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RESEARCH ARTICLE

Sugarcane Yield and Technological Ripening Responses to Chemical Ripeners

A. Karmollachaab[1] · A. Bakhshandeh[1] · M. R. Moradi Telavat[1] · F. Moradi[2] · M. Shomeili[3]

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Abstract The present investigation was carried out in Khuzestan province of Iran to evaluate the effects of chemical ripeners on the advancement of cane maturity (var. CP57-614) during incline phase. Three chemicals viz. Ethephon (2-Chloroethyl phosphoric acid), Glyphosate, and Fitomas M (a growth regulator) were applied as foliar spray on the crop using a small aircraft. The result showed that application of glyphosate increased brix, pol%, fiber, and recoverable sugar; however, its application reduced cane length and invert sugars and also showed marginal decline in the cane yield. The improvement in cane quality was more pronounced compared to the reduction in cane yield. Ethephon application had no impact on cane tonnage, and showed marginal improvement in pol per cent (3.3 %) and recoverable sugar (3.4 %) compared to untreated control. Fitomas-M had no effect on cane tonnage; on the contrary, it showed decline in pol%. Based on the large-scale trials done in Khuzestan province, it was demonstrated that 0.5 l ha^{-1} of glyphosate increased recoverable sugar to the extent of 10.60 % indicating that this treatment was most suitable for increasing sucrose content during incline period of crop maturity or early stages of harvest.

✉ A. Karmollachaab
azizchaab@gmail.com

1 Department of Agronomy, Ramin Agriculture and Natural Resources University, Ahvaz, Khuzestan, Iran

2 Department of Physiology, Agricultural Biotechnology Research Institute of Iran (ABRII), Karaj, Iran

3 Department of Agronomy, Sugarcane Research and Training Institute, Khuzestan, Iran

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Introduction

Sugarcane productivity is dependent upon cane yield and its components traits, whereas sugar productivity *per se* is affected significantly by cane yield and qualitative traits at harvest. In climatic conditions of Khuzestan, Iran, favorable period for sugarcane growth is limited only to 6 months. Sugar mills in this region begin processing operations in late October to avoid the detrimental effects of chilling temperatures on sugar recovery. Once the milling process is initiated in Khuzestan, harvest is continuous, regardless of precipitation in the months of September through November (Table 1). During the early periods of harvest season, most of the sugarcane varieties are not fully ripened due to intermittent rains, and therefore, sugar recovery is usually low during incline phase. To improve sucrose yield during this period, pre-harvest application of chemical ripeners is recommended, which is an established technology in many sugarcane-producing areas of the world (Solomon and Li 2004). However, the Chemical ripening technology practiced in several overseas sugar industries has not been tried by the Khuzestan sugar industry due to various operational and management reasons (Abo El-Hamd et al. 2013). In view of the low sugar recovery during early season, there is renewed interest to use chemical ripeners to increase the sucrose content of sugarcane crop, enabling the industry to harvest the crop either earlier, or at the normal time with a higher sucrose recovery (Rostron 1985). The use of chemicals to increase sucrose content in the incline period of cane maturity has received much attention since 1970s and this technology

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Table 1 Mean temperature, rainfall and ripening period, and harvesting time of sugarcane in Khuzestan province, Iran

Climate characteristics	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Temperature (°C)	22.2	29.8	33.7	37.5	36.2	33.5	27.9	18.1	11.1	9.6	11.7	18.4
Rainfall (mm)	21.7	23.1	0	0	0	0	16.1	28.3	45.2	34.3	26.3	41.3
Technological ripening									×	×	×	×
Harvesting time								×	×	×	×	×

has been successfully implemented in many countries. Early-season sucrose levels have been improved with the application of glyphosine, glyphosate, ethephon, fluazifop, haloxyfop, and trinexapac-ethyl (Moddus) (McDonald et al. 2001).

