



Sugarcane yield and ripening response to chemical ripeners

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Abstract The effects of chemical ripeners on increasing sugar content (cv. CP57-614) during the sugar-accumulation period were evaluated in Khuzestan province, Iran. Three chemicals, ethephon (2-chloroethyl phosphoric acid), glyphosate and Fitomas[®]-M (a growth regulator), were each applied as a foliar spray on the crop using a small aircraft. Application of glyphosate increased Brix, Pol%, fibre and recoverable sugar, but application reduced cane length and invert sugars and there was also a marginal decline in cane yield. The improvement in cane quality outweighed the reduction in cane yield. Ethephon application had no impact on cane yield, but showed a marginal improvement in Pol % (3.3%) and recoverable sugar (3.4%) compared to the untreated control. Fitomas-M had no effect on cane yield, but caused a decline in Pol%. Based on the large-scale trials done in Khuzestan province it was demonstrated that 0.5 L/ha of glyphosate increased recoverable sugar by 10.6%, indicating that this treatment was most suitable for increasing sucrose content during the sugar-accumulation period of crop maturity or early stages of harvest.

Key words Brix, glyphosate, ethephon, invert sugar, ripener, Pol%

INTRODUCTION

Productivity of sugarcane (*Saccharum* spp. hybrids) is dependent upon cane yield and its component traits, whereas sugar productivity per se is affected markedly by cane yield and qualitative traits at harvest. In the climatic conditions of Khuzestan, Iran, favorable growing conditions for sugarcane are to about 6 months per year. Sugar mills in this region begin processing cane in late October each year to avoid the detrimental effects of low temperatures on sugar recovery (Karmollachaab et al. 2015). Once the milling process is initiated in Khuzestan, harvesting occurs continuously, irrespective of the usual rainfall that is expected during September to November (Table 1). During the early period of the harvesting season, most of the sugarcane varieties are not fully ripened due to intermittent rains and sugar recovery is therefore usually low. To improve sucrose yield during this period, pre-harvest application of chemical ripeners is recommended - this is an established technology in many sugarcane-producing areas of the world (Solomon and Li 2004). However, the chemical ripening practices used in several overseas sugar industries has not been tested 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 the early season, there is renewed interest in using chemical ripeners to increase the sucrose content of the sugarcane crop, enabling the industry to harvest the crop either earlier, or at the normal time with a higher sucrose recovery (Rostron 1985). Increases in early season sucrose levels following applications of chemicals such as glyphosine, glyphosate, ethephon, fluazifop, haloxyfop and trinexapac-ethyl (Moddus[®]) have been reported for irrigated cane in Australia (McDonald et al. 2001).

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

Parameter	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
Ripening period										x	x	x
Harvesting period									x	x	x	x

Glyphosate, an amino-acid synthesis inhibitor, applied at sub-lethal doses has been used widely to increase sucrose levels in sugarcane (Solomon and Li 2004). Application of glyphosate on sugarcane leads to necrosis of meristematic tissues, particularly in the stalk apex and developing leaves (Donaldson and van Staden 1995). At a 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, GA₁, by repressing its biosynthesis from GA₂₀ (Guimaraes et al. 2005). Ethephon (Ethre®) produces ethylene within the sugarcane tissue and reduces the activity of extracellular invertase (Morgan et al. 2007).

The response of sugarcane to chemical ripeners varies with the rate of application of the chemical, sugarcane cultivar, 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 application of ripeners for early harvest sugarcane led to an increase in sugar yield and quality, and contributed positively to 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, such as sucrose content, also increased proportionately. Guimaraes et al. (2005) showed that Fitomas® significantly increased sugar yield when applied at 200 g ai/ha, 45-60 days before harvest in many Brazilian commercial varieties, and enhanced tillering, root growth and other agronomic traits in the following harvests. Al-Mubarak and Al-Chalabi (2011) showed that application of 200 mg/L ethephon applied during the early tillering stage caused significant decrease in the height of plant but increased the number of tillers, stem diameter, the number of milling stalks, total stalk yield and sugar yield.

