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RESEARCH ARTICLE

# Response of sugar beet varieties to plant geometrical distribution

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**Abstract** Sugar beet is the most important sugar crop that can be grown commercially in a wide variety of temperate regions. The beet sugar industry in the tropical and subtropical regions, which are mostly developing countries is growing as an important component of sugar production. A field experiment was conducted at Delta Sugar Company Research Farm, El-Hamool, Kafr El- Sheikh, Egypt to evaluate the response of sugar beet varieties to inter- and intra-row distances. The analysis of variance (ANOVA) revealed significant effects of inter- and intra-row distances on all studied traits, i.e., sucrose content (Pol%), Na%, K%, α-amino-N%, quality index (Qz)%, root yield (RY), recoverable sugar (RS)%, recoverable sugar yield (RSY), sugar loss (SL)% and sugar loss yield (SLY) either in one or both growing seasons except for the effect of inter-row planting distances on Na% and loss sugar yield in both growing seasons. The results revealed that increasing the inter-row planting distance from 50 to 60 cm led to a significant reduction in sucrose content, Na%, RY, RS% and RSY. However, increasing the inter-row planting distance from 50 to 60 cm is associated with a significant reduction in the Qz%, RS%, SL% and SLY. Increasing the intra-row planting distances from 10 to 15 cm led to a significant reduction in sucrose%, Na%, Qz% and RS%. Additionally, significant variations in all studied traits were observed among varieties. The interactions between the studies factors and varieties exhibited significant effects on all studied traits. Planting the variety Garrot at 15 and 50 cm intra- and inter-row distances produced the highest Qz%, RY and RSY. The lowest SLY resulted from planting the sugar beet variety Husam at 10 and 60 cm intra- and inter-row planting distances. The results of the present study of great importance for a sustainable production of sugar beet in Egypt.

**Keywords:** *Beta vulgaris*; Planting density; Planting distances; Root yield; Beet quality; Sugar yield.

## Introduction

Sugar beet (*Beta vulgaris*, L.) is the first source of sugar in Egypt. It was introduced to the Egyptian agricultural system in the early 1980's. Recently, it has acquired more importance and has become an important source of refined sugar in Egypt. The total sugar beet cultivated area in Egypt exceeds 600,000 feddan, producing about 20 million Mt of sugar beets with an average sucrose content of about 18% (www.fao.org 2020; Abou-Elwafa et al. 2020). Sugar beet is the most important sugar crop that can be grown commercially in a wide variety of temperate regions. The beet sugar industry in the tropical and subtropical regions, which are mostly developing countries, including Egypt, is growing as an important component of sugar production (Balakrishnan and Selvakumar 2009; Abou-Elwafa et al. 2020).

Recently, extensive efforts have been made to cultivate and adapt sugar beet in tropical and subtropical countries in order to replace or supplement the sugar production from sugarcane, which is dominating the industry for the following reasons: 1) It has a lower irrigation requirement, which is an important factor in determining sustainable cultivation in arid and semi-arid regions. Furthermore, studies showed that: root and sugar yields were not significantly reduced as low as 70% of the optimum water requirement; 2) sugar beet has a shorter growing season (5–6 months) compared to sugarcane, which is approximately 12 months; and 3)

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sugar beet could be a possible solution as tolerant crops of soil alkalinity or of newly reclaimed soils are common in arid and semi-arid regions that are not suitable for sugarcane or other crops (Balakrishnan and Selvakumar 2009; Abo-Elwafa et al. 2013; Abo-Elwafa et al. 2020; Abofard et al. 2021). Additionally, cultivation of sugar beet in developing countries could be profitable for farmers in two ways: 1) by diversifying their incomes by enabling them to grow an additional cash crop, and 2) by supplying sugar factories with raw material in addition to the sugar cane that will extend the factories' supply for up to 10 months of the year (Abou-Elwafa et al. 2020; Balakrishnan and Selvakumar 2009; Mandere et al. 2010). Selecting the most suitable agronomical practices, which differ from region to region according to climatic conditions, is essential for sustainable production and cultivation of sugar beet. Furthermore, it was demonstrated that the root yield of sugar beet is highly related not only to the number of plants per unit area but also to the adapted agronomical practices for increasing growth and yield that result from sowing method, seed treatment, planting dates, soil fertility, climatic conditions, varieties, and pest control (Abd Elrahim et al. 2005). Improving the potential sugar and root yields of sugar beet seemed to be a slow process and restricted because of the negative correlation between sucrose concentration and root yield as well as the need to maintain an acceptable level of sucrose concentration. Several studies have been carried out to find the proper technical recommendations for improving the productivity and quality of sugar beet under different conditions (Curcic et al. 2018; Gameh et al. 2020). Research on the extent to which plant density influences the growth and formation of leaf area in particular development stages, especially those decisive for the yield and quality of sugar beet seed, has major scientific and production importance since it contributes to better seed utilization in final processing. It is thought that the number and distribution of plants per unit area, as well as appropriate fertilization, are controllable problems in the technological production process of all field crops, especially in sugar beet seed production.

The adverse consequences of climate change and global warming negatively affect the productivity and quality of crop plants, including sugar beet, and greatly impact sustainable agricultural production. The identification of the most suitable planting date for sugar beet is pivotal for sustainable production and cultivation of sugar beet (Curcic et al. 2018). However, taking into account some other influencing factors such as pests' activity and marketing and industrial-related considerations, the most suitable planting date is defined as the time of sowing that enables the crop to achieve the required heat units without excessive heat-or cold-shocks (Abdallah 2012; Alsadon 2002). Plant density and geometrical distribution of plants (bed width and hill spacing), which are crucial for the conservation of water and the efficient use of fertilizers, have to be taken into account for improving the productivity and quality of sugar beet. Sugar beet grown in ridges or bed systems gave the highest values of root length and diameter, root weight, sucrose%, and quality index, as well as root and recoverable sugar yields (Abdou and Salim 2008). Smooth root sugar beet genotypes responded to plant density in different environments similarly to adapted standard root commercial cultivars.

Therefore, the present investigation was carried out to study the response of four sugar beet varieties to geometrical distribution, i.e., intra- and inter-row planting distances, in terms of yield and quality.

## Materials and methods

### Plant material and field experiments

This study was conducted at the Agricultural Research Farm of the Delta Sugar Company, El-Hamoul, Kafr El-Sheikh, Egypt (31° 92′ N, 31° 14′ E, 14 m asl), in the two successful growing seasons 2019/2020 and 2020/2021 to investigate the yield and quality response of four sugar beet genotypes to geometrical distribution, i.e., row width and planting spacing.

The randomized complete block design (RCBD) in a split-split plot arrangement with three replicates was employed in this investigation. In the field experiment, two row widths of 50 and 60 cm were allocated to the main plots, whereas the two planting distances (10 and 15 cm) were allocated to the sub-plots. Four commercial sugar beet varieties, i.e., the two monogerm seeds cultivars designated as Nimaless and Garrot, and two multigerm cultivars designated as Husam and Karam, were allocated to the sub-sub plots in both growing seasons. The plot area in the case of 50 cm row width was (32.00 $m^2$), including eight rows, each of 8 m long. Meanwhile, in the case of 60 cm row width, the plot area was (33.60 $m^2$), including seven rows, each of 8 m long.

Plants were grown on October 3$^{rd}$, 2019 and 2020 and harvested on May 3$^{rd}$, 2020 and 2021 in the first and second growing seasons, respectively. Seeds from either the monogerm and multigerm sugar beet cultivars were sown by machine at the rate of one seed per hill. Recommended doses of N, P and K and all other cultural practices were performed according to locally recommended practices for sugar beet production. In brief, single super phosphate (15.5% $P_2O_5$) at a rate of 200 kg $fed^{-1}$. was applied during soil bed preparation. Nitrogen in the form of urea (46.5% N) at a rate of 120 kg $fed^{-1}$. was applied in two equal doses, i.e., the first one after 45 days from the sowing, and the second one was applied 30 days later. Potassium sulphate (50% $K_2O$) at the rate of 100 kg $fed^{-1}$. was added with the first irrigation. Other agronomical practices were performed as locally recommended for sugar beet cultivation and production. The preceding crop was rice in both seasons.

**Soil analysis of the experimental sites**

Composite represented soil (0-30 cm) samples were randomly collected from the experimental sites before sowing and after harvest and prepared for both physical and chemical analysis. Samples were air dried, ground and finally were sieved using 2 mm sieves to determine the physical and chemical properties. Mechanical analysis was determined according to the international pipette method (Piper 1950). Soil pH was measured in (1: 2.5) soil: water suspension using HannapH-meter (Jackson 1967). Total soluble salts were determined by measuring the electrical conductivity ($EC_e$) by electrical conductivity meter (EC meter model consort 410) in saturation extract of soil in dS/ m, United States Salinity Laboratory staff (Richards 1954). Total carbonates were determined using Collins calcimeter (Dexter et al. 1967). Organic matter was determined by Walkley and Blacks method (Hesse and Hesse 1971). The basic physical and chemical properties of the experimental soils are presented in Table 1.

**Table 1** Basic physical and chemical properties of the experimental soils in 2019/20 and 2020/21 growing season.

| variable | 2019/2020 growing season | | 2020/2021 growing season | |
|---|---|---|---|---|
| | Before planting | Post - harvest | Before planting | Post - harvest |
| Physical properties | | | | |
| Sand % | 24.50 | 26.29 | 25.23 | 26.44 |
| Silt % | 22.55 | 23.43 | 21.51 | 22.63 |
| Clay % | 52.56 | 50.33 | 51.79 | 49.80 |
| Texture class | Clay | Clay | Clay | Clay |
| Chemical analysis | | | | |
| Soil pH (1 :2.5 susp.) | 8.10 | 8.03 | 8.40 | 7.95 |
| EC (dS $m^{-1}$) | 5.61 | 5.32 | 5.33 | 5.01 |
| Organic matter % | 1.32 | 1.24 | 1.41 | 1.19 |
| Available N ppm | 16.75 | 16.10 | 16.82 | 16.30 |
| Available P ppm | 10.40 | 10.23 | 10.51 | 10.21 |
| Available K ppm | 376 | 357 | 373 | 352 |
| Soluble cations (meq $L^{-1}$) | | | | |
| Ca++ | 5.20 | 5.63 | 5.19 | 5.39 |
| Mg++ | 6.47 | 7.02 | 6.25 | 7.00 |
| Na+ | 45.10 | 41.51 | 45.03 | 40.93 |
| K+ | 1.32 | 1.15 | 1.47 | 1.24 |
| Soluble anions (meq $L^{-1}$) | | | | |
| $HCO^{-}_3$ | 3.74 | 3.54 | 3.65 | 34.70 |
| $CI^{-}$ | 32.12 | 29.89 | 31.67 | 29.50 |
| $SO^{-}_4$ | 15.04 | 13.34 | 14.98 | 14.00 |
| $CO^{-}_3$ | 0.00 | 0.00 | 0.00 | 0.00 |

**Phenotypic evaluation**

At harvest, only the central area of the plots was considered for determining yield and quality traits. In the case of 50 cm intra-row spacing, plot was considered as the 6 inner rows of 7 m in length to yield an area of 21 $m^2$. Meanwhile, in the case of 60 cm intra-row spacing, plot was considered as the 5 inner rows of 7 m in length to yield the same plot area of 21 $m^2$. A representative root sample of about 20 kg of roots from each plot was used for juice quality analysis by measuring sucrose%, potassium (K)%, sodium (Na)% and α-amino-N% in the root juice. Root juice quality parameters were estimated using the venma, Automation BV AnalyzerIIG-16-12-99, 9716JP/ Groningen/Holland at Delta Sugar Company Limited Laboratories according to the procedure used by Le Docte (1927) and Brown and Lilland (1964). Quality index, sucrose losses%, and sugar loss yield were calculated using the following equations according to Reinefeld et al. (1974).

**Table 2** Analysis of variance for inter- and intra-row planting distances, varieties and their interactions on evaluated traits in the 2019/2020 and 2020/2021 growing seasons.

| S.O.V. | d.f. | Sucrose% | | Na% | | K% | | α-amino-N% | | Qz (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 |
| Blocks | 2 | 0.134ns | 0.164ns | 0.008ns | 0.001ns | 0.001ns | 0.017ns | 0.007ns | 0.024ns | 1.049ns | 0.165ns |
| Intra-row distance (R) | 1 | 3.780** | 0.605ns | 0.034ns | 0.001ns | 0.057** | 0.011ns | 0.486** | 1.144ns | 18.266** | 22.688ns |
| Main plot error | 2 | 0.011 | 0.022 | 0.003 | 0.001 | 0.001 | 0.001 | 0.004 | 0.019 | 0.007 | 0.375 |
| Inter-row distance (P) | 1 | 10.038** | 3.045* | 0.389** | 0.063* | 0.096* | 0.118ns | 0.684** | 1.798** | 17.148*** | 30.624** |
| RXP | 1 | 0.039ns | 0.758ns | 0.001ns | 0.001ns | 0.095* | 0.029ns | 0.016ns | 0.248ns | 0.196ns | 1.110ns |
| Sub plot error | 4 | 0.016 | 0.031 | 0.006 | 0.001 | 0.005 | 0.002 | 0.008 | 0.007 | 0.005 | 0.1 |
| Varieties | 3 | 16.047** | 13.96** | 0.348** | 0.161** | 0.115** | 0.043** | 4.788** | 0.599** | 104.691*** | 31.02*** |
| R×V | 3 | 0.014ns | 0.143ns | 0.002ns | 0.008ns | 0.036** | 0.013* | 0.408** | 0.037ns | 4.829*** | 1.935ns |
| P×V | 3 | 0.349** | 0.174ns | 0.040** | 0.046** | 0.025** | 0.014* | 0.226** | 0.032ns | 6.055*** | 1.865ns |
| R×P×V | 3 | 0.086ns | 0.105ns | 0.001ns | 0.012* | 0.073** | 0.051** | 0.024ns | 0.089ns | 0.990* | 1.198ns |
| Error | 24 | 0.036 | 0.049 | 0.003 | 0.001 | 0.003 | 0.001 | 0.015 | 0.01 | 0.027 | 0.21 |

**Table 2** Cont.

| S.O.V. | d.f. | RY | | RS% | | SL% | | RSY | | LSY | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 |
| Blocks | 2 | 0.069ns | 0.767ns | 0.016ns | 0.231ns | 0.002ns | 0.069ns | 0.767ns | 0.016ns | 0.231ns | 0.002ns |
| Intra-row distance (R) | 1 | 16.101** | 8.501ns | 6.380** | 0.538ns | 0.429** | 16.101** | 8.501ns | 6.380** | 0.538ns | 0.429** |
| Main plot error | 2 | 0.023 | 0.081 | 0.006 | 0.024 | 0.004 | 0.023 | 0.081 | 0.006 | 0.024 | 0.004 |
| Inter-row distance (P) | 1 | 1160.3** | 1065.9** | 15.233** | 3.040* | 0.403** | 1160.3** | 1065.9** | 15.233** | 3.040* | 0.403** |
| RXP | 1 | 0.068ns | 0.333ns | 0.027* | 1.050ns | 0.062* | 0.068ns | 0.333ns | 0.027* | 1.050ns | 0.062* |
| Sub plot error | 4 | 0.039 | 0.01 | 0.002 | 0.032 | 0.004 | 0.039 | 0.01 | 0.002 | 0.032 | 0.004 |
| Varieties | 3 | 442.4** | 378.7** | 23.69** | 14.59** | 0.675** | 442.4** | 378.7** | 23.69** | 14.59** | 0.675** |
| R×V | 3 | 0.125ns | 0.233ns | 0.006ns | 0.175ns | 0.021** | 0.125ns | 0.233ns | 0.006ns | 0.175ns | 0.021** |
| P×V | 3 | 5.621** | 23.88** | 0.717** | 0.159ns | 0.216** | 5.621** | 23.88** | 0.717** | 0.159ns | 0.216** |
| R×P×V | 3 | 0.097ns | 1.142ns | 0.109** | 0.102ns | 0.018** | 0.097ns | 1.142ns | 0.109** | 0.102ns | 0.018** |
| Error | 24 | 0.058 | 0.075 | 0.015 | 0.046 | 0.003 | 0.058 | 0.075 | 0.015 | 0.046 | 0.003 |

*, ** and ns denote significant, highly significant and non-significant effects, respectively

The following yield and quality traits were estimated:

1. Root and yield (ton fed$^{-1}$):

Roots yield (ton fed$^{-1}$) after (210 days from sowing) plants of sugar beet from the inner beds of each subplot (21.0 m$^2$) were harvested, topped and cleaned to determine roots yield as ton fed$^{-1}$ on fresh weight basis.

2. Sucrose content (Pol%).
3. Sodium content (Na%).
4. Potassium content (K%).
5. α-amino-N (%).
6. Quality index (Qz%), was calculated according to the following formula:

$$\text{Quality }\% = Pol\% - 0.29 + 0.343\,(K + Na) + 0.0939(\alpha - amino\ N)x100/Pol\%$$

7. Recoverable sugar (RS%), was calculated according to the following formula:

$$\text{Sugar recovery}\% = \text{Pol} - 0.29 - 0.343(\text{K} + \text{Na} - 0.094(-\text{amino N})$$

8. Sugar losses (SL%), was calculated according to the following formula:

$$\text{Sugar loss } = 0.343(K + Na) + 0.094(\alpha - amino\ N) + 0.29$$

9. Recoverable sugar yield (RSY; ton fed$^{-1}$).
10. Sugar loss yield (SLY; ton fed$^{-1}$).

**Statistical analysis:**

The Proc Mixed of SAS 130 package version 9.2 was used to perform analysis of variance (ANOVA) and Fisher's least significant difference (LSD) of significantly differed treatments.

**Results and Discussion**

**Effect of inter- and intra-row planting distances on beet juice quality parameters**

Most arable crops produce high yields when planted in well-spaced rows with an optimal plant population. The excellent plant stands exploit all of the available area to optimize light capture. The analysis of variance (ANOVA) revealed significant effects of all the studied factors on all studied traits either in one or both growing seasons except for the effect of inter-row planting distances on Na% and loss sugar yield in both growing seasons (Table 2). These results ascertain the previous assumptions for the effects of inter- and intra-row planting distances and the distinct genetic background of the varieties used in this study. Consequently, various comparisons suggested to be done were valid and should be conducted to fulfil the objectives of the present study.

It is clear from Table 3 that sucrose content resulted from planting sugar beet at an inter-row distance of 50 cm significantly surpassed that resulted from cultivating sugar beet at an inter-row distances of 60 cm with estimated values of (18.41 and 18.17%) for 50 cm inter-row distances compared to (17.85 and 17.95%) for 60 cm inter-row distances in the first and second growing seasons, respectively. Increasing the inter-row planting distance from 50 to 60 cm is associated with a significant reduction in the quality index% and recoverable sugar% in both growing seasons (77.90 and 79.16 and 15.80 and 15.66% under 50 cm, compared to (76.67 and 77.78 and 15.07 and 15.44% under 60 cm). The observed changes in the quality related traits in response to increasing the inter-row planting distance (e.g., decreasing RS%) might be due to that the effect of inter-row distances on sucrose content was higher than its effect of root weight. These results are in harmony with those previously reported by Brar et al. (2015) and Bayat et al. (2019).

**Table 3** Mean values of all studied traits of two inter-row planting distance in the 2019/2020 and 2020/2021growing seasons.

| Trait | Growing season | Inter-row planting distance | | LSD$_{0.05}$ |
|---|---|---|---|---|
| | | 50 cm | 60 cm | |
| Sucrose% | 2019/2020 | 18.41 | 17.85 | 0.13 |
| | 2020/2021 | 18.18 | 17.95 | 0.18 |
| Na% | 2019/2020 | 1.46 | 1.41 | 0.07 |
| | 2020/2021 | 1.44 | 1.44 | 0.02 |
| K% | 2019/2020 | 5.14 | 5.34 | 0.08 |
| | 2020/2021 | 4.74 | 5.04 | 0.17 |
| α-amino-N% | 2019/2020 | 1.39 | 1.46 | 0.04 |
| | 2020/2021 | 1.43 | 1.46 | 0.02 |
| Qz% | 2019/2020 | 34.09 | 32.93 | 0.19 |
| | 2020/2021 | 33.33 | 32.49 | 0.35 |
| RY (t fed$^{-1}$) | 2019/2020 | 15.80 | 15.07 | 0.10 |
| | 2020/2021 | 15.65 | 15.44 | 0.19 |
| RS% | 2019/2020 | 2.58 | 2.77 | 0.07 |
| | 2020/2021 | 2.53 | 2.51 | 0.04 |
| SL% | 2019/2020 | 5.29 | 4.88 | 0.15 |
| | 2020/2021 | 5.15 | 4.95 | 0.17 |
| RSY (t fed$^{-1}$) | 2019/2020 | 0.90 | 0.92 | 0.04 |
| | 2020/2021 | 1.77 | 1.66 | 0.07 |
| SLY (tfed$^{-1}$) | 2019/2020 | 18.41 | 17.85 | 0.13 |
| | 2020/2021 | 18.18 | 17.95 | 0.18 |

The effect of two intra-row planting distances between plants, i.e., 10 and 15 cm, on sucrose content, Na%, K%, α-amino-N% and recoverable sugar%. The results revealed that increasing the intra-row planting distances from 10 to 15 cm led to a significant reduction in sucrose%, Na%, quality index% and recoverable sugar%. On the other hand, increasing the intra-row planting distances from 10 to 15 cm significantly increased K% and α-amino-N% (Table 4).

The results in Table 4 show that sucrose% has significantly increased under cultivation of plants at an intra-row distance of 10 cm (18.59 and 18.32% in the first and second growing seasons, respectively) compared to the cultivation 15 cm intra-row distance (17.67 and 17.82% in the first and second growing seasons, respectively). Meanwhile, increasing the intra-row planting distances from 10 to 15 cm increased the contents of Na (from 1.34 and 1.40 to 1.52 and 1.48% in the first and second growing seasons, respectively), K (from 5.12 and 4.70 to 5.36 and 5.08% in the first and second growing seasons, respectively) and α-amino-N (from 1.38 and 1.40 to 1.47 and 1.50% in the first and second growing seasons, respectively) in the beet root juice in the two second growing seasons.

**Table 4** Mean values for all studied traits of two intra-row planting 2020/2021 growing seasons.

| Trait | Growing season | Intra-row planting distance 10 cm | 15 cm | $LSD_{0.05}$ |
|---|---|---|---|---|
| Sucrose% | 2019/2020 | 18.59 | 17.67 | 0.07 |
| | 2020/2021 | 18.32 | 17.82 | 0.14 |
| Na% | 2019/2020 | 1.34 | 1.52 | 0.05 |
| | 2020/2021 | 1.40 | 1.48 | 0.02 |
| K% | 2019/2020 | 5.12 | 5.36 | 0.06 |
| | 2020/2021 | 4.70 | 5.08 | 0.07 |
| α-amino-N% | 2019/2020 | 1.38 | 1.47 | 0.02 |
| | 2020/2021 | 1.40 | 1.50 | 0.04 |
| Qz% | 2019/2020 | 77.88 | 76.68 | 0.06 |
| | 2020/2021 | 79.16 | 77.78 | 0.76 |
| RY (t $fed^{-1}$) | 2019/2020 | 28.59 | 38.43 | 0.10 |
| | 2020/2021 | 28.20 | 37.62 | 0.08 |
| RS% | 2019/2020 | 16.00 | 14.87 | 0.10 |
| | 2020/2021 | 15.80 | 15.30 | 0.14 |
| SL% | 2019/2020 | 2.58 | 2.76 | 0.03 |
| | 2020/2021 | 2.52 | 2.53 | 0.02 |
| RSY (t $fed^{-1}$) | 2019/2020 | 5.65 | 4.52 | 0.03 |
| | 2020/2021 | 5.69 | 4.41 | 0.06 |
| SLY (t $fed^{-1}$) | 2019/2020 | 0.74 | 1.08 | 0.06 |
| | 2020/2021 | 1.26 | 2.17 | 0.04 |

As expected, quality index% and recoverable sugar% followed the same trend of sucrose content. Quality index% and recoverable sugar% were significantly increased in response to decreasing the intra-row planting distances from 10 to 15 cm (from 77.88 and 76.68 and from16.00 and 15.80% under 10 cm to 79.16 and 77.78 and 14.87 and 15.30% under 15 cm in the first and second growing seasons, respectively. These results are in agreement with those reported by Beata et al. (2018) and Khaiti (2012). The high sugar content produced from the low intra-row planting distances could be attributed to that the partitioning of photoassimilates was in favor of improving sugar content under the low intra-row planting distances where it was reduced (Hosseini et al. 2019; Koch et al. 2019; Lemoine et al. 2013; Sowiński 1999). Rice (1999) reported that the low plant counts had a significant effect on the sucrose and sugar recovery of sugar beets.

The present results are in the same line with those reported by Awad (2000) and Ferweez et al. (2010).

The results presented in Table 5 reveal significant variations among the four evaluated varieties, i.e., Nimaless and Garrot, Husam and Karam, in the ten studies traits. The multigerm variety Husam produced the highest values of sucrose content (19.48 and 19.21%) in the first and second growing seasons, respectively. Although the variety Husam exhibited the highest values of Na (1.63 and 1.57%) and α-amino-N (1.50 and 1.48%) contents in the first and second growing seasons, respectively, however, due to its higher sucrose content and K% (4.35 and 4.57% in the first and second growing seasons, respectively) it has surpassed the other studied varieties in the quality index% (78.04 and 79.25%) and recoverable sugar% (17.09 and 16.74%) in the first and second growing seasons, respectively). The superiority of the variety Husam in these particular quality parameters could be ascribed to its genetic make-up that enabled it from partitioning of more photoassimilates towards increasing sucrose content. The superiority of the Garrot variety in these particular traits might be attributed to its genetic make-up that enabled to maximize light interception, enhance its photosynthetic capacity and partitioning more photoassimilates towards increasing storage root growth.

The interaction between inter- (50 cm, 60 cm) and intra- (10 cm, 15 cm) row planting distances revealed significant effects on the studied traits in both growing seasons (Table 6). Decreasing both the intra- and inter-row planting distances resulted in a significant increase in the sucrose content and recoverable sugar%. The highest values of sucrose content (18.90 and 18.56%) and recoverable sugar% (16.38 and 16.05%) in the first and second growing seasons, respectively, produced from cultivating the sugar beet plants at an intra-row distance of 10 cm and an inter-row distance of 50 cm. Meanwhile, the lowest values from both traits resulted from the cultivation at wider intra- and inter-row distances (15 and 60 cm). Likewise, cultivating sugar beet plants at narrower intra- and inter-row distances (10 and 50 cm) resulted in the lowest values of K and α-amino-N contents beet root juice of 5.00 and 4.61%, and 1.30 and 1.36% in the first and second growing seasons, respectively. In contrary, the wider intra- and inter-row planting distances (15 and 60 cm) produced the highest values of both traits in both growing seasons. However, the lowest Na content in the beet root juice was obtained from planting sugar beet at wider intra-row distance of 15 cm either at 50 (1.37 and 1.40%) or 60 cm (1.32 and 1.41%) intra-row distance in the first and second growing seasons, respectively. Meanwhile, planting sugar beet at narrower intra- and inter-row distances (10 and 50 cm) produced the highest values of Na content in both growing seasons. Planting sugar beet at 10 and 50 cm intra- and inter-row distances exhibited the highest values of quality index (Qz%) of 78.56 and 79.81% in the first and second growing seasons, respectively. Meanwhile, the lowest values of Qz% of 76.13 and

76.83% resulted from the cultivation of sugar beet at 15 and 60 cm intra- and inter-row distances in the first and second growing seasons, respectively.

**Table 5** Mean values of all studied traits of four different varieties in the 2019/2020 and 2020/2021 growing seasons.

| Trait | Growing season | Variety | | | | LSD |
|---|---|---|---|---|---|---|
| | | Nimaless | Garrot | Husam | Karam | 0.05 |
| Sucrose% | 2019/2020 | 17.04 | 17.30 | 19.48 | 18.70 | 0.10 |
| | 2020/2021 | 17.10 | 17.19 | 19.21 | 18.76 | 0.20 |
| Na% | 2019/2020 | 1.25 | 1.34 | 1.63 | 1.51 | 0.07 |
| | 2020/2021 | 1.32 | 1.37 | 1.57 | 1.50 | 0.02 |
| K% | 2019/2020 | 5.84 | 5.46 | 4.35 | 5.29 | 0.09 |
| | 2020/2021 | 5.05 | 5.04 | 4.57 | 4.90 | 0.10 |
| α-amino-N% | 2019/2020 | 1.42 | 1.29 | 1.50 | 1.50 | 0.00 |
| | 2020/2021 | 1.49 | 1.36 | 1.48 | 1.46 | 0.06 |
| Qz% | 2019/2020 | 77.32 | 76.24 | 78.04 | 77.53 | 0.08 |
| | 2020/2021 | 78.49 | 77.43 | 79.25 | 78.72 | 0.36 |
| RY (t $fed^{-1}$) | 2019/2020 | 38.16 | 39.33 | 28.70 | 27.85 | 0.14 |
| | 2020/2021 | 36.93 | 38.54 | 28.43 | 27.73 | 0.11 |
| RS% | 2019/2020 | 14.15 | 14.39 | 17.09 | 16.09 | 0.14 |
| | 2020/2021 | 14.60 | 14.63 | 16.74 | 16.23 | 0.20 |
| SL% | 2019/2020 | 2.82 | 2.91 | 2.38 | 2.58 | 0.05 |
| | 2020/2021 | 2.51 | 2.56 | 2.47 | 2.54 | 0.02 |
| RSY (t $fed^{-1}$) | 2019/2020 | 5.38 | 5.63 | 4.72 | 4.60 | 0.04 |
| | 2020/2021 | 5.36 | 5.62 | 4.62 | 4.60 | 0.08 |
| SLY (t $fed^{-1}$) | 2019/2020 | 1.10 | 1.13 | 0.67 | 0.75 | 0.08 |
| | 2020/2021 | 2.06 | 2.18 | 1.29 | 1.32 | 0.05 |

The interaction between inter-row planting distances and the four sugar beet varieties exhibited significant effects on all studied traits (Table 2). The multigerm variety Husam was superior in sucrose content (19.81 and 19.21%), K% (4.48 and 4.44%), quality index % (78.37 and 79.86) and recoverable sugar% (17.48 and 16.74%), in the first and second growing seasons respectively, when cultivated at 50 cm inter-row planting distances (Table 7). Meanwhile, superiority in α-amino-N% was scored for the monogerm variety Garrot planted at 50 cm inter-row distance by producing the lowest values of α- amino-N% of 1.13 and 1.31%, in the first and second growing seasons, respectively. The lowest values of Na content of 1.21 and 1.25%, in the first and second growing seasons, respectively, resulted from the Nimaless sugar beet variety planted at an inter-row distance of 60 cm. The superiority of a specific sugar beet variety in particular of traits under specific agricultural conditions could be attributed to its genetic make-up which enables it to respond differently to the changed environmental conditions, available nutrients and light interception, and thus affects its photosynthetic capacity and partitioning of photoassimilates. These results are in agreement with previously reported findings (Abu-Ellail et al. 2019; Mekdad 2012; Sahar and Salem 2016).

The interaction between intra-row planting distances and the four evaluated sugar beet varieties revealed significant effects on all studied traits (Table 8). The multigerm variety Husam planted at 10 cm intra-row distances produced the highest values of sucrose content (20.18 and 19.63%), recoverable sugar% (17.99 and 17.16%), and K% (4.18 and 4.37%) in the first and second growing seasons, respectively (Table 8). Meanwhile, the lowest values of Na content in the beet root juice of 1.19 and 1,.25%, and 1.20 and 1.29% were produced from the Garrrot and Nimaless varieties, in the first and second growing seasons, respectively, cultivated at 15 cm intra-row distances. The lowest values of α-amino-N in the beet root juice of 1.20 and 1.27% in the first and second growing seasons, respectively, resulted from the sugar beet variety Garrot planted at 10 cm intra-row distances. The highest quality index values of 78.94 and 80.84% in the first and second growing seasons, respectively, resulted from planting the Husam variety at an intra-row distance of 10 cm. The results presented in Tables 9 and 10 showed the effects of the interactions between inter- and intra-row planting distances with the four sugar beet varieties on RY and RSY. The results showed that planting the variety Garrot at 15 and 50 cm intra- and inter-row distances produced the highest root yield (45.03 and 44.93 t $fed^{-1}$) and recoverable sugar yield (6.40 and 6.54 t $fed^{-1}$) in the first and second growing seasons, respectively. The superiority of Garrot as a monogerm variety may be attributed to its genetic make-up. Besides, the superiority of the Garrot variety in recoverable sugar yield under 15 and 50 cm intra- and inter-row planting distances could be ascribed to its superiority in root yield under these planting conditions. These results are in conformity with earlier findings by Refay (2010). Meanwhile, planting the Husam variety at 10 and 60 cm intra- and inter-row planting distances yielded the lowest root yield values in both growing seasons, and cultivating either the Husam and Karam varieties at 10 and 60 cm intra- and inter-row planting distances resulted in the lowest recoverable sugar yields in both growing seasons (Table 10).

**Table 6** Mean values of all studied traits as affected by the interaction between intra- and inter-row planting distances in the 2019/2020 and 2020/2021 growing seasons.

| Trait | Inter-row distance | 50 cm | | 60 cm | | LSD0.05 |
|---|---|---|---|---|---|---|
| | Intra-row distance | 10 cm | 15 cm | 10 cm | 15 cm | |
| Sucrose% | 2019/2020 | 19.00 | 17.93 | 18.28 | 17.42 | 0.10 |
| | 2020/2021 | 18.56 | 17.80 | 18.08 | 17.83 | 0.20 |
| Na% | 2019/2020 | 1.55 | 1.37 | 1.49 | 1.32 | 0.07 |
| | 2020/2021 | 1.48 | 1.40 | 1.47 | 1.41 | 0.02 |
| K% | 2019/2020 | 5.00 | 5.27 | 5.24 | 5.44 | 0.09 |
| | 2020/2021 | 4.61 | 4.86 | 4.78 | 5.31 | 0.10 |
| α-amino-N% | 2019/2020 | 1.30 | 1.48 | 1.46 | 1.46 | 0.02 |
| | 2020/2021 | 1.36 | 1.51 | 1.44 | 1.49 | 0.06 |
| Qz% | 2019/2020 | 78.56 | 77.24 | 77.20 | 76.13 | 0.08 |
| | 2020/2021 | 79.81 | 78.51 | 78.74 | 76.83 | 0.36 |
| RY (t fed$^{-1}$) | 2019/2020 | 29.13 | 39.04 | 28.05 | 37.81 | 0.14 |
| | 2020/2021 | 28.53 | 38.13 | 27.86 | 37.12 | 0.11 |
| RS% | 2019/2020 | 16.38 | 15.21 | 15.61 | 14.53 | 0.14 |
| | 2020/2021 | 16.05 | 15.26 | 15.55 | 15.34 | 0.20 |
| SL% | 2019/2020 | 2.52 | 2.63 | 2.64 | 2.89 | 0.05 |
| | 2020/2021 | 2.50 | 2.56 | 2.53 | 2.49 | 0.02 |
| RSY (t fed$^{-1}$) | 2019/2020 | 4.71 | 5.87 | 4.32 | 5.43 | 0.04 |
| | 2020/2021 | 4.54 | 5.77 | 4.29 | 5.61 | 0.08 |
| SLY (t fed$^{-1}$) | 2019/2020 | 0.73 | 1.07 | 0.75 | 1.10 | 0.08 |
| | 2020/2021 | 1.11 | 2.22 | 1.21 | 2.11 | 0.05 |

**Effect of inter- and intra-row planting distances on root and recoverable sugar yields**

Most arable crops produce high yields when planted in well-spaced rows with an optimal plant population. The excellent plant stands exploit all of the available area to optimize light capture. The analysis of variance for the effects of inter- and intra-row, varieties and their interactions on the yield and quality of sugar beet is presented in Table 2 .

The analysis of variance (ANOVA) exhibited significant effects of all the studied factors on root (RY) and recoverable sugar (RSY) yields either in one or both growing seasons (Table 2). The results revealed that increasing the inter-row planting distance from 50 to 60 cm led to a significant reduction root and recoverable sugar yields (Table 3). Root yield has significantly increased when sugar beet was planted at 50 cm inter-row distances (34.088 and 33.329 t fed$^{-1}$) compared to that planted at 60 cm inter-row distances (32.929 and 32.488 t fed$^{-1}$). Obviously, root yield was proven to be higher under the narrowest inter-row distance (50 cm) compared to the wider one (60 cm). The results are in agreement with those obtained by Hilal (2010) and Ferweez et al. (2010). These results could be attributed to the fact that optimal crop canopy structure is associated with improved canopy photosynthetic productivity and thereby higher crop yield potential. The best structure of the crop canopy mainly depends on the spatial arrangement of the plant which is associated with yield, and morphological and functional combination that influences light distribution and interception and increase light-energy absorption (Feng et al. 2016).

The results further showed that increasing inter-row planting distance from 50 to 60 cm led to a significant decrease in the RSY in both growing seasons (5.29 and 5.15 (t fed$^{-1}$) under 50 cm, compared to 4.88 and 4.95 (t fed$^{-1}$) under 60 cm). Increasing the intra-row planting distances from 10 to 15 cm significantly increased root and recoverable sugar yields (Table 4). Increasing the intra-row planting distances from 10 to 15 cm was in favor of increasing root yield (from 28.59 and 28.19 to 38.43 and 37.62 t fed$^{-1}$ in the first and second growing seasons, respectively) and sugar loss yield (from 0.74 and 1.26 to 1.8 and 2.17 t fed$^{-1}$ in the first and second growing seasons, respectively) and decreasing recoverable sugar yield (from 5.65 and 5.69 to 4.52 and 4.41t fed$^{-1}$ in the first and second growing seasons, respectively) in both growing seasons. The observed reduction in the recoverable sugar yield in response to increasing the intra-row planting distances, although increasing the root yield, is due to the high reduction in the sucrose content and the increase in the impurity parameters (Na, K and α-amino-N) under the 15 cm intra-row planting distance (Table 4).

The obtained results may be due to that increasing intra-row planting distances led to increasing root mass and consequently, increasing the root juice impurities. Besides, the association between decreasing the sugar percentage and higher root yield under higher intra-row planting distances could be explained by the dilution effect (Shaheen et al. 2017).

**Table 7** Mean values of all studied traits as affected by the interaction between inter-row planting distance and sugar beet varieties in the 2019/2020 and 2020/2021 growing seasons.

| Trait | Inter-row distance | 50 cm | | | | 60 cm | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Variety | Nimaless | Garrot | Husam | Karam | Nimaless | Garrot | Husam | Karam | |
| Sucrose% | 2019/2020 | 17.31 | 17.57 | 19.81 | 18.96 | 16.78 | 17.04 | 19.15 | 18.44 | 0.14 |
| | 2020/2021 | 17.24 | 17.45 | 19.21 | 18.82 | 16.96 | 16.94 | 19.21 | 18.71 | 0.26 |
| Na% | 2019/2020 | 1.29 | 1.36 | 1.64 | 1.54 | 1.21 | 1.32 | 1.62 | 1.48 | 0.07 |
| | 2020/2021 | 1.29 | 1.36 | 1.58 | 1.53 | 1.25 | 1.34 | 1.55 | 1.48 | 0.02 |
| K% | 2019/2020 | 5.51 | 5.36 | 4.48 | 5.20 | 6.17 | 5.57 | 4.53 | 5.39 | 0.07 |
| | 2020/2021 | 4.82 | 4.91 | 4.44 | 4.77 | 5.29 | 5.17 | 4.70 | 5.02 | 0.12 |
| α-amino-N% | 2019/2020 | 1.39 | 1.19 | 1.46 | 1.53 | 651. | 1.39 | 1.54 | 41.5 | 0.02 |
| | 2020/2021 | 1.51 | 1.31 | 1.45 | 1.47 | 1.51 | 1.41 | 1.42 | 1.48 | 0.02 |
| (Qz% | 2019/2020 | 77.90 | 77.20 | 78.37 | 78.13 | 76.75 | 75.27 | 76.93 | 77.71 | 0.20 |
| | 2020/2021 | 79.00 | 78.23 | 79.86 | 79.56 | 77.99 | 76.62 | 78.65 | 77.88 | 0.54 |
| RY (t $fed^{-1}$) | 2019/2020 | 38.75 | 39.85 | 29.18 | 28.57 | 37.57 | 38.80 | 28.22 | 27.13 | 0.23 |
| | 2020/2021 | 37.281 | 39.15 | 28.72 | 28.17 | 36.57 | 37.93 | 28.15 | 27.30 | 0.33 |
| RS (%) | 2019/2020 | 14.49 | 14.74 | 17.48 | 16.47 | 13.81 | 14.05 | 16.71 | 15.71 | 0.09 |
| | 2020/2021 | 14.75 | 14.88 | 16.74 | 16.25 | 14.45 | 14.37 | 16.75 | 16.21 | 0.26 |
| SL (%) | 2019/2020 | 2.67 | 2.82 | 2.33 | 2.49 | 2.97 | 2.99 | 2.44 | 2.66 | 0.15 |
| | 2020/2021 | 2.50 | 2.56 | 2.48 | 2.58 | 2.52 | 2.57 | 2.50 | 2.59 | 0.02 |
| RSY (t $fed^{-1}$) | 2019/2020 | 5.59 | 5.84 | 4.96 | 4.78 | 5.17 | 5.42 | 4.48 | 4.42 | 0.08 |
| | 2020/2021 | 5.48 | 5.80 | 4.68 | 4.65 | 5.24 | 5.44 | 4.57 | 4.56 | 0.12 |
| SLY (t $fed^{-1}$) | 2019/2020 | 1.10 | 1.10 | 0.67 | 0.73 | 1.10 | 1.16 | 0.67 | 0.76 | 0.06 |
| | 2020/2021 | 2.03 | 2.05 | 1.26 | 1.30 | 2.09 | 2.31 | 1.31 | 1.35 | 0.04 |

The results presented in Table 5 reveal significant variations among the four evaluated varieties, i.e., Nimaless and Garrot, Husam and Karam, in RY and RSY. The monogerm variety Garrot produced the highest root yield of 39.33 and 38.54 t $fed^{-1}$) and recoverable sugar yield (5.63 and 5.62 t $fed^{-1}$) in the first and second growing seasons, respectively. The superiority of the Garrot variety in these particular traits might be attributed to its genetic make-up that enabled to maximize light interception, enhance its photosynthetic capacity and partitioning more photoassimilates towards increasing storage root growth.

The interaction between inter- (50 cm, 60 cm) and intra- (10 cm, 15 cm) row planting distances revealed significant effects on RY and RSY in both growing seasons (