The conditions of all seasons affect the development of sugarcane is intrinsically linked to environment. Because ripening is the inverse of growth, the method of negative-degree days is used to correlate ripening and temperature. 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.

6. Flowering of sugarcane

Sugarcane flowering is 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. The phenomenon of the pith process (Fig. 2) related to the flowering and ripening of sugarcane, in some varieties is characterized by the drying of the interior of the stalk from the top. The pith process leads to loss of moisture in the tissue, with a consequent reduction of juice stock and increase in the fiber content. 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 yield. Quantification of the degree of pith process and the possible changes in the quality of raw material provide data for each variety and the best time for industrial use. The intensity of flowering and its consequences on quality of raw materials vary with the variety and climate. Therefore, reduction in the amount of juice is affected by flowering. The flowering occurs simultaneously with the ripening. The factors that influence flowering are the sensitivity of the variety to flower, age of the plant (varieties that are very sensitive to flowering may be induced at six months), photoperiod (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 favours flowering), chemical products (hormonal chemical products decrease flowering) and fertilization (excess nitrogen can prevent flowering). Sugarcane flowers during short days. In the Southern Hemisphere, the differentiation of the flower bud

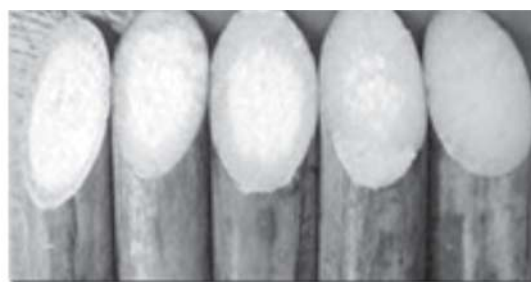


Fig. 2. Different grades of pith formation. Left to the Right: Intense pith to no pith

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. (*Ethephon is applied between July and August to inhibit flowering; another application of ripener is administered to ripen the sugarcane in October*). The different sugarcane varieties with flowering habits emphasize that the pith process accompanies flowering, with behavioral differences between varieties for certain technological characteristics. Differences in terms of Brix, pol, purity and fiber were observed between the different regions of the stalk. For the sugarcane, **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 low levels. In a study of nutrient solutions, it was observed that the roots excrete nitrogenated and potassiated substances into solution during flowering. 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, is diminished at the time of flowering. In blooming stalks, the upper internodes contain the highest fiber content. The % of fiber in top six internodes is 14% higher in flowered sugarcane than in non-flowered sugarcane.

7. 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 requires high technical skill to achieve satisfactory yields.

8. Chemical ripeners in sugarcane

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 raw material to be processed, optimize the economic results and aid in the planning of the harvest, as natural ripening in early season can be deficient, even in early varieties. The ripeners 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 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 can influence the efficiency of flowering inhibitors and ripeners.

9. 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. The use of chemical ripeners stands out as an important tool. Due to the areas cultivated with sugar cane are extensive, the application of these products is normally done with drone (Fig. 3 & 4). Among the chemical products used as ripeners, include ethephon (Ethrel, ZAZ and Arvest), a growth regulator; sulfometuron methyl



Fig. 3 Aerial application of ripeners with drone

Fig. 4 Aerial application of ripeners with aircraft

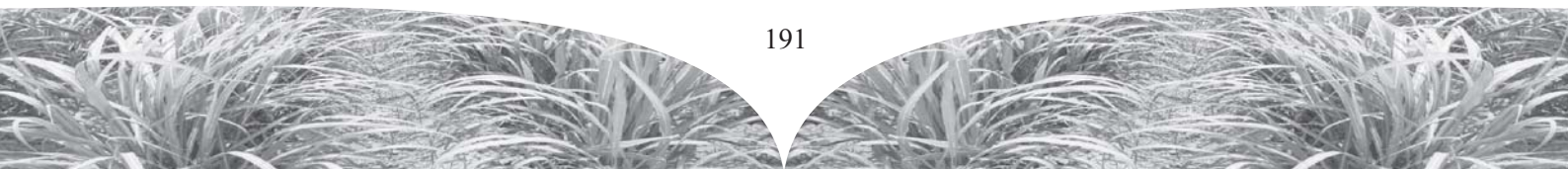
(*Curavial*), a plant growth regulator from the sulfonylurea chemical group; glyphosate (*Roundup*), a growth inhibitor that *cause destruction of the apical bud of the plant* and induce lateral growth (which is detrimental to the quality of the raw material); and ethyl-trinexapac (*Moddus*), which reduces the level of gibberellin without affecting photosynthesis. Other chemicals include fluazifop-p-butyl (*Fusilade*), maleic hydrazide, paraquat and imazapyr.

9.1 Ethephon

Ethephon (2-chloroethylphosphonic acid) is a plant growth regulator with systemic properties. Highly soluble in water, 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 then it decomposes into ethylene, affecting the growth process (Tomlin, 1994). It inhibits flowering in sugarcane and increases tillering. These products release ethylene that 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. 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 and have concentrations of the active ingredient ranging from 240 gL⁻¹ to 720 gL⁻¹. Thus, the application rate varies from 0.67 to 2 L ha⁻¹ of commercial product. Table 1 provides a brief summary of ethephon. The ethephon has yielded improvements in the quality in areas that donot have flowering and when blooms are present, there is improvement in the production of sugarcane. However, Rao et al. (1996) found distinct responses for different varieties of sugarcane when considering production. The ethephon was able to inhibit flowering and significantly reduce the pith of sugarcane varieties. 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. The use of ethephon, elevated sucrose content at the beginning of the season. 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. 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 is reduced, reaching a level that would normally have with no application. One of the advantages, aside from inhibiting flowering, is to significantly reduce the phenomenon of the pith process. Another advantage 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.

9.2 Sulfometuron-methyl

Products of the sulfonylurea chemical group are characterized as inhibitors of plant growth, affecting growth and cell division without interfering directly with mitosis and DNA synthesis. Sulfonylureas inhibit the synthesis of branched-chain amino acids, 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 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



phyto-toxicity. 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, inhibiting cell division after absorption by 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 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. 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., 2008). It is found that the rate of the pith process was reduced from 50% - 60% with the application of sulfometuron-methyl. When sulfometuron-methyl was administered there was an increase of 1.26 in pol and ripening occurred 21 days earlier; in addition, treatment induced a decrease in reducing sugars. The product, when applied to different sugarcane varieties, allows for an improvement in the 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. Organic acids and other undesirable constituents, such as polysaccharides (starches) are responsible for increasing the viscosity of sugar solutions 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. This chemical does not promote detrimental effects on the sprouting of ratoons, although an increase in tillering has been observed up to 180 days after the onset of budding.

9.3 Trinexapac-ethyl

Trinexapac-ethyl belongs to the cyclohexanedione group and induces a greater accumulation of sucrose in stalks of sugarcane. This growth regulator inhibits the synthesis of gibberellic acid, 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 to 55 days after application. After application, this product is absorbed by the leaves and shoots and is translocated to areas of meristematic activity, where it inhibits the elongation of internodes. The suppressive effect on apical meristem leads to formation of shorter internodes. Still, it is possible to reduce the levels of reducing sugars while also observing increases in Brix concentrations and an increase in juice purity.

9.4 Glyphosate

Glyphosate (N-glycine phosphonomethyl) is one of the most popular herbicides; 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



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

and tyrosine. 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. As a ripener, glyphosate has been fairly consistent and effective in speeding sugarcane ripening (Dalley and 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. 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 phospho-enol-pyruvate to produce enolpyruvylshikimate-3-phosphate and inorganic phosphate.

As a ripener, the effective dose of glyphosate varies widely, ranging from 144 and 240 g ha⁻¹ (i.e., from 0.3 to 0.5 L pc ha⁻¹). It is widely reported in the literature, that the application of glyphosate promoted the improvement in 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; however, all formulations promoted increases in sucrose content and sugar production compared to controls (Bennett and Montes, 2003). 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, which leads to low quality of raw material. The second is the detrimental effect on sprouting ratoons after harvest, with a reduction of tillers per meter (Fig. 6) which would lead to lower productivity in the next harvest. However, there are also reports that glyphosate did not cause any detrimental effects on sugarcane quality and productivity (Viana et al., 2008).



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

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

These are other herbicides products being used as sugarcane ripeners, which when used in lower doses, have a stressing action on the plant, promoting ripening.

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, 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 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.

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. Castro et al. (1985) verified that the application of maleic hydrazide promoted the accumulation of sucrose, though there was a reduction in sugarcane 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.

Paraquat: The application of paraquat, an inhibitor of photosystem I, may or may not affect the quality of 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.

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

Product	Ethephon	Trinexapac-ethyl	Sulfometuron-methyl	Glyphosate
Active Ingredient	2-chloroethylphosphonic acid	4-(cyclopropyl - -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
Mode of Action	Liberates Ethylene	Inhibits Gibberellin	Inhibits ALS	Inhibits EPSPS
Dosage (L/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	Favourable	Favourable	Indifferent	Unfavorable
Sprouting of the Ratoon	Favorable	Favorable	Indifferent	Unfavorable

Conclusion

For sugarcane ripening, 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 contains high levels of sucrose. Sugarcane flowering is also 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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