As noted from the available literature, the use of chemical ripeners has had variable results on sugarcane crops due to many reasons. For this reason it was important to assess the efficacy of ripeners under Khuzestan conditions. Our research was undertaken to determine the effects of three chemical ripeners on sugarcane yield and quality during early harvest (early October) with a view to developing guidelines for use in commercial sugarcane in Khuzestan.

MATERIALS AND METHODS

Effects of three chemical ripeners on qualitative traits, cane and sugar yield during early harvest were evaluated in a field experiment carried out in randomized complete-block design with four replications at the Khuzestan Sugarcane and By-Products Development Company, Iman Khomeini in 2014. Sugarcane cultivar CP57-614, an early maturing high sugarcane variety that is widely grown in commercial plantations in Khuzestan province, was grown according to recommended practices for this region (Anonymous 2014). Field preparations were undertaken according to the conventional practices used by Khuzestan Company and included an initial irrigation, sub-soiling to a depth of 0.9 m, followed by discing, laser leveling and furrowing. Hydro-flume and furrow irrigation were applied according to the crop water requirement at 1-2 week intervals, depending on environmental conditions. Chemical fertilizers were applied according to the results of soil analyses and expected yield: 160 kg N and 140 kg P per hectare. Urea was applied in 3-4 splits through a gated pipe irrigation system, and triple superphosphate was mixed with the soil before planting. The chemical ripeners tested in this experiment were ethephon (2-chloroethyl phosphonic acid), glyphosate, and Fitomas-M. In each case, 1 L of commercial grade chemical was mixed with 300 L of water and sprayed on the appropriate plots during early morning hours. No ripener was applied to the control plots.

The experiment consisted of 16 plots, each plot with a length of 10 m and six paired rows, with a row-spacing of 1.83 m. All ripener treatments were applied at the age of 10 months on 6 September 2014. The trial was harvested on 11 November 2014. The field had high relative homogeneity. Results of soil and irrigation water analysis are given in Table 2.

Table 2. Chemical and physical characteristics of the soil and irrigation water.

Soil depth (cm)	EC (dS/m)	pH (in water)	Organic matter (%)	Ca ⁺²	Mg ⁺²	K ⁺	Cl	N	P	Soil texture
				(meq/L)				(mg/kg)		
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	-	-	-

We collected 20 healthy cane stalks randomly from the experimental and control plots every 10 d for quality analysis after the ripeners were applied. At harvest, cane yield was determined for a 10 m² area per plot. The juice of 20 stalks was extracted with a Cuban Mill for analysis. Pol% was measured with a polarimeter (Saccharomat NIR W₂), Brix% was



recorded with a refractometer (Schemidt, Dursw at 20°C), and fibre% cane determined (ICUMSA 1999). Invert sugar percentage in juice was measured by the titrimetric method of Rein (2007).

The experimental data were analyzed statistically using the analysis of variance (ANOVA) option in SAS software v9. 2. The least significant differences (LSD) test at probability level of 0.05 was used to compare the differences among treatments means.

RESULTS AND DISCUSSION

Glyphosate had the most pronounced qualitative effect on Brix and Pol% 30-40 days after application, followed by Ethephon. Fitomas-M had very little effect on the quality parameters (Fig. 1). At the time of harvest about 2 months after spraying, the largest cane-quality response (Brix and Pol) was recorded for the glyphosate treatment compared to ethephon and Fitomas-M (Figs 1 and 2). The invert sugar in the juice of the glyphosate-treated cane declined steeply by 52% compared to the control (Fig. 3). In the case of ethephon, the reduction of invert sugar was less than that in the glyphosate treatment, but still steeper than that of the control. The application of Fitomas-M increased the invert sugar percentage to a final value of approximately 0.64%, which was about 40% higher than that of the control treatment (Fig. 3). Glyphosate and ethephon application resulted in appreciable increases in juice Pol and Brix values and relatively low inverted sugar levels at 40 and 65 days after application, respectively. Fitomas-M had no effect on the Pol and Brix percentage, but increased the amount of invert sugars, which could have been due to higher inversion of stored sucrose. According to Silva and Caputo (2012) invert sugars are predominantly absorbed by the leaves and shoots and is translocated to areas of meristematic activity where it inhibits the elongation of internodes. Rostron (1989) applied ethephon, Fusilade Super and glyphosate to sugarcane cultivars NCo376, NCo293, N11, N12 and N13. He reported that all three ripeners improved cane quality and sugar yield by similar amounts in most cultivars.

