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Effect of Different Concentrations of Paclobutrazol on Increasing Tolerance of Sugarcane (CP48-103 variety) to Winter Conditions in the Southern Region of Ahvaz (South West of Iran)

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RESEARCH ARTICLE

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ABSTRACT

BACKGROUND: The application of paclobutrazol as a growth stimulant not only increases the cold tolerance of sugarcane but also enhances its yield.
OBJECTIVES: To investigate the effect of different concentrations of paclobutrazol in enhancing winter tolerance of sugarcane variety CP48-103 this study was carried out.
METHODS: Current research was done during the 2013 cropping season according randomized complete block design (RCBD) with three replications. The studied treatments were as control group (untreated), burning of cold-damaged shoots, harvesting cold-damaged shoots without hormone consumption, harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.
RESULT: The highest chlorophyll content, measured at 40 (Spad), was observed in harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol. Among the treatments, the highest amount of syrup (with an average of 31%) was observed in the treatment of burning of cold-damaged shoots, while the lowest amount (with an average of 28%) was found in the treatment of harvesting cold-damaged shoots without hormone consumption. The sucrose percentage displayed a significant increase from October 15 to October 30 in different treatments. This indicates that the sucrose content in the sugarcane increased during this period across all treatments. The burning treatment resulted in the lowest percentage of sucrose, with an average of 11%. The percentage of extractable sugar reached its peak on December 6 and across different treatments, the highest amount of extractable sugar (with an average of 8.5%) was obtained from treatment involving the harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol. In terms of stem yield, the highest and lowest values (with an average of 59800 and 51280 kg.ha^{-1}, respectively) were recorded in treatment of harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol and control treatment, respectively.
CONCLUSION: The treatment involving the application of paclobutrazol significantly increased the stem yield of sugarcane compared to the control treatment.
KEYWORDS: *Brix, Chlorophyll, Phosphorus, Sucrose, Sugar yield, Syrup purity.*

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1. BACKGROUND

Sugarcane is a tropical plant from the cereal family that is cultivated up to about 32 degrees north and south in different parts of the world and according to environmental conditions. It is clear that the resistance of this plant against cold is not very high, but this is not an obstacle for its cultivation in subtropical regions, where there is a possibility of sub-zero cold in those regions. Because the damage caused by cold can be minimized by creating a balance between the cultivated land and the production capacity of the factory, as well as carrying out appropriate agricultural operations. Usually, the occurrence of cold and frost in winter is one of the climatic characteristics of Khuzestan province, which occurs with differences in different years (Hay and Walker, 1989). The reaction of different species of sugarcane against frost is different according to the severity and weakness of its occurrence. If severe cold occurs, in this case, many plant cells are destroyed due to severe cold, and in this case, it is possible to harvest up to about 6 weeks after the occurrence of severe cold, and the product should be collected as soon as possible (Taiz and Zeiger, 2017). The severity of cold and the duration of its occurrence as well as the reaction of sugarcane varieties are important factors that determine the amount of damage caused by frost. So that in the constant thermal regime in ripe stems, a different reaction from death to health is observed in different varieties. The rate of loss of syrup quality after freezing depends on the ambient temperature, so that the rate of loss is faster when the air warms up after freezing. Chilling also damages young sugarcane in newly planted farms producing cuttings and harvested fields, so that the number of stems per plant may be reduced due to stem death. About 25% of the world's sugarcane producing countries, such as the United States (especially the states of Texas, Louisiana and Florida), Australia (the state of Queensland around Makani and the state of New Zealand), Spain (the region of Andalusia), northern Argentina, southern Brazil, Egypt, central part of China and Iraq often face sub-zero cold and freezing during winter. The 40-year statistics of Haft Tepeh sugarcane industry and cultivation show that Khuzestan province in Iran is one of the regions that have freezing temperatures with different intensity and duration in most years. The highest cold regime was recorded in the year 1963 with 224.2 hours of sub-zero temperature, and the minimum temperature in that year is -10^{o}C, and the lowest cold regime occurred in 1968 with 4.45 hours, when the minimum temperature is 0.5^{o}C. The investigation of the condition of sugarcane fields during a period of 38 years in Haft Tapeh region showed that when the air temperature drops to about 0^{o}C, the visible signs of the effect of cold on sugarcane appear, and in this case, the color leaves of sensitive varieties to cold, turned purple, which is the reason for the appearance of anthocyanin pigments (Taherkhani, 2010). In the natural process of cold, the morphological, physiological and biochemical characteristics of sugarcane change due to cold stress. Since the time of sugarcane cultivation in the newly established sugarcane and ancillary industries Development Company, except for 1996, chilling had not occurred at the levels of economic losses. This natural phenomenon took place in 2006, from December 29, 2006 to January 4, 2007 in sugarcane cultivation and industries, and the economic damage caused by it was high. Also, this phenomenon occurred in sugarcane cultivation and industry in 2016, which was accompanied by a lot of damage to sugarcane fields. In order to reduce the effects of environmental stresses, including cold, it is recommended to use some chemicals and growth regulators. An important group of these substances is triazoles. These compounds were used in the past to control fungal diseases in plants and animals (Austin Fletcher *et al*., 2010). One of the primary effects of these compounds is to prevent the activity of kaurene oxidase. This enzyme catalyzes the conversion of ante-kauren to curonic acid, thus reducing the amount of gibberellin (Helliwell *et al*., 1999). Inhibition of gibberellin biosynthesis is the primary action of plant regulation by triazoles, which is associated with the reduction of internode length and leaf area (Austin Fletcher *et al*., 2010). There are similar reports on barley (Vettakkorumakakav *et al*., 1999) and rice (Xim *et al*., 1996) in paclobutrazol treatment. Triazole compounds also cause changes in the balance of ABA, cytokinin, and ethylene hormones. One of the secondary effects of these compounds is reducing the amount of ethylene. It has been reported that the decrease in ethylene is probably related to the decrease in the activity of amino cyclopropane carboxylic acid oxidase. Since the precursor of ethylene and polyamines is S-adenosyl methionine (SAM), inhibition of ethylene biosynthesis increases polyamines (Sood and Nagar, 2008). These compounds play an important role in stress resistance. In general, sugarcane is one of the most important agricultural products in Iran and Khuzestan. Considering the climate changes, the presence of chilling, the increase in the world population and the increasing human need for food, increasing the yield of sugarcane, as one of the most important products in the human diet, will be very important. Also, one of the important and determining factors in plant tolerance to cold is the balance of internal plant hormones, which causes changes in plant metabolism and improves tolerance to various stresses, including cold.

2. OBJECTIVES

Based on this, the research was designed and conducted with the aim of mitigating cold damage and enhancing sugarcane's tolerance to winter conditions. The objective was to employ various methods to not only increase stem yield but also improve the quality characteristics of the sugarcane.

3. MATERIALS AND METHODS

The experiment was conducted during the 2013 cropping season in Salman Farsi agriculture and industry, located at 45 km south of Ahvaz, east of the Karun River.

3.1. *Geographical location of the test site*

Geographically, the area where the experiment is carried out has a hot and dry climate. This area does not have summer rainfall and the most rainfall occurs in winter and cold season. In the climate classification according to the Ambergate method, it is part of the middle hot desert climate. The average temperature of the coldest month of the year is 3.4^{o}C. According to available statistics, the absolute maximum temperature of 50.2^{o}C and the absolute minimum temperature of -3^{o}C in January and the average annual minimum temperature of 17.3^{o}C have been reported in the agriculture and industry of Salman Farsi.

3.2. *Characteristics of the soil of the test site*

The physical and chemical characteristics of the test site soil are shown in table 1.

Table 1. Physiochemical characteristics of farm soil before cultivation

Soil depth (cm)	Soil texture	Clay (%)	Silt (%)	Sand (%)	EC (dS.m^{-1})	pH	OM (%)	N (%)	P (ppm)	K (ppm)	BD (g.cm^{-3})
0-30	Clay loam	46.5	41	12.5	2.6	8	0.55	0.07	9.1	181	1.34
0-60	Clay loam	48.5	40	11.5	3.1	7.8	0.36	0.03	6.8	125	1.36

3.3. *Specifications of the experimental design*

The experiment was designed as randomized complete block design (RCBD) with three replications. The studied treatments were control group (untreated, T_1), burning of cold-damaged shoots (T_2), harvesting cold-damaged shoots without hormone consumption (T_3), harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol (T_4), harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol (T_5), spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol (T_6), spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol (T_7).

3.4. *Test execution method*

Each plot has 5 planting lines and two side lines were considered as margins. Three middle lines of each plot were used to measure traits. The implementation of the experiment started on 10 March. In the control treatment, chilled and dried sugarcane were left in the field in the same way, so that with the beginning of the growing season, which is usually after the middle of March, they can revive their leaves and photosynthetic tissues and resume growth. In the sugarcane harvesting treatment, the stems were cut from the crown part and the residues were transferred outside the field.

In the burning treatment, first the sugarcane around the treatment up to a radius of 4m were cut in order to prevent the risk of fire spreading to other parts of the field, and their remains were completely removed from the field. Then, in calm and windless weather and in the safe conditions of the farm, the chilled and dry sugarcane was set on fire. The time of implementation of this treatment was 11.03.2013 and in the stage before the examination of the plant after chilling.

3.5. *Foliar application of paclobutrazol*

Hormonal foliar application was conducted on 25.05.2013 when the sugarcane was at the stage of 50% green area and just before the onset of the rapid growth phase, early in the morning at 5 am. During the hormone application, the green leaves of sugarcane were treated with paclobutrazol at concentrations of 100 and 150 $mg.lit^{-1}$.

3.6. *Characteristics of sugarcane variety CP48-103*

The CP48-103 variety was developed from the cross 296 Co × 320-29CP in 1948 in the Canal Point region of America. It is widely cultivated in various regions around the world, including Iran, Argentina, and Pakistan, due to its excellent sugar and stem yield. This variety is highly valued for its low fiber content and susceptibility to dormancy, which is a result of its high yield. It exhibits remarkable cold tolerance and strong resistance to various diseases. The leaves of CP48-103 are easily separated from its zigzag stems, making it favored by harvester workers. However, the leaves are narrow and vulnerable to damage from hot winds. During processing, the stem color turns yellow. This variety holds significant importance in sugar production, especially in sugarcane cultivation and industries in the northern region of Khuzestan, Iran. Currently, CP48-103 covers approximately 30-50% of the total area dedicated to sugarcane cultivation.

3.7. *Sampling processes*

The sampling process commenced in the second decade of June, coinciding with the primary period of sugarcane growth in Khuzestan and ensuring the impact of hormone application on the plants. Starting from October, the sugarcane ripening process began, accompanied by a decrease in air temperature and a decline in the growth of the sugarcane plant. At this stage, an area equivalent to 0.5 m^{-2} was selected from the three middle rows of each plot to extract and determine the quality parameters of sugar. After extraction using a mill, the percentage of sugar in the sugarcane syrup and the amount of dissolved solids in the syrup were measured in laboratory using a saccharimeter and a refractometer. Additionally, the percentage of syrup purity and percentage of extractable sugar were calculated using recommended formulas.

3.8. *Studied traits*

3.8.1. *Measuring the height of the sugarcane plant*

During the main growth period, the height of the index stem from the soil surface to the end of the stem was measured and recorded.

3.8.1. *Measuring plant nitrogen content using Kjeldahl device*

From each treatment, three stems were harvested at specific stations, and their fourth to sixth leaves were collected. A segment measuring 10-15 cm from the middle of the leaf blade was used for analysis, excluding the main vein and any dried parts of the leaf. To determine the percentage of leaf nitrogen and the amount of chlorophyll, the leaves were cut into pieces and dried in an oven at a temperature of 75°C for 24 hours. Subsequently, the dried leaf samples were processed using the Kjeldahl apparatus to measure the nitrogen content and chlorophyll level.

3.8.2. *Measurement of leaf chlorophyll ratio by chlorophyll meter (SPAD)*

The chlorophyll measurement method with a chlorophyll meter is a spectrophotometric approach conducted in the field. This method allows for non-destructive estimation of chlorophyll concentration per unit area without separating the leaf from the plant. To determine the amount of chlorophyll, readings were taken and averaged using a 504-SPAD model chlorophyll meter from multiple points on leaf blade. This approach ensures a representative measurement of chlorophyll levels without causing harm to leaf or plant.

3.8.3. *Measuring the percentage of sugar in sugarcane syrup (pol)*

To measure the Pol (polarization) in the syrup, 2g of lead acetate was added to 100 ml of the syrup extract. The solution was then filtered using filter paper to obtain a clear extract. Next, the strained extract was placed into the saccharimeter device and the digital screen of the device was fixed. The reading obtained from the saccharimeter device is referred to as the Pol reading or saccharimeter reading. To determine the true polarization (Pol) of the syrup based on the Brix level of the syrup, the correction coefficient of Pol was extracted from the table of correction coefficients. This coefficient was calculated by multiplying the saccharimeter reading by the correction coefficient corresponding to the actual Brix level of the syrup.This process allows for an accurate determination of the Pol content in the syrup, taking into account the specific Brix level and ensuring accurate measurements for sugar content evaluation.

Equ. 1. PTY = POL/BRIX

The syrup quality ratio (Q.R) was calculated through the following formula:

Equ.2. Q.R = (P.F)/POL

In the formula, P.F (Purity Factor) is obtained through the formula and based on the first degree of syrup purity.

Equ.3. P.F = (79.3126×J) / (J÷35/5)

J: the degree of purity of the syrup, which is equal to:

Equ.4. J = pty-1

The number 79.3126 is an empirical and fixed coefficient. The number 35.5 is also given as degree of purity of molasses syrup experimentally in the formula.

3.8.4. *Measuring the percentage of dissolved solids in syrup* (*Brix*)

To measure the percentage of dissolved solids in the syrup (Brix), a few drops of the primary extract were placed on the screen of the brix meter or refractometer. The cover of the screen was closed and the Brix value was allowed to appear on digital screen of device. This value represents the percentage of dissolved solids in extract and was measured using a scientific method commonly employed in such analyses.

3.8.5. *Calculation of syrup purity and extractable sugar percentage* (*R.S*)

In order to determine the degree of purity of sugarcane syrup based on Brix read from table 2 in the appendix of Pine's book, the pol factor was calculated and multiplied by the read pol to get the real pol, the real pol was multiplied by 100 and divided by brix.

Equ.5. Degree of purity of sugarcane syrup = (pol×pol factor×100)/Brix

Pol = the number read by the polarimeter device

Pol Factor = It is obtained with the help of the table and the brix number.

Brix = the number read by the refractometer. Pty (%) = degree of purity of sugarcane syrup. To calculate the percentage of refined sugar, using the relevant tables, divide the purity factor correction factor by the real pol to obtain the quality ratio (QR). Then divide the number 100 by the ratio of quality, and the result is yellow sugar. PF = Purity factor, MP = True bridge, Yield = Yellow sugar percentage yield, Yield = 100/QR, QR = PF/MP. To calculate the sugar yield, the quantity of yellow sugar is multiplied by the coefficient of 0.83 (the coefficient of extraction from yellow sugar to white sugar) to derive the percentage of white sugar (RS%). Subsequently, the cane yield is multiplied by the percentage of white sugar to determine the final product of refined white sugar (SY%).

The RS (%) can be obtained using Equation 6 as follows:

Equ.6. RS (%) = Yield × 0.83.

Using this formula, the sugar yield and cane yield data can be utilized to assess the percentage of white sugar (RS%) and subsequently determine the final refined white sugar product (SY%).

3.9. *Statistical analysis*

Data variance analysis was conducted using the SAS statistical software. The means were compared using Duncan's multiple range method at a significance level of 5% Error probability. Graphs were drawn by Excel software.

4. RESULT AND DISCUSSION

4.1. *The process of plant height changes*

The plant height showed significant differences among the different treatments, as indicated in Table 2. As time progressed from the greening stage, the stem height increased significantly, reaching nearly 150 cm across various treatments (Fig.1). The treatment of harvesting cold-damaged shoots without hormone consumption (T_3) had the highest plant height (with an average of 175 cm). Conversely, the treatments of harvesting cold-damaged shoots and spraying with a solution of 150 $mg.lit^{-1}$ paclobutrazol (T_5), spraying solution on cold-damaged shoots with a concentration of 100 $mg.lit^{-1}$ paclobutrazol (T_6) and spraying solution on cold-damaged shoots with a concentration of 150 $mg.lit^{-1}$ paclobutrazol (T_7) demonstrated the lowest plant height (with an average of 125cm) (Fig.2).

Table 2. Result of analysis of variance effect of treatment on studied traits

S.O.V	df	Plant height	Nitrogen	Phosphorus	Chlorophyll	Syrup percentage	Brix
Replication	2	591.88	1.012	0.011	9.37	33.24	13.5
Treatment	6	1452.7**	7.63*	0.83**	119.45**	127.7*	35.1*
Error	12	466.4	3.20	0.1	8.9	52.87	12.2
CV (%)		13.2	11.5	11.47	10.3	9.25	10.57

^{ns}, * and **: no significant, significant at 5% and 1% of probability level, respectively.

Continue table 2.

S.O.V	df	Sucrose	Syrup purity	Extractable sugar	Stem yield	Sugar yield
Replication	2	4.18	57.53	4.03	20764	2481
Treatment	6	12.62*	51.3^{ns}	27.61**	144329*	11962*
Error	12	4.5	49.78	3.9	55977	5189
CV (%)		6.9	12.1	9.6	16.5	14.3

^{ns}, * and **: no significant, significant at 5% and 1% of probability level, respectively.

At the onset of the growing season, the sugarcane exhibited slow growth. However, once favorable environmental conditions were provided, including higher ambient temperatures, irrigation, increased sunny hours and greater exposure to light, the plant entered a phase of rapid growth. During this phase, the plant's height increased almost linearly and this growth pattern was consistent across all treatments. The rapid growth period commenced from the beginning of July and persisted until the middle of September. This duration highlights that the environmental and soil conditions during this interval were exceptionally conducive to the growth of sugarcane, rendering them optimal compared to other time periods. The combination of these favorable factors contributed to the accelerated and uniform growth of the sugarcane plants during this specific time frame. This situation indicates a positive correlation between the weekly growth and the height increase of the sugarcane plant, aligning with the rise in ambient temperature during the primary growth period. This characteristic is typical of C_4 plants, such as sugarcane. C_4 plants show optimal photosynthesis rates around 35°C. Notably, the maximum weekly growth rate was observed during hotter months of the year (June, July and August), when maximum temperature ranged between 44-45°C (Hunsigi, 2017). This observation further supports notion that sugarcane exhibits accelerated growth in response to higher temperatures, particularly during mentioned months. Mean of stem height (Fig. 1,2) revealed significant difference in stem height for stem harvesting treatment compared to other treatments, including hormone application treatments.

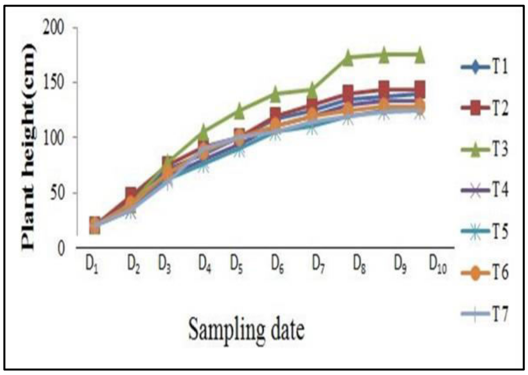

Fig. 1. Plant height changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol. D1: 5 June, D2: 20 June, D3: 6 July, D4: 21 July D5: 6 August, D6: 21 August, D7: 6 September, D8: 21 September, D9: 7 October, D10: 22 October.

This disparity may be attributed to the fact that, under conditions where the plant is exposed to ample light and an open canopy, it experiences rapid growth by efficiently utilizing favorable environmental conditions. Consequently, it reaches the linear phase of growth at a faster rate, thereby compensating for the initial lag in height observed in comparison to the control and hormone-sprayed treatments. Additionally, paclobutrazol treatment contributes to a reduction in plant height and vegetative growth by inhibiting cell division.

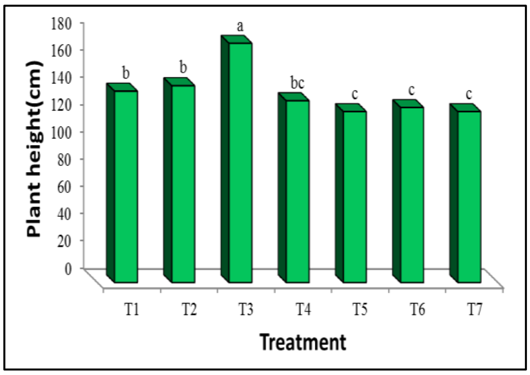

Fig. 2. Effect of different treatments on plant height. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.

In practical farming settings, as the intensity of received light increases, the rate of photosynthesis also escalates, leading to higher yields (Bakker, 1999). In the treatments where hormones were sprayed on the cold-damaged plants and in the control treatments, because the dried plants from the previous season remained on the plant due to the cold weather conditions, as a result, these plants were unable to efficiently utilize the environmental potential and received limited light. Consequently, their height increase per unit of time was lower compared to the harvesting treatments. Based on the higher height observed in the stem harvesting treatment compared to the burning treatment, it can be inferred that the growth conditions were more favorable in the former. This difference in growth could be attributed to the negative effect of fire on the crown part of the plants in the burning treatment. The adverse impact of fire on the crown may have hindered the overall growth and development of the plants in that specific treatment. As a result, the stem harvesting treatment showed better growth conditions, leading to a higher plant height.

4.2. *Chlorophyll*

The trend of chlorophyll changes in different treatments during various growth stages demonstrated an initial increase in chlorophyll content from spring until mid-July, followed by a decline. Towards the end of September, there was a subsequent upward trend, which was later followed by a decrease (Fig.3). According to the results of the analysis of variance, different treatments significantly affected the amount of chlorophyll (Table 2). The treatment of harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol (T_5), followed by harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol (T_4), exhibited the highest chlorophyll content (with an average value of 40). So, the lowest chlorophyll content (with an average of 26) was observed in the treatment involving the burning of cold-damaged shoots (T_2) (Fig.4). These findings suggest the different treatments had a notable impact on chlorophyll levels in sugarcane throughout their growth stages.

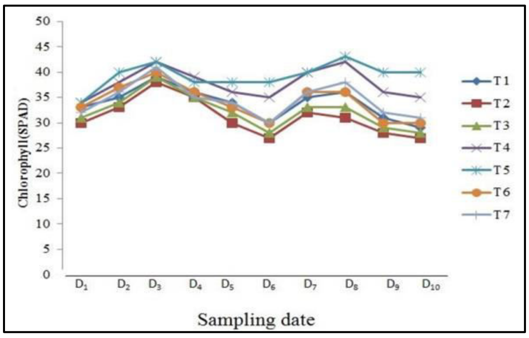

Fig. 3. Chlorophyll changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with 150 mg.lit^{-1} paclobutrazol. D1: 5 June, D2: 20 June, D3: 6 July, D4: 21 July D5: 6 August, D6: 21 August, D7: 6 September, D8: 21 September, D9: 7 October, D10: 22 October.

The chlorophyll level fluctuated significantly throughout the season. The noticeable increase in chlorophyll during mid-August and early September suggests improved growth conditions during that period. As a result, the plant responded by increasing chlorophyll production in its leaves, leading to higher carbohydrate accumulation and promoting rapid growth. So, when irrigation was stopped, plants experienced stress. The initial responses to this stress in plants are the reduction of chlorophyll in the leaves, allowing the plant to cope with adverse conditions.

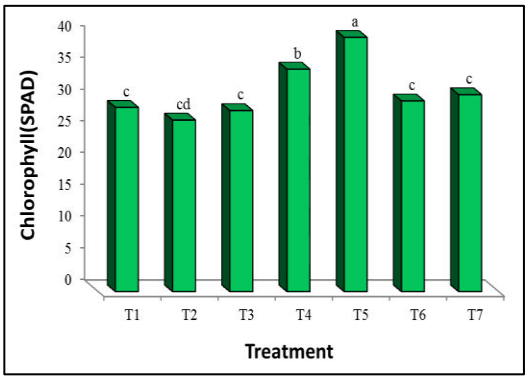

Fig. 4. Effect of different treatments on chlorophyll. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T_1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 $mg.lit^{-1}$ paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 $mg.lit^{-1}$ paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 $mg.lit^{-1}$ paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 $mg.lit^{-1}$ paclobutrazol.

Consequently, there was an immediate decrease in chlorophyll content. Once the stress was removed by resuming irrigation, the chlorophyll level in the leaves gradually returned to its pre-stress level. The hormone application treatment showed a statistically significant difference in terms of chlorophyll content compared to the control and burning of cold-damaged shoots treatments. These findings align with previous research conducted by other researchers, which also reported the positive effects of paclobutrazol on plant chlorophyll content (Baachi *et al*., 1977; Burunson and White, 1986; Saroop *et al*., 2006).

4.3. *Nitrogen and phosphorus*

The trend of nitrogen and phosphorus changes in different samplings and treatments displayed variations. Among the different treatments, the changes in the amount of nitrogen showed minor differences. The highest amount of nitrogen was observed in the sampling conducted on July 6, after which it exhibited a decline (Fig.5).

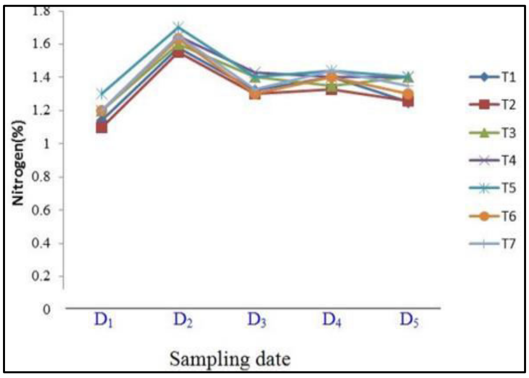

Fig. 5. Nitrogen changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control(untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 $mg.lit^{-1}$ paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 $mg.lit^{-1}$ paclobutrazol, T6: spraying solution on cold-damaged shoots with 100 $mg.lit^{-1}$ paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 $mg.lit^{-1}$ paclobutrazol. D_1: 5 June, D_2: 6 July, D_3: 6 August, D_4: 6 September, D_5: 7 October.

The results of analysis of variance indicated that the effect of different treatments on leaf nitrogen content was significant at the 5% of probability level, While the effect on phosphorus content was significant at the 1% of probability level (Table 2). Among the different treatments, the highest amount of nitrogen (with an average of 1.4%) was obtained from the treatments involving harvesting cold-damaged shoots without hormone consumption (T3), harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol (T_4) and harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol (T_5) (Fig.6).

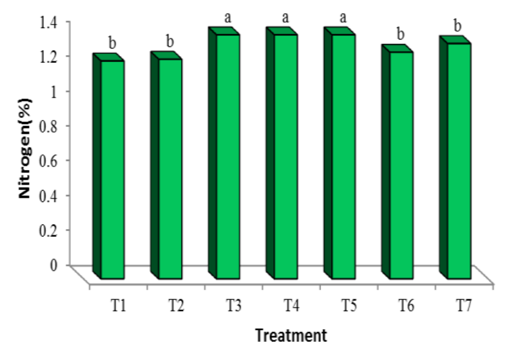

Fig. 6. Effect of different treatments on leaf nitrogen percentage. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.

The amount of phosphorus also varied at different sampling times, with the highest amount observed in treatments T_1, T_2 and T_3 during September and the lowest amount recorded on June 5 (Fig.7). Additionally, the amount of phosphorus differed among the various treatments, with the highest amount found in the treatment involving the burning of cold-damaged shoots (T_2) with an average of 0.15 and the lowest amount in the treatment involving harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol (T_5) with an average of 0.09 (Fig.8).

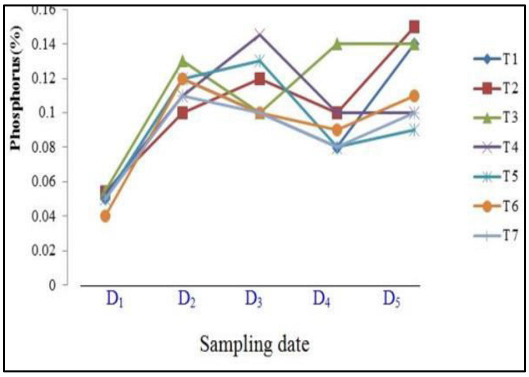

Fig. 7. Phosphorus changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control(untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol. D_1: 5 June, D_2: 6 July, D_3: 6 August, D_4: 6 September, D_5: 7 October.

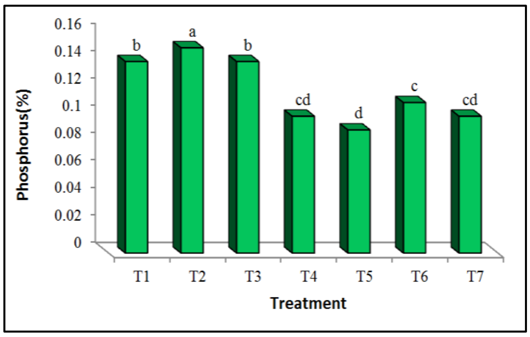

Fig. 8. Effect of different treatments on phosphorus percentage. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 $mg.lit^{-1}$ paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 $mg.lit^{-1}$ paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 $mg.lit^{-1}$ paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 $mg.lit^{-1}$ paclobutrazol.

Examining Fig. 5 and the nitrogen values of leaves in different treatments reveals that at the beginning of the season, the plant resumes its growth after chilling and requires abundant food resources, especially nitrogen, to support its growth. Since the soils at the start of the plant's regrowth have an ample supply of nutrients and fertilizers are applied at the beginning of the crop year, the plant has access to sufficient nitrogen. Consequently, the nitrogen level in the plant increases significantly during this period and this increase in nitrogen content is positively correlated with the plant's growth and height. In the middle of the season, due to non-irrigation, the plant experiences moisture stress, leading to decreased root absorption and subsequently, a reduction in the nitrogen level of the plant. This decrease in nitrogen content serves as one of the plant's strategies to cope with the stress caused by limited water availability. However, as the moisture stress is partially alleviated and irrigation resumes, the plant's root absorption improves, leading to an increase in the nitrogen level of the plant once again. At the end of the stem elongation period, which coincides with the onset of sugar accumulation in the sugarcane stem, the amount of nitrogen in the plant decreases, which is considered a positive trait in sugarcane plants? This decrease in nitrogen content is desirable because a higher percentage of mineral elements in the plant and subsequently in the sugarcane extract, results in lower nitrogen content. Lower nitrogen content is beneficial for the sugar production process. Regarding the critical and minimum levels of nitrogen required for sufficient and appropriate growth, it was observed that throughout the season, all treatments did not have a sufficient amount of nitrogen. This deficiency in nitrogen content may be attributed to specific conditions during the experiment year, such as a sharp decrease in water resources and reduced field irrigation. The amount of phosphorus increased throughout the growing season, which can be attributed to the favorable environmental and climatic conditions, especially suitable temperatures (Fig.8). However, during the middle of the stem elongation period, non-irrigation and high ambient temperatures caused stress to the plant, leading to a decrease in phosphorus absorption due to reduced root uptake to cope with the stress. Once the stress was alleviated, phosphorus absorption showed an increasing trend again. Throughout the growing season, the sugarcane plant faced limitations in terms of phosphorus availability in its organs, especially in the leaves, along with nitrogen. However, it is worth noting that the treatment involving burning the stems showed a higher amount of phosphorus. This can be explained by the fact that burning chilled and dry plants in field resulted in deposition of some phosphorus-containing elements (present in the ash produced by burning the plant) in to the soil. When the soil was watered, these elements penetrated soil, thereby increasing phosphorus absorption by plant.

4.4. *Syrup percentage*

The percentage of syrup varied in different seasons and exhibited an upward trend in all treatments from October 7 to December 6. The lowest amounts of syrup were recorded on October 7 and then it increased on December 6 (Fig.9). The results of the analysis of variance also indicated a significant difference between different treatments at the 5% of probability level in terms of syrup percentage (Table 2). The treatment involving burning (T_2) had the highest amount of syrup among different treatments, with an average of 31%. On the other hand, the treatment of harvesting cold-damaged shoots without hormone consumption (T_3) had the lowest amount of syrup, with an average of 28% (Fig.10).

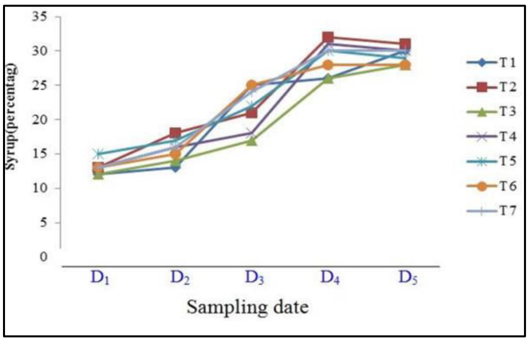

Fig. 9. Syrup percentage changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4 : harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol. D_1: 7 October, D_2: 22 October, D_3: 6 November, D_4: 21 November, D_5: 6 December.

From the early stage of extensive sugar production in sugarcane stems, this characteristic showed a general increase in all treatments. The increase in syrup percentage continues until the end of the season and harvest time, as long as the plant is not subjected to chilling stress during this stage, and this increase has a direct relationship with the amount of sugar extraction from sugarcane. As the amount of syrup in the sugarcane stems increases, the same amount of extracted sugar also increases.

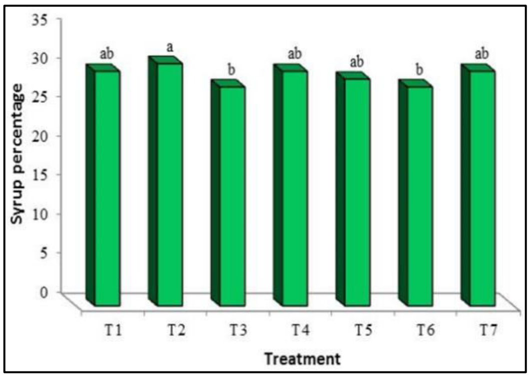

Fig. 10. Effect of different treatments on syrup percentage. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.

In terms of this characteristic, despite the higher percentage of syrup in the burning treatment, no significant differences were observed among treatments.

4.5. *Brix percentage*

The Brix percentage showed a downward trend during the period from October 7 to December 6. The highest brix percentage belonged to harvesting cold-damaged shoots and spraying by 150 mg.lit^{-1} of paclobutrazol (Fig.11). The results of the analysis of variance showed that the effect of treatments on brix percentage was significant at the 5% of probability level (Table 2).

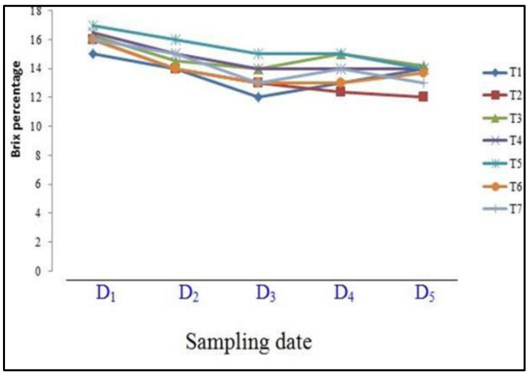

Fig. 11. Brix percentage changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4 : harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol. D_1: 7 October, D_2: 22 October, D_3: 6 November, D_4: 21 November, D_5: 6 December.

The lowest Brix percentage was obtained from burning the stems, and other treatments did not show a significant difference in terms of brix percentage (Fig.12). One of the most important analytical steps in extracting sugar from sugarcane is estimating the solid content in a solution. This work has been carried out for years through hydrometric, which involves measuring the density of an intermediate solution and the final products of the sugar industry. The density of the solution containing pure sucrose and water is directly related to its concentration.

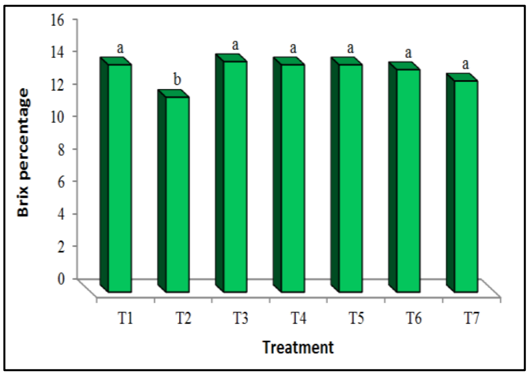

Fig. 12. Effect of different treatments on brix percentage. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 $mg.lit^{-1}$ paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 $mg.lit^{-1}$ paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 $mg.lit^{-1}$ paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 $mg.lit^{-1}$ paclobutrazol.

Therefore, by adjusting the scale of density changes, it becomes possible to quickly and easily determine the sucrose content in this solution. This scale is known as the brix scale. In the graphs of different treatments dealing with the changes in the brix percentage, it was found that the brix percentage had a weak decreasing trend simultaneously with the changes in the amount of sugar accumulated in the stem. Considering that an inverse relationship exists between brix percentage and syrup purity, this observation can be explained by the increase in syrup purity as the sugarcane ripens and approaches harvest time (Blackburn, 1984). In other words, the syrup purity percentage, which is one of the important factors in determining the maximum purity of sugarcane at harvest time, is calculated by dividing the sucrose percentage by the brix percentage. Mathematically, there are three ways to increase the syrup purity percentage expected: 1- Sucrose amount remains constant and brix percentage decreases.
2- Brix percentage remains constant and sucrose increases.
3- The increase of both during the season, so that the increase in sucrose is greater than the percentage of brix. During years with favorable climatic conditions and no moisture stress, the third condition arises. However, in the year of the research, due to severe droughts both nationwide and in Khuzestan province, sugarcane is facing limited water resources and under these conditions, the first condition occurred (brix percentage reduction), indicating unfavorable conditions for the plant. Among the different treatments, the lowest amount of brix was related to the treatment of burning sugarcane stems, which may have resulted in the burning of stressed plants, causing disturbances in physiological processes and interactions related to brix and significantly reducing this attribute compared to other treatments.

4.6. *Sucrose percentage*

The sucrose percentage showed a significant increase in different treatments from October 7 to 22. However, after that period, it exhibited an almost constant trend, except in the control and burning treatments (T_1 and T_2) (Fig.13).

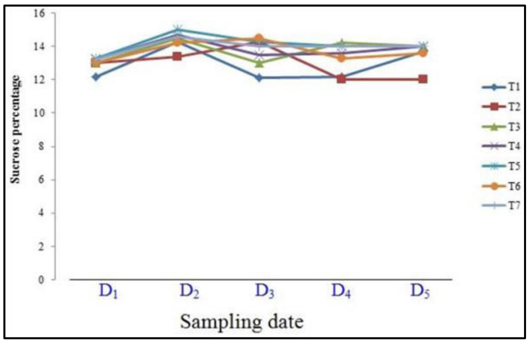

Fig. 13. Sucrose percentage changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol. D_1: 7 October, D_2: 22 October, D_3: 6 November, D_4: 21 November, D_5: 6 December.

The results of the analysis of variance indicated a significant effect of the treatments on the sucrose percentage at the 5% of probability level (Table 2). Among the various treatments, the lowest sucrose percentage (averaging 11%) was observed in the burning stem treatment. Other treatments did not show significant differences in terms of sucrose percentage and their sucrose percentages were nearly identical (Fig.14). As seen in the charts related to sucrose changes, the percentage of sucrose in sugarcane extract increased over time. According to the information about brix percentage and its relationship with sucrose percentage and syrup purity, it was concluded that with small increase in sucrose percentage and a simultaneous decrease in brix percentage, syrup purity percentage increases. This phenomenon was almost the same in all treatments, except for burning treatment. There was no significant difference between different treatments regarding this parameter (Fig.14).

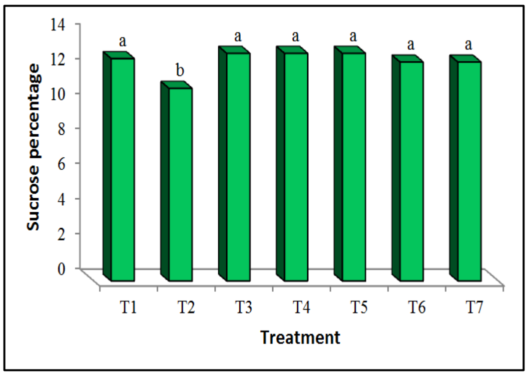

Fig. 14. Effect of different treatments on sucrose percentage. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots by 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.

4.7. *Syrup purity percentage*

The lowest syrup purity percentage was observed on October 7, while the highest occurred on December 6 (Fig.15). Regarding the different treatments, they did not show a significant impact on the syrup purity percentage.

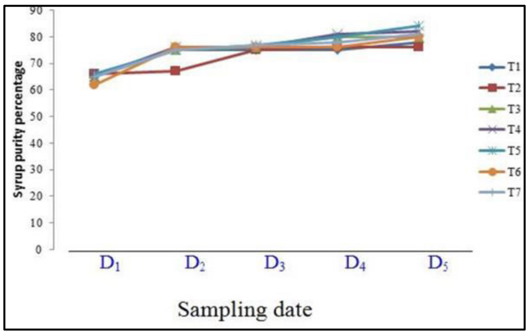

Fig. 15. Syrup purity percentage changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol. D1: 7 October, D2: 22 October, D3: 6 November, D4: 21 November, D5: 6 December.

The average syrup purity percentage across various treatments remained nearly the same and no statistically significant difference was found between the treatments (Fig.16). The syrup purity percentage is one of the most critical factors for evaluating the condition of the sugarcane crop before harvesting and processing. This characteristic has shown an increase over time, which can be divided into two phases: During the first phase of the increase, as mentioned in relation to two factors, namely brix percentage and sucrose percentage, the rise in syrup purity was due to a small increase in sucrose percentage, while there was a simultaneous decrease in brix percentage. Subsequently, the second phase of increase commenced during the final ripening stage of the plant and continued until harvest. This pattern was consistently observed across all investigated treatments. Concerning the percentage of syrup purity, no significant difference was observed between the various investigated treatments.

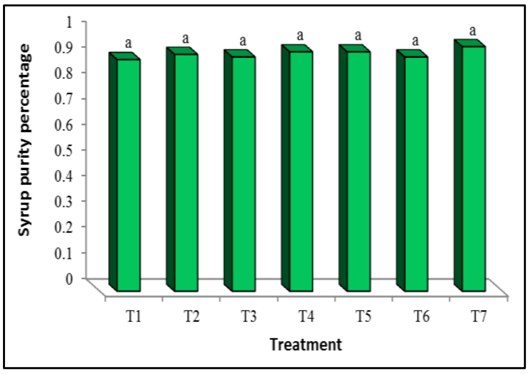

Fig. 16. Effect of different treatments on syrup purity percentage. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.

4.8. *Extractable sugar percentage*

The extractable sugar percentage was low in mid-October, then increased towards late October and continued to decline until mid-November. Finally, on December 6, it reached its maximum level (Fig.17).

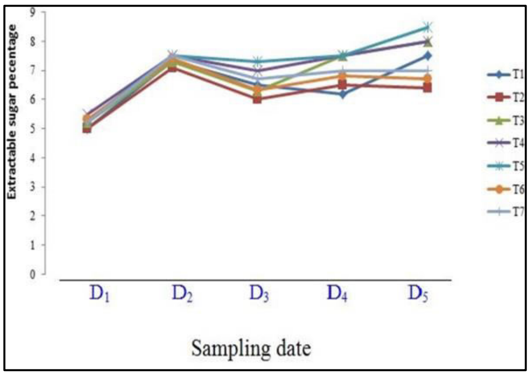

Fig. 17. Extractable sugar percentage changes in different treatments during growth period. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol. D1: October 7, D2: October 22, D3: November 6, D4: November 21, D5: December 6.

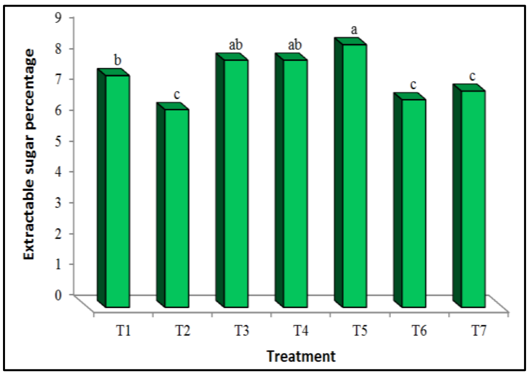

Fig. 18. Effect of different treatments on extractable sugar percentage. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control(untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.

The effect of treatments on the extractable sugar percentage was significant at the 1% of probability level (Table 2). The treatment involving harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol (T_5) showed the highest amount of extractable sugar (with an average of 8.5%). On the other hand, the burning of sugarcane stems (T_2) exhibited the lowest amount of extractable sugar (with an average of 6.4%) (Fig.18).

4.9. *Stem yield*

The results of the analysis of variance showed the effect of treatments on stem yield was significant at the 5% of probability level (Table 2). Among the different treatments, the highest stem yield (with an average of 59775 kg.ha^{-1}) was observed in the treatment involving the harvesting of cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} of paclobutrazol (T_5). The lowest stem yield (with average of 51277 kg.ha^{-1}) was assigned to the control treatment (T_1). No significant difference was observed between the treatments T_3, T_4 and T_5 in terms of stem yield (Fig.19).

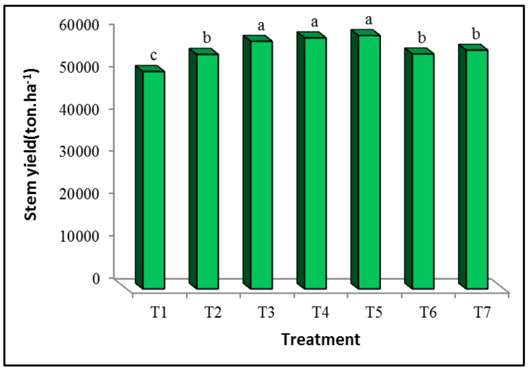

Fig. 19. Effect of different treatments on stem yield. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control (untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.

4.10. *Sugar yield*

The results of the analysis of variance indicated that the different treatments had a significant effect on sugar yield at the 5% of probability level (Table 2). The highest sugar yield (with an average of 5100 kg.ha^{-1}) was achieved by harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} of paclobutrazol (T_5), while the control treatment (T_1) and burning of stems (T_2) had the lowest sugar yield, averaging 4113 and 4255 kg.ha^{-1}, respectively (Fig.20).

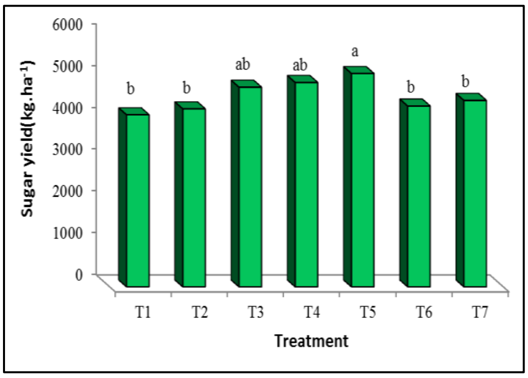

Fig. 20. Effect of different treatments on sugar yield. Mean which have at least once common letter are not significant different at the 5% level using (DMRT). T1: control(untreated), T2: burning of cold-damaged shoots, T3: harvesting cold-damaged shoots without hormone consumption, T4: harvesting cold-damaged shoots and spraying with a solution of 100 mg.lit^{-1} paclobutrazol, T5: harvesting cold-damaged shoots and spraying with a solution of 150 mg.lit^{-1} paclobutrazol, T6: spraying solution on cold-damaged shoots with a concentration of 100 mg.lit^{-1} paclobutrazol, T7: spraying solution on cold-damaged shoots with a concentration of 150 mg.lit^{-1} paclobutrazol.

5. CONCLUSION

Based on the results, it was observed that harvesting sugarcane stems with hormone foliar application resulted in the highest stem yield, primarily due to the positive effect of paclobutrazol in mitigating the adverse effects of cold stress. Considering the relatively low cost of providing paclobutrazol, it is recommended to use this treatment during years when sugarcane fields face cold or chilling problems.

This approach can effectively reduce the negative impacts of cold stress and lead to higher stem yields. Moreover, the treatments exhibited significant differences concerning the amount of sugar production. Although the treatment involving harvesting stems with foliar application showed superiority in terms of the quantity of harvested stems and was significantly different from other treatments, the high percentage of extractable sugar in this treatment also contributed to the higher stem yield. This indicates that the combination of harvesting stems with foliar application not only increases the quantity of harvested stems but also enhances the sugar content of the stems, resulting in higher sugar production. Furthermore, the study revealed that there was no significant difference in yield between foliar application on cold-damaged and burned plants. Considering the labor and machine costs associated with harvesting, as well as the environmental pollution caused by burning fields affected by cold or chilling injury, it is recommended to leave such fields for regrowth without charging fees for field harvesting. This approach proves to be more economically viable and environmentally friendly. Regarding the treatment of sugarcane harvesting, it demonstrated superiority over other treatments in terms of various investigated traits. This treatment, although more susceptible in terms of tiller (stem) production and significantly different from other treatments in this regard, resulted in a higher number of sugarcane stems per unit area. This factor plays a crucial role in influencing sugar production and other by-products in sugarcane cultivation, which is the primary objective of growing sugarcane. Therefore, this method proves to be effective in mitigating the impact of chilling injury during similar years while maintaining sugar yield. By adopting this approach, the cost of treating chilling injury can be minimized in an economically reasonable and affordable manner. It provides an effective strategy to cope with cold stress and optimize sugarcane production while considering both economic and environmental factors.

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FOOTNOTES

AUTHORS' CONTRIBUTION: All authors are equally involved.

CONFLICT OF INTEREST: Authors declared no conflict of interest.

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