Glyphosate, an amino acid synthesis inhibitor, applied at sub-lethal doses has been widely used to increase sucrose levels (Solomon and Li 2004) in sugarcane. Application of glyphosate on sugarcane leads to necrosis of meristematic tissues, particularly in the stalk apex and developing leaves (Donaldson and Staden 1995). At biochemical level, the shikimate pathway is deregulated by glyphosate application (Amrhein et al. 1980). Trinexapac-ethyl is one of the main ripeners used in Brazil and it reduces endogenous levels of an active form of gibberellic acid, GA_1, by repressing its biosynthesis from GA_{20} (Guimaraes et al. 2005). Ethephon (Ethrel) produces ethylene within the sugarcane tissue and reduced the activity of extracellular invertase(s) (Morgan et al. 2007).

The response of sugarcane to chemical ripeners has been found to vary with the rate of application of the chemical, sugarcane variety, the physiological stage of the crop at the time of application, type of ripener or ripener combination, and the growing conditions before and after application (Dusky et al. 1986). Leite et al. (2009) noted that ripener application for early harvest sugarcane led to an increase in technological quality, although sugar yield had been significantly affected, which positively contributed to the profit per unit area. Abo El-Hamd et al. (2013) found that glyphosate application increased total soluble solids in cane juice but other quality parameters viz. sucrose content also increased proportionately. Guimaraes et al. (2005) showed that Fitomas significantly increased sugar yield when applied at a rate of 200 g ai ha^{-1}, 45–60 days before harvest in many Brazilian commercial varieties, and enhances tillering, root growth, and other agronomic traits in the following harvests. Al-Chabi (2011) showed that applying 200 mg l^{-1} ethephon during early tillering stage caused significant decrease in the height of plant but increased the number of tillers, stem diameter, the number of milling stems, total stems yield, and sugar yield. As per the available literature, chemical ripeners had shown variable results on the sugarcane crop due to many reasons and therefore it was imperative to assess their detailed response under Khuzestan conditions. The present research was undertaken to determine the effects of three chemical ripeners on sugarcane yield and quality during early harvest and to recommend it for using in the commercial plantation of sugar mill area of Khuzestan province.

Materials and Methods

In order to evaluate the effects of the three chemical ripeners on qualitative traits, cane and sugar yield during early harvest, an experiment was carried out in complete randomized block design with four replications at Khuzestan Sugarcane and By-Products Development Company, Iman Khomeini in 2014. The sugarcane variety CP57-614, early-maturing high sugarcane cultivar which is profusely grown in commercial plantation in Khuzestan province, was raised as per the normal crop husbandry methods recommended in this region and used throughout this study. Field preparations were done according to the conventional practices in Khuzestan Company and included the initial irrigation, 90 cm sub-soiler, disk, laser leveling, and furrowing. Hydro flume and furrow irrigation were applied based on the crop requirement with one-to-two-week intervals, depending on the environmental conditions. Chemical fertilizers were used based on soil test analysis, plant deficiency, and expected yield that included 350 kg ha^{-1} urea and the same amount of triple superphosphate. Urea was applied in 3–4 splits through gated pipe irrigation system, and triple superphosphate was mixed with the soil before planting. The chemical ripeners viz. Ethephon (2-chloroethyl phosphonic acid), Glyphosate, and Fitomas M were evaluated in this study. One liter of commercial grade chemical was mixed with 300 l of water and sprayed on selected plots during morning hours. In control plots, no treatment was done.

The experiment consists of 16 plots, each plot with length of 10 m and six paired rows, and the distance from furrow to furrow was 1.83 m. The healthy crop after 10 months of growth was sprayed with the three chemicals on 6th September 2014. The treated and control crops were harvested on 11th November 2014. The field had high relative homogeneity. Results of soil and irrigation water chemical and physical analysis of the farm soil and the irrigation water are given in Table 2.

At each harvest, 20 healthy cane stalks from the experimental and control plots were collected randomly for qualitative analysis, and cane yield in 10 sq m^2 area was recorded after harvesting the crop. The juice of 20 stalks was extracted using Cuban Mill. The extracted juice was used for quality analysis. Pol% was measured with a polarimeter (Saccharomat NIR W_2), Brix% was recorded with refractometer device (Schemidt, Dursw at 20 °C), and fiber% cane (ICUMSA 2009). The invert sugar percentage in juice was measured by titrimetric method of Rein (2007).

The data of experiments were pooled and analyzed statistically by ANOVA performed with SAS software v9. 2, and the least significant differences (LSD) test at probability level of 0.05 were calculated to compare the differences among treatments means.

Results and Discussion

Results of foliar application of Glyphosate were more pronounced on brix and pol%, after 30–40 days, followed by Ethephon. Fitomas M had very little effect on the quality parameters. At harvest time and about 2 months after spraying, glyphosate application recorded maximum beneficial response on quality compared to ethephon or Fitomas M (Fig. 1, 2). The Glyphosate-treated crop showed maximum increase in pol% value under Khuzestan climate. The invert sugar in the juice recorded steep decline compared to the control; at harvest time, about 52 % reduction was observed in the invert sugar in glyphosate-treated crop compared to untreated control. In case of ethephon, less reduction in the invert sugar was noticed compared to glyphosate. Application of Fitomas M increased invert sugar percentage which was around 64 %, and this was around 40 % more than control (Fig. 3). Glyphosate application at 40 days and ethephon

Table 2 Chemical and physical characteristics of soil and water of experimental fields

Soil depth (cm)	EC (dS m^{-1})	pH	Organic matter (%)	Ca^{+2} (meq l^{-1})	Mg^{+2} (meq l^{-1})	K^{+} (meq l^{-1})	Cl^{-} (meq l^{-1})	N (ppm)	P (ppm)	Soil texture
0–30	2.91	7.23	0.71	9.3	14.6	0.183	10.8	680	10.52	Silty clay
30–60	3.75	7.76	0.60	12.5	15.9	0.157	11.3	541	9.04	Clay
60–90	4.34	8.04	0.41	18.7	18.4	0.142	12.1	483	8.43	Clay
Water	2.21	7.68	–	7.41	12.08	0.052	7.2	–	–	–

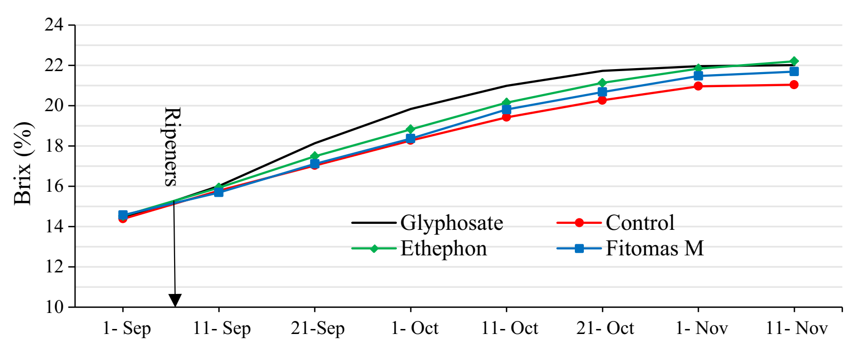

Fig. 1 Effect of chemical ripeners on brix value of sugarcane

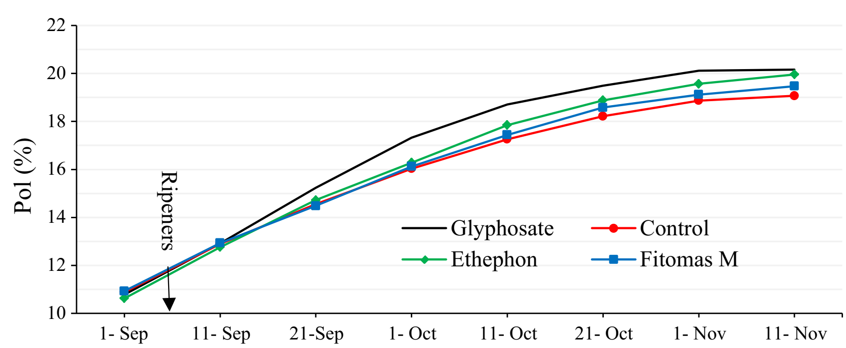

Fig. 2 Effect of chemical ripeners on pol% juice in sugarcane

application at 65 days showed appreciable increase in juice pol and brix value and relatively lesser reduction in the inert sugar levels. Fitomas M had no significant effect on the pol and brix percentage; moreover, its effect was less than other ripeners in the long-term, and application of this ripener increased the level of invert sugars, which could be due to higher inversion of stored sucrose. According to Silva and Caputo (2012) after ripener 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. Rostron (1989) used ethephon, Fusilade super, and Glyphosate on sugarcane cultivars NCo.376, NCo.293, N11, N12, and N13 and reported that all ripeners improved cane quality and sugar yield by similar amounts in most cultivars.

The mean value for stalk length of sugarcane crop treated with various ripeners is shown in Fig. 4. The Fitomas M application led to increased stalk length of sugarcane compared to control, whereas the stalk length was not influenced by ethephon application. On the other hand, application of glyphosate led to cessation of stalk elongation and a significant decrease in the height compared to other treatments. This is the reason that glyphosate-treated crop showed marginal reduction in yield. The glyphosate application impacts enzymes of shikimate pathway (Herrmann 1995) which is responsible for the formation of aromatic amino acids and are precursors of secondary metabolites, of which lignin is the most important. After application of glyphosate, apical meristem is affected, which leads to slowing of stem elongation process and, with the passage of time growth, is completely stopped due to death of upper meristematic tissues. Hilton et al. (1980) reported translocation of glyphosate from sugarcane leaf blades to the apical region, stalk, and roots. The vegetative development is reduced after the application of glyphosate in sugarcane. The stalk length in control and Fitomas M-treated canes were increased 7.1 and 10 cm, respectively, as these treatments show no visible signs of damage to the apical meristem. Fitomas M application leads to increase in the invert sugar percent and the stalk length compared to other treatments (Fig. 4). Data presented in Table 2 revealed a positive significant correlation among the height and the invert sugar per cent. But there is a negative correlation between the stalk length and other qualitative traits of sugarcane. Therefore, the increase in the length was in the form of increase in number or length of internodes at the end of stem, and high level of invert sugar and also the minimum purity of juice are observed in these internodes. Although Fitomas M treatment leads to slight improvement in sugar content, but increase in invert sugar and decrease in harvesting index are slightly higher,

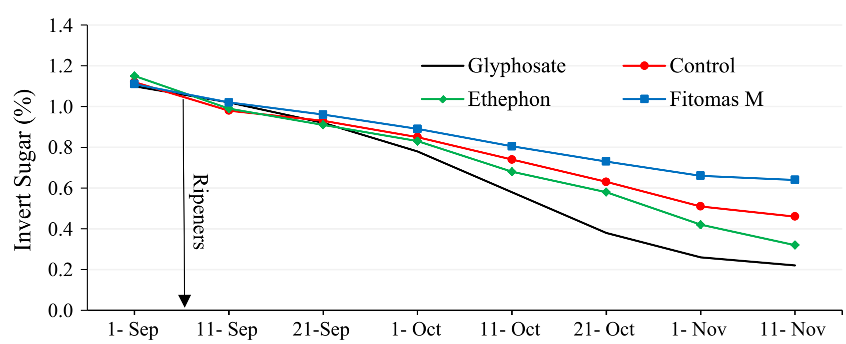

Fig. 3 Effect of chemical ripeners on invert sugar% of sugarcane

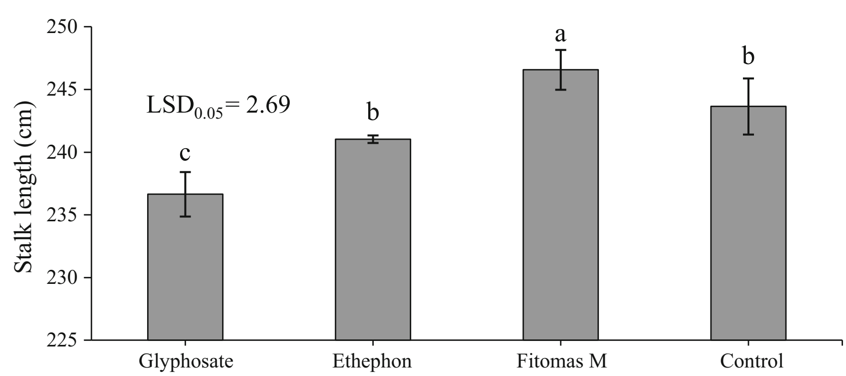

Fig. 4 Effect of chemical ripeners on sugarcane stalk length after 2 months of treatment

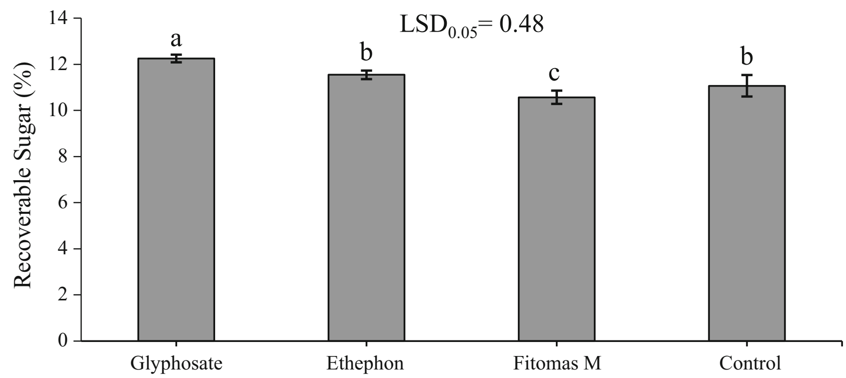

Fig. 5 Effect of chemical ripeners on recoverable sugar 2 months after treatment

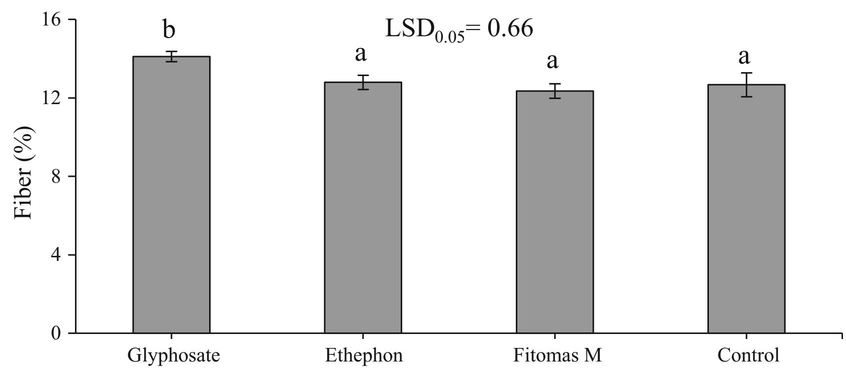

Fig. 6 Effect of chemical ripeners on fiber% of sugarcane after 2 months of treatment

and Fitomas M treatment has no economic value owing to its feeble impact on sucrose content.

The recoverable sugar (RS) content in glyphosate-treated crop increased by 12.25 %, and this effect was lowered by FM application (10.57 %). In control plots (no ripener application), the RS was 11.07 % and it was not significantly different with ethephon treatment (Fig. 5). Therefore, an increase in the recoverable sugar content by 10.6 % after glyphosate application was quite remarkable and has good economic value for the industry. There was a negative correlation between the recoverable sugar and the cane height, and invert sugar and cane yield but the maximum positive correlation ($r^2 = 0.99$) was obtained with pol%. In case of Fitomas M treatment, the number and the length of internodes with the low brix and pol are more, leading to reduction in brix and pol percentage, and thus, there is a negative correlation between the quantitative and qualitative yield. These results are in harmony with those found by Kirubakaran et al. (2013).

The results presented in Fig. 6 showed that the fiber% following glyphosate treatment has increased by 11.3 % compared to the control. The Fiber% cane in control was 12.67 % and did no show any significant difference with ethephon and FM treatments. Glyphosate treatment caused simultaneous increase in the fiber and total soluble solids in sugarcane, indicating a positive significant correlation between these two parameters; however, the correlation coefficient is not so strong. It seems that glyphosate application causes the hardening of cane by eliminating the apical meristem, enhances water loss, and increases fiber content, and the tissue dehydration is probably responsible for higher brix value. These studies conclusively proved that under Khuzestan conditions, glyphosate is an effective cane ripening chemical compared to ethephon or Fitomas M. Glyphosate application consistently increased pol% and juice purity and found to be the best chemical ripener for early season harvest. Glyphosate application led to appreciable decrease in cane yield, i.e., 5.5 % lower than the control, and had a significant difference with both the treatments viz., ethephon and Fitomas M (Fig. 7). The yield reduction is mainly attributed to reduction in the stalk length (3 %) followed by glyphosate treatment (Fig. 7; Table 3).

Conclusion

Application of chemical ripeners to improve sucrose content during incline phase of maturity is a predominant area of research in many countries and has immense commercial significance. Many chemical ripeners such as ethephon, fusilade super, and glyphosate have low cost and no health hazards if used in required quantity and with proper care. Our study has conclusively shown that chemical ripening using appropriate doses of glyphosate enhances sucrose content *vis-à-vis* sugar recovery during early

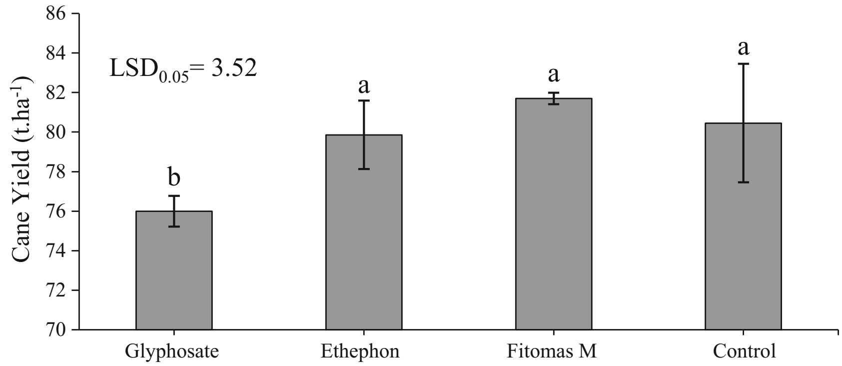

Fig. 7 Effect of chemical ripeners treatment on sugarcane yield 2 months after treatment

Table 3 Pearson coefficients correlation among measured traits in sugarcane cultivar CP57-614

	Length	Brix	Pol	Invert	RS	Fiber	Yield
Length	1						
Brix	−0.80**	1					
Pol	−0.86**	0.94**	1				
Invert	0.77**	−0.75**	−0.81**	1			
RS	−0.84**	0.88**	0.99**	−0.81**	1		
Fiber	−0.61 ns	0.74*	0.68 ns	−0.63na	0.63**	1	
Yield	0.61**	−0.67*	−0.65**	0.56*	−0.62*	−0.59**	1

ns Not significant

* and ** significant at 5 and 1 % probability levels, respectively

harvest. The gain in sugar recovery hovers between 0.5 and 1.0 unit, especially during the wet season in this area, and therefore, this could be an important technology for Khuzestan sugar mills. Further, application of Glyphosate showed maximum economical benefits due to better sucrose recovery. Although Glyphosate application caused cessation of growth, moderate reduction in cane yield, and drying of leaves, economic benefit due to increase sucrose recovery could nullify the losses caused due to marginal decline in cane weight. This gain due to increase in sucrose content (10.6 %) was higher than the decrease in the yield (5.5 %); furthermore, a substantial hike in recoverable sugar took place within 30–40 days after its application. Ethephon application has moderate positive impact on recoverable sugar but did not show any effect on the cane length, fiber%, invert sugar%, and the cane yield. The Fitomas M has no positive or beneficial effect on recoverable sugar. In general, two important quality parameters, i.e., brix and pol%, show maximum positive significant correlation coefficient with the recoverable sugar, especially following glyphosate application, and its use in commercial sugarcane plantation is justifiable from the economic point of view. This study shows that in order to get better sugar recovery during early season under Khuzestan climatic conditions, the use of glyphosate or glyphosate-based chemical formulation is most beneficial and economical.

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