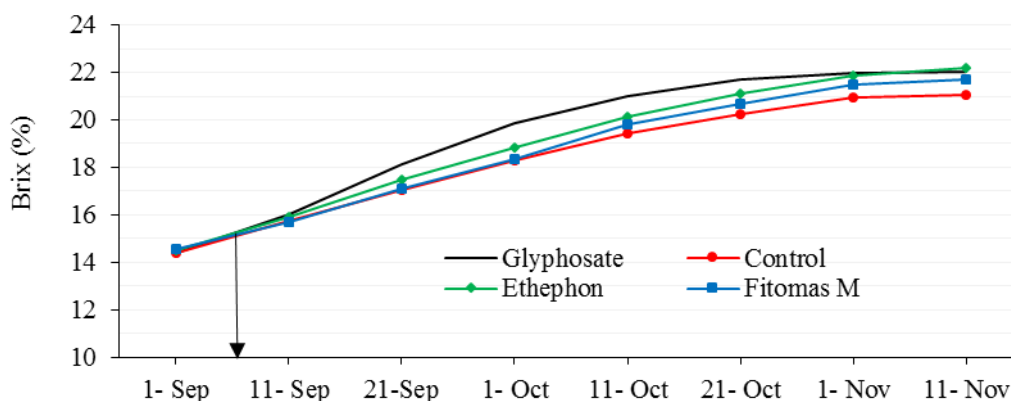


Fig. 1. Effect of chemical ripeners on Brix values in sugarcane.

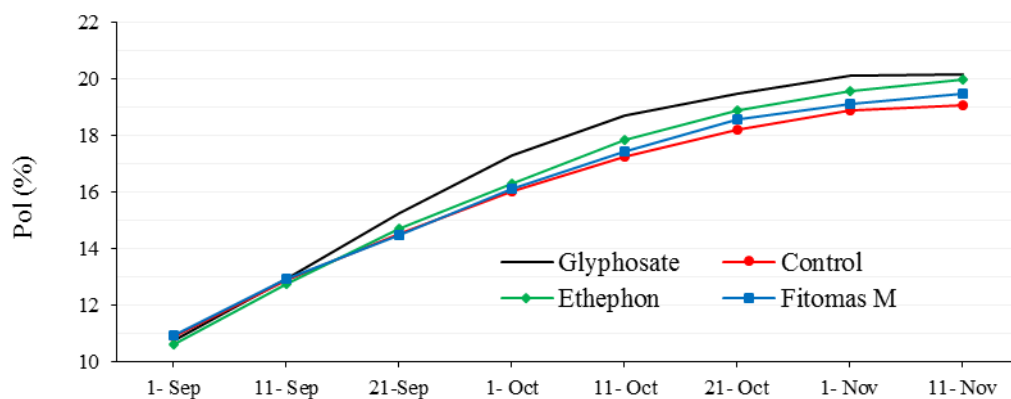


Fig. 2. Effect of chemical ripeners on Pol% juice in sugarcane.

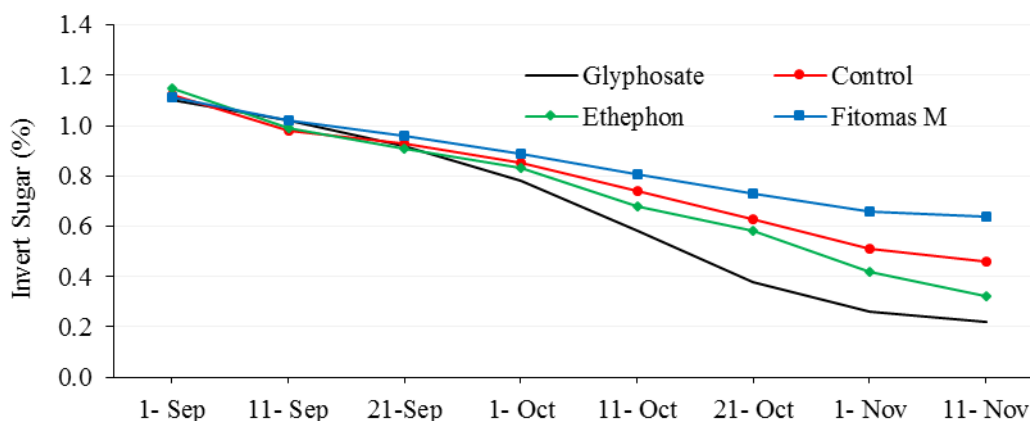


Fig. 3. Effect of chemical ripeners on invert sugar % of sugarcane.

The mean stalk lengths of sugarcane treated with the three ripeners are shown in Figure 4. Fitomas-M application led to increased stalk length compared to the control, but this parameter was not influenced by the ethephon treatment. Application of glyphosate led to cessation of stalk elongation and a significant decrease in length compared to the other treatments. It is for this reason that the glyphosate-treated crop showed a significant reduction in yield. According to Herrmann (1995), glyphosate application impacts enzymes of the shikimate pathway that are responsible for the formation of aromatic amino acids that are the precursors of secondary metabolites, of which lignin is the most important. After application of glyphosate, the apical meristem is affected and stalk elongation slows down. After some time growth is completely stopped due to the death of upper meristematic tissues. Hilton et al. (1980) reported translocation of glyphosate from sugarcane leaf blades to the apical region, stalk, and roots. In our study, stalk length of the control and Fitomas-M treated cane increased by 7.1 and 10 cm, respectively, and there were no visible signs of damage to the apical meristem. Fitomas-M application led to an increase of the invert sugar percent and stalk length compared to other treatments (Fig. 4). We found a significant positive correlation between stalk length and the invert sugar percent (Table 3). The remainder of the parameters listed in Table 3 all correlated negatively with stalk length. Fitomas-M treatment led to a slight reduction in sugar content (Fig. 5), but with increased invert sugar content and cane yield (Fig. 7). The cane yield in this case was significantly larger than that associated with the glyphosate treatment.

The recoverable sugar (RS) content in the glyphosate treated crop was the highest at 12.25% and lowest for Fitomas-M at 10.57% (Fig. 5). The RS for the control treatment was 11.07% and this was not significantly different from the ethephon treatment (Fig. 5). Therefore, an increase in the recoverable sugar content by 10.6% after glyphosate application was quite remarkable and has potential economic value for the industry. There was a negative correlation between RS and each of cane height, inverted sugar and cane yield, but a positive correlation ($r=0.99$) with Pol%. In case of the Fitomas-M treatment, the number and length of internodes with low Brix and Pol were relatively high, leading to reductions in brix and Pol% and the negative correlation between the quantitative and qualitative yield. These results are in agreement with those reported by Kirubakaran et al. (2013).

The fibre % cane following glyphosate treatment increased by 11.3% relative to the control (Fig. 6). The fibre % cane of the control was 12.67% and this was not significantly different from that for the ethephon and Fitomas-M treatments. It appears that the application of glyphosate causes the hardening of cane by eliminating the apical meristem, enhances water loss and increases fibre content - tissue dehydration is probably responsible for higher Brix value.

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

	Length	Brix	Pol	Invert	RS	Fibre
Brix	-0.80 **					
Pol	-0.86 **	0.94 **				
Invert	0.77 **	-0.75 **	-0.81 **			
RS	-0.84 **	0.88 **	0.99 **	-0.81 **		
Fibre	-0.61 ^{ns}	0.74 *	0.68 ^{ns}	-0.63 ^{ns}	0.63 **	
Yield	0.61 **	-0.67 *	-0.65 **	0.56 *	-0.62 *	-0.59 **

^{ns}, * and **, not significant and significant at 5% and 1% probability levels respectively.

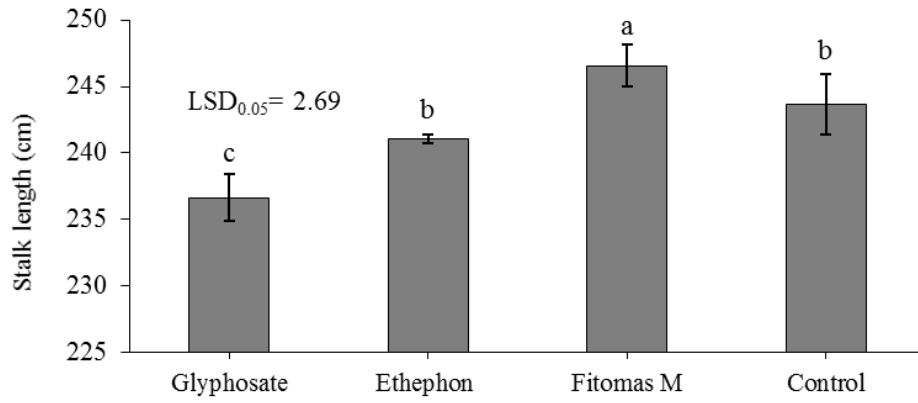


Fig. 4. Effect of chemical ripeners on sugarcane stalk length 2 months after treatment.

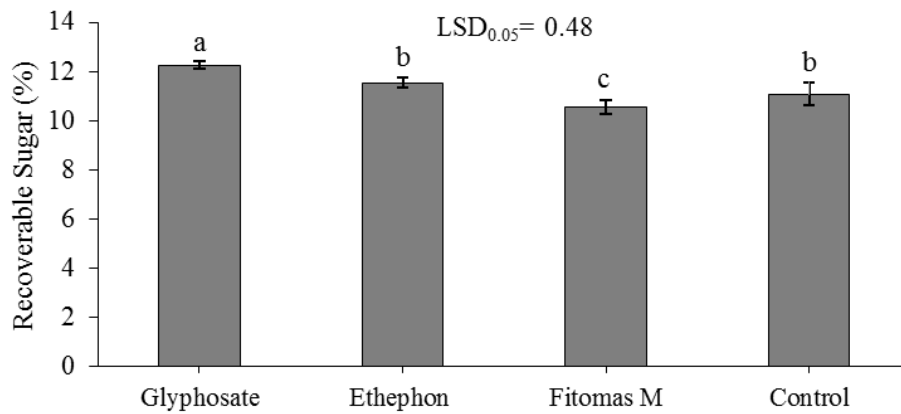


Fig. 5. Effect of chemical ripeners on recoverable sugar 2 months after treatment.

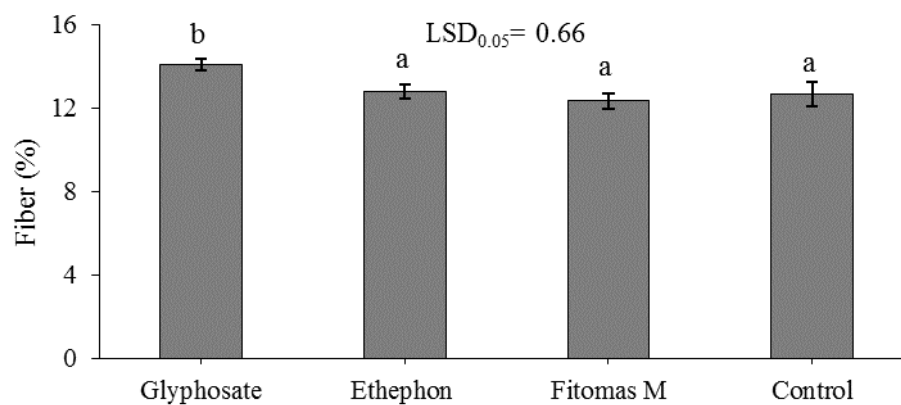


Fig. 6. Effect of chemical ripeners on fibre % of sugarcane 2 months after treatment.

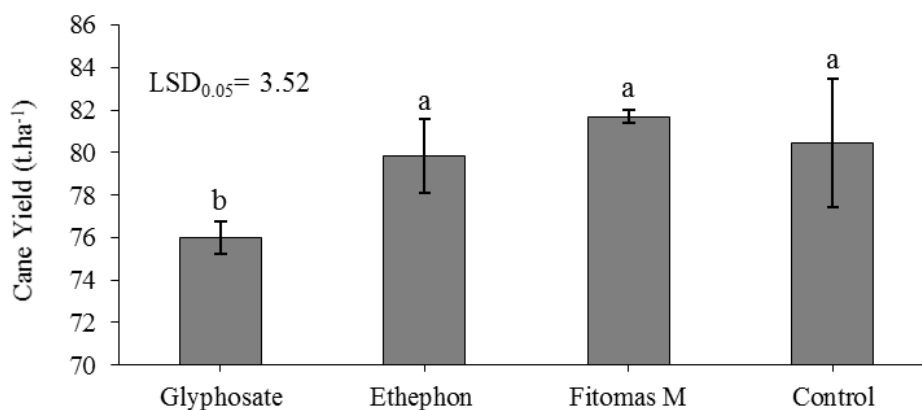


Fig. 7. Effect of chemical ripeners on sugarcane yield 2 months after treatment.

Our study demonstrates that under Khuzestan conditions, glyphosate is a more effective cane-ripening chemical than ethephon or Fitomas-M. Glyphosate application led to increase Pol% and juice purity and was the best chemical ripener for early season harvest. However, glyphosate application led to an appreciable decrease in cane yield, i.e. 5.5% lower than the control and significantly lower than the yields obtained with ethephon and Fitomas-M treatments. The yield reduction is mainly attributed to reduction in the stalk length (3%) from the application of glyphosate.

CONCLUSIONS

The application of chemical ripeners to improve sucrose content during the sugar-accumulation phase is important area of research in many countries. Successful increases in sugar content has immense potential commercial benefit. Many chemical ripeners such as ethephon and glyphosate are cheap and have no reported health hazards if used in recommended quantities and with proper care. Our study has shown that chemical ripening using appropriate doses of glyphosate enhances sucrose content vis-à-vis sugar recovery during early harvest. The gain in sugar recovery ranged between 0.5-1.0 units, especially during the wet season. It is therefore an important technology for consideration by Khuzestan sugar mills. In particular, application of glyphosate would result in distinct economic benefits due to better sucrose recovery. Although, glyphosate application caused cessation of growth, moderate reduction in cane yield and drying of leaves, the increase in sucrose recovery could nullify the losses caused due to marginal decline in cane weight. This gain due to the increase in sucrose content (10.6%) was higher than the decrease in the yield (5.5%). Importantly, the increase in recoverable sugar took place within 30-40 days after application. Ethephon application had a moderately positive impact on recoverable sugar but did not affect cane length, fibre %, invert sugar % or cane yield. Fitomas-M did not result in a positive effect on recoverable sugar. In general, two important quality parameters i.e. Brix and Pol% show maximum positive significant correlation coefficients with recoverable sugar, especially following glyphosate application. Our study showed that increased sugar recovery during early season harvesting under Khuzestan climatic conditions can be achieved using glyphosate or glyphosate-based chemical formulations, which, by extrapolation, will lead to economic benefit.

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French title

Résumé.

Mots-clés:

Spanish title

Resumen.

Palabras clave: