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Review Article

Potential Use of Chemical Ripeners to Improve Sugarcane Yield and Quality in Indonesia: A Review

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Abstract

The low quality of sugarcane at the early milling is caused by multiple factors, including climatic conditions, excess nitrogen (N) fertilizer and the dominance of late-maturity varieties. Cane Ripeners (CRs) are one of the alternatives to raise the maturity of sugarcane. CRs can come from two groups, *i.e.*, growth regulators and herbicides. Typical growth regulators used as CRs are ethylene and trinexapac ethyl, while the widely used herbicide is glyphosate. Commercial cane sugar (CCS) enhancement with CRs varies between 0.5 – 2.0 units. Increasing sugarcane maturity begins with the translocation of active compounds of CRs to the apical shoot meristem so that it can suppress the formation of new tissues by inhibiting the EPSPS enzyme. CR application could be made by several equipment *i.e*., a long spray stick, airplane or unmanned aerial vehicle (UAV) spraying drone. Research results show growth suppression in ratoon plants due to residual effects of CRs in previous crops. However, other results show that CR residues are still below the normal threshold. The results show that the potential for using CR is still wide open to improve the quality of sugarcane.

Keywords: Sugarcane; Maturity-promoting agent; Quality; Sugar; Residue

Introduction

The quality of milled sugarcane in Indonesia is still quite low, especially at the beginning of milling. Low quality of sugarcane is caused by various factors. This is because the sugarcane is harvested but not at optimum maturity. The majority of sugarcane varieties in Indonesia have mid-late maturity type so that they have not reached optimum maturity at the beginning of milling. In addition, due to excessive nitrogen (N) fertilization and wet climatic conditions almost throughout the year, the quality of sugarcane has declined. Another problem also occurs, especially in East Java, because of competition for sugarcane raw materials which results in harvesting sugarcane without optimum maturity because the milling capacity is not sufficient. This condition results in low sucrose content in sugarcane.

Environmental factors are one of the key indicators of sugarcane ripening. These factors such as: temperature, sunlight, nutrient content and moisture can cause the accumulation of sucrose in the internode (Cardozo and Sentelhas 2013). Cane Ripeners (CRs) are chemical compound that can accelerate the maturity of sugarcane that is immature, or the maturity process is hampered as a result of unfavorable environmental conditions (Hadisaputro 1996) such as excess N fertilizer and excess water in soil conditions (Silva and Caputo 2012). The primary benefit of CRs is their ability to inhibit the growth of stalk more quickly and effectively than natural processes such lower soil moisture content or air temperature (Heerden *et al.* 2015). Besides increasing the level of maturity, the benefits of using CRs include: (1) increasing sucrose content; (2) increasing purity (ratio of sucrose to non-sucrose solutes in the juice); (3) increasing sugar recoverability in sugar mill, and (4) reducing the ratio of sugarcane biomass to sugar (Dusky *et al.* 1985). Additionally, sugarcane variety, age at application, growing environment circumstances prior to and following application, and the amount or dose of chemicals administered affect how effective CRs are or how the sugarcane reacts to CRs (Su *et al.* 1992). Previous studies reported that the response and effectiveness of each sugarcane variety to CR application varies (Spaunhorst *et al.* 2019; Ayele *et al.* 2021). Therefore, the effect of CRs application is needed in regulating the maturity level of sugarcane which is closely related to the fulfillment of sugarcane raw materials for sugar factories.

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Types of CRs

CRs are generally divided into two groups *i.e*., growth regulators (GRs) and herbicides (Lawrie and Vlitos 1965). GRs are synthetic substances that are applied exogenously and act similarly to known hormone groups (auxins, gibberellins, cytokinins, inhibitors, inhibitory and ethylene), whereas plant hormones are natural compounds produced by plants at low concentrations (10^{-4} M) that promote, inhibit, or modify plant physiological and morphological processes. Growth inhibitors are natural or generated compounds that may block the growth of the sub-apical meristem (Weyers and Paterson 2001).

This group of GRs includes compounds that affect hormone-regulated growth processes in plants, especially auxin-regulated processes. Ethylene can also affect plant development and fruit ripening. Most plants produce the highest concentration of ethylene in shoots and senescing tissues. Ethylene also reduces extracellular invertase activity in sugarcane and therefore reduces the amount of sucrose unloaded (Chen *et al.* 2019). Another GR that shows excellent potential for ripening sugarcane is Ttrinexapac-ethyl. Researchers in Brazil reported that Ttrinexapac-ethyl could increase the sucrose content of 25 sugarcane varieties by about 10% on average (Heerden *et al.* 2015). Chemical CRs act just like natural phytohormones found in plants (Viana *et al.* 2019). CRs will affect ethylene production so that it can spur earlier maturity (Tufail and Hussain 2020). The application of CRs also changes the morphological and physiological properties of sugarcane, which in turn has an impact on sugarcane production quantitatively and qualitatively (Cholid 2015).

The groups of herbicides commonly used as CRs are Glyphosate and Fusilade. 5-enolpyruvyl 3-phosphate synthase (EPSP synthase) is inhibited by glyphosate. It interferes with the biosynthesis of aromatic amino acids in plants by preventing the synthesis of EPSP from phosphoenolpyruvate and shikimate 3-phosphate (Su *et al.* 1992). Fusilade inhibits acetyl coenzyme-A carboxylase, an enzyme involved in the conversion of acetyl-CoA to malonyl-CoA, which impairs fatty acid production and inhibits cell membrane development (Karmollachaab *et al*. 2015). The characteristics of several CRs used in the world are presented in Table 1.

Methods to apply CRs

CRs were initially applied manually using long sticks (Fig. 1a) and airplanes (Fig. 1b). Currently, technology has been developed to apply CR using Unmanned Aerial Vehicle (UAV) technology. UAVs are presently and extensively used worldwide in precision agriculture (Shendryk *et al*. 2020). Remote-controlled UAVs are becoming popular due to their low operational costs, flexibility and higher spatial image resolution. UAVs can be utilized for CR application to sugarcane plantations through spraying. So far, manual application with knapsacks can pose health risks to workers exposed to chemicals (Júnior *et al*. 2022). However, compared to manual application, CRs application using aircraft or UAV drones may be ineffective if the CR droplets dispersed through UAVs are not well deposited and distributed on the plants (Zhang *et al*. 2020).

a b

Fig. 1: Cane Ripener application using **a**. manual sprayer; **b**. UAV (drone)

Mechanism of increasing maturity

Increasing sugarcane maturity with CRs starts with the translocation of active compounds to the apical shoot meristem to suppress new tissue formation (Kanissery *et al*. 2019) by inhibiting the plant enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) in the aromatic amino acid (AAA) biosynthesis pathway, also known as the shikimate pathway (Zulet-González *et al*. 2020). Applied glyphosate has been found to accumulate in the apical meristem region of sugarcane (Azania *et al*. 2016) and inhibit shoot growth (Crusciol *et al*. 2017). The plant hormone auxin has long been known to originate from the apical meristem of young, growing shoots and leaves (Mason *et al*. 2014; Sosnowski *et al*. 2023) and data show that auxin is linked to both soluble and binding acid invertase (Mishra *et al.* 2023). Auxin is also known to be important for cell growth, so the shoot growth inhibition observed by glyphosate in sugarcane may also be related to auxin (Didier *et al*. 2017; Vasantha *et al*. 2022).

Chlorosis of the upper leaves takes off slowly, with impressive yellowing of the canopy after CR application. Leaves within young stems (spindles) often die or are dramatically reduced in size. Reddening of the leaf sheaths and lower leaf blades are often seen in the first few weeks after CRs spraying. The apical region becomes hardened and discolored, usually changing from brown to red or mauve, and rotting generally occurs in due course. Signs of

Table 1: CRs characteristics of sugarcane harvest components (Silva and Maitto 2012)

Product	Ethepon	Trinexapac-ethyl	Sulfometuron-methyl	Glyphosate
Active ingredients	2-chloroethylphosphonic acid	4-cycloprophyl-α-hydroxyl-methylene)-3,5-dioxo-cyclohexane carboxylic acid ethyl-ester	Methyl-2[[[[(4,6-diamethyl-2-pyrimidinyl)-amino]carbonyl]amino]sulfonyl]benzoate	N-phosponomethyl glycine
Dose (L ha^{-1})	0.67–2.0	0.8–1.2	0.02	0.3–1.8
Precipitation after application (h)	6	1	6	6
Harvest (day after application)	45–90	35–55	25–45	25–35
Lateral shoot	Yes	Yes	Yes	Yes
Flowering inhibition	Yes	Yes	Yes	No
Growth stop	Yes	Yes	Yes	Yes
Meristematic death	Yes	No	No	Yes
Varietal response	Almost	All	All	All
Rooting	Yes (20%)	Yes (30%)	No	No
Germination	Good	Good	Standard	Poor

decay are usually first seen in the shaft and spread downward to the growing point area. The leaf canopy of CR treated sugarcane sometimes takes on a yellow-brown color about three weeks after spraying. When sugarcane grows rapidly at early or end of the milling season, inhibition of apical growth results in shorter stems so that the canopy is reduced between three and six weeks after spraying. The number of internodes produced after glyphosate application is less compared to plants not sprayed (Banasihan *et al*. 2007; Spaunhorst *et al*. 2019).

In addition, CR application inhibited stem elongation, which may also be related to the ability of auxin to increase ethylene synthesis by increasing 1-aminocyclopropane-1-acid (ACC) synthase activity (Rayle and Cleland 1992; Alarcón *et al*. 2014). Increased ethylene levels may stimulate lateral bud senescence and germination, while the hormonal balance between IAA and ethylene may also lead to inhibition of stem elongation and decreased apical dominance (Vasantha *et al*. 2018). Growth of lateral buds and root primordia generally occurs at the top six internodes, visible between three and six weeks after CR spraying (Silva and Caputo 2012). Su *et al.* (1992) found that increased sucrose accumulation due to glyphosate was more evident in younger internodes compared to older internodes. They discovered insignificant changes in the level of reducing sugars in either the fifth or eighth internode in the five days. Sucrose phosphate synthase (SPS) and sucrose phosphatase (SP) are considered the main enzymatic pathways for sucrose synthesis. Sucrose synthase (SS) is deemed primarily critical for sucrose hydrolysis; however, SS is also capable of sucrose synthesis (Maloney *et al*. 2015). Although sucrose accumulation occurred rapidly within five days of glyphosate treatment, the activities of enzymes responsible for sucrose synthesis (SPS and possibly SS) remained unchanged. This is consistent with findings that reducing sugars decreased with sucrose accumulation several weeks after glyphosate treatment, but the rate of reduction in reducing sugars was slower than the rate of increase in sucrose (Silva *et al*. 2022). This also suggests that reducing sugars were not being incorporated into the metabolic pool at an increased rate due to glyphosate treatment. An overview of the mechanism of increasing maturity due to the use of CRs is shown in Fig. 2.

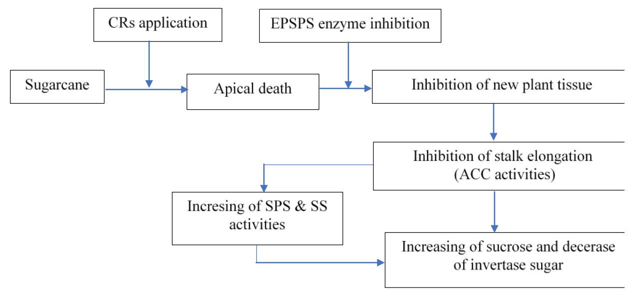

Fig. 2: Mechanism of CRs in increasing maturity

Impacts of CRs on sugarcane

Glyphosate is one of the most effective chemicals for increasing sucrose content and sugar recovery at the beginning of the milling season. Although it slightly reduces cane weight and dries leaves, it is still considered the most suitable and economical chemical for increasing sugar recovery under the climatic conditions of Khuzestan (Karmollachaab *et al*. 2015). However, the use of chemicals such as CRs also has negative effects on sugarcane yield and stem borer (Dilder *et al*. 2017). A research report by Utama *et al*. (2017) showed that glyphosate treatment at a dose of 0.8 L ha^{-1} significantly affected the percentage of growing point mortality, side growth, pol, purity grade, juice value, and yield at 6th week after application (WAA).

Numerous studies have reported two negative effects of glyphosate. First is the increased number of side shoots on the stem after application, leading to lower quality of raw materials. Second is the detrimental effect on ratoon growth after harvesting from the treated area, with a reduction in tillers per meter, leading to lower productivity in the next harvest (Silva and Caputo 2012; Puspitasari *et al.* 2024). Therefore, glyphosate has been widely used in areas that will be used for new sugarcane crops (Donga and Eklo 2018). However, there are also reports that glyphosate has no known adverse effects on sugarcane quality and productivity (Banasihan *et al*. 2007). The negative effects of plant-borne glyphosate are variety-specific, with some varieties being completely unaffected by glyphosate application in previous ratoon crops, making it possible to

Table 2: Impact and effect of CR residues on ratoon growth

Impact of CRs	Residual effect	CRs active ingredients	References
No inhibition	Negligible amounts of residues (0.01 mg kg^{-1}) were detected in leaf or stalk samples eight months to one year after treatment with 0.56 kg ha^{-1} Ethrel.	Ethepon	Dilder *et al*. (2017); Vasantha *et al*. (2022)
	At recommended application rates and spray-to-harvest intervals, the likelihood of negative side effects on subsequent crops is very small	Fluazifop butyl	
	Not observed	Trinexapac ethyl	Dilder *et al*. (2017)
	Residues decompose in the soil	Bisphospho methyl glycine glyphosine	Solomon and Li (2004); Vasantha *et al*. (2022)
	Residue lower than the permitted level	Glyphosate	Donaldson (1999); Morgan (2003); Spaunhorst *et al*. (2019); Vasantha *et al*. (2022)
Lowering the number of shoots	Residue lower than the permitted level	Glyphosate	Viator *et al.* (2011); Silva *et al.* (2022)
Decrease in stalk height			Viator *et al*. (2008)
Sugar quality deterioration			Heerden *et al*. (2013)

select varieties that can tolerate chronic application of glyphosate. Therefore, glyphosate can be recommended for use on tolerant varieties in all crops or only on crops that need to be removed in cases where varieties have negative effects (Morgan 2003).

Unlike glyphosate, trinexapac ethyl can be used on all types of sugarcane. However, glyphosate is limited to ratooning in Louisiana and final ratoon in Florida. Application of CRs should be taken with care to stressed sugarcane and cultivars that do not respond to glyphosate due to potential negative effects on subsequent ratoon (Spaunhorst *et al*. 2019). In ratoon crops, despite a significant increase in yield with glyphosate treatment, the total sugar yield still decreased significantly due to a decrease in cane weight. Glyphosate also detrimentally affected brix and pol in ratoon crops after treatment (Dalley and Richard 2010; Didier *et al.* 2017). Negative effects on crops treated with glyphosate in the previous growing season are also reported from United States (Donaldson 1999). Therefore, glyphosate was registered for use only in the last ratoon crop in Florida, Louisiana, and Texas (Dusky *et al*. 1985).

Silva *et al*. (2022) reported that there was an effect of low doses of glyphosate in increasing juice purity and sucrose content in sugarcane stalks. The residual effects of ripening on subsequent sugarcane crops grown under favorable conditions are short-lived and rarely affect yield. The results of these other studies confirm that glyphosate sprayed on well-grown sugarcane at the recommended time and rate has little (Clowes 1978) to moderately heavy (Dilder *et al*. 2017) effect on the following ratoon. In one large trial where three consecutive crops were sprayed, no evidence of residual effects on yield was found. However, yields increased considerably due to the maturity effect of glyphosate. This is consistent with the reports, which indicates some residual effects of CRs on sugarcane crops are slightly low (Table 2).

Global use of CRs

The potential use of CRs has been developed since the 1940s. CRs have even become an integral part of sugarcane plantation management in many countries (Vasantha *et al*. 2022). In various countries, more than 100 types of chemicals have been tested as potential CRs for sugarcane (Dalley and Richard 2010). These CRs including fluazifop butyl (FB), isoprophylamine glyphosate (IG), sulfosate or glyphosate potassium (GP) and trynexapac ethyl (TNE) are therefore recommended in Indonesia (Hadisaputro 1996; Solomon and Li 2004). The first three compounds are categorized as herbicide CRs, while TNE is a GR. Various studies have shown that the type of CRs responds differently to sugarcane maturity parameters, although this is also influenced by other factors such as the variety and age of sugarcane as well as environmental factors (Viana *et al*. 2019; Tufail and Hussain 2020), so research on the right CRs formulation is paramount.

Glyphosate is also used at dose of 1.800 to 2.160 a.i. per hectare for sugarcane ratoon eradication for replacement to new sugarcane plant (Pincelli-Souza *et al.* 2020). At low doses (0.8 to 1 L ha^{-1}), glyphosate is often used as a CRs under unfavorable conditions for sugarcane maturity, such as low daily thermal differences and high air relative humidity (Odero *et al*. 2011). The following presents some of the CRs used in different countries with increasing effects on sugar content (Table 3).

CRs use in Indonesia

The use of CRs in Indonesia was carried out since the late 1970s and its use began to be widely used since the 2000s, especially in PGs in the Lampung area (Toharisman 2009). CRs spraying is carried out on plantations that have business use rights so that the implementation of spraying and also sugarcane harvesting can be controlled. CRs application increased from the beginning of 2000 in line with the increasingly abundant supply of sugarcane raw materials (Solomon and Li 2004).

In Indonesia, the often-used CRs are a group of herbicides with the active ingredient IG (Sudarsono *et al*. 2011; Utama *et al*. 2017). Glyphosate is also the most commonly used herbicide for sugarcane in the world for

Table 3: Use of CRs and their effects on yield increase

CRs active ingredients	Trademark	Country	Usage dosage ha^{-1}	Ripening time (weeks)	Increase in sugar yield (%)	References
Ethepon	Ethrel	South Africa, India, Peru, Melawai, Guyana, Zambia, Swaziland, Taiwan, China and Iran	2 kg ha^{-1}	8	3.18 – 8.13%	Solomon and Li (2004); Karmollachaab *et al.* (2015); Vasantha *et al*. (2022)
Fluazifop butyl	Fusilade; Fusilade forte	Ethiopia, Egypt USA and South Africa	0.1 – 0.45 L ha^{-1}	8	3.70 – 35.6%	Hadisaputro *et al*. (1990); James (1999); Morgan (2003); Muhwiridzwa and Madanzi (2016); Ayele *et al.* (2021); Vasantha *et al*. (2022)
Glyphosate	Round up, Round up Weather MAX; Touchdown, Polado	Hawai, USA, South Africa, Jamaica, India, Trinidad, Brazil, Argentina, Australia, Pakistan and Ivory Coast	0.18 – 0.625 kg a.i or 0.5 – 0.8 L ha^{-1}	3–9	1.60 – 29.00%	Clowes (1978); Karmollachaab *et al*. (2015); Didier *et al*. (2017); Tufail and Hussain (2020); Vasantha *et al*. (2022)
Trinexapac ethyl	Palisade; Moddus	USA	0.20 – 0.78 kg ha^{-1}	4–8	16 – 23%	McDonald *et al*. (2000); Oregon (2012); Silva and Caputo (2012); Spaunhorst *et al*. (2019)
Bisphosphomethyl glycine glyphosine	Polaris	Cuba, Brazil, Guyana, India, Jamaica, Taiwan, Mauritus, Malawi, Swaziland, Panama and South Africa	2–5 kg ha^{-1}	4–8	1.2 – 20.6%	Solomon and Li (2004); Vasantha *et al*. (2022)

Table 4: Results of CR application research in Indonesia

Active Ingredients of CRs	Dose (L ha^{-1})	Location	Increased sugar yield (%)	Impact ratoon crops (Yes/No)	References
Glyphosate	0.7 – 0.8	South Sumatera, East Java	0.02 – 3.34	Yes	Hadisaputro (1996); Mirzawan *et al*. (2001); Anonim (2009)
	0.5	North Sumatera	0.60 – 0.72	Yes	Anonim (2023)
	0.5 – 0.7	Lampung	1.16 – 7.56	Yes	Anonim (2022)
Fluazifop butyl	0.5 – 0.6	East Java, Lampung, South Sumatera	14.14 – 29.06	No	Hadisaputro *et al.* (1990), Sudarijanto and Mulyatmo (1996); Isnaini *et al*. (2008); Anonim (2009)
Sodium Bispyribac	0.1–0.2	East Java	0.36 – 16.19	Yes	Anonim (2022)

sugarcane. Glyphosate can be used as herbicide at field doses or as a CR at low doses (Duke 2018). The highest increase in maturity occurs at three to six weeks after application (WAP) and is recommended at a dose of 336 g ha^{-1} (Solomon and Li 2004).

CRs in locations with high rainfall such as in North Sumatra (PT Perkebunan Nusantara II) and also in the Banyuwangi area have not been used even though it has good potential to increase sugarcane maturity. Some research results of CRs application on sugarcane in Indonesia are listed in Table 4.

Although CRs application has many positive impacts on sugarcane quality, especially on increasing maturity, many sugar companies in Indonesia are still reluctant to apply the technology. One of the obstacles is the accuracy between the time of application and harvest after CRs spray (Karmollachaab *et al.* 2015), so as to reduce the concern about the decline in sugarcane quality and the death of buds in the next harvest. Therefore, coordination and harvest management arrangements are needed between sugar mills and business use rights as well as sugarcane farmers.

Conclusion

CRs have the potential to be one of the solutions to improve sugarcane quality. Maturity-promoting substances are one way to increase the economic value (quality) of sugarcane under conditions where natural maturity is not possible. The viability of employing CRs in sugarcane production systems is contingent upon various factors, such as climatic conditions, technical considerations, and economic aspects, with particular emphasis on the incremental benefits that each variety may offer within cultivation practices. The types of CRs vary from herbicides to growth regulators. The current method of CRs application is not only manual but can use UAVs making it easier and cheaper. The physiological response to the use of CRs especially glyphosate is in addition to reducing acid invertase activity to increase sucrose to the observed levels. CRs at the recommended dose with timely harvesting will have little effect on the next ratoon. An update on the use of CRs in Indonesia is needed regarding the selection of active ingredient, dosage, application method and application in new development areas for sugarcane.

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Author Contributions

While other authors equally contributed by proposing distinct areas of contribution, the primary author assembled and edited the review piece. Before submission, AEA reviewed the article.

Conflict of Interest

All authors declare no conflict of interest.

Data Availability

Data presented in this study will be available on a fair request to the corresponding author.

Ethnics Approval

Not applicable to this work.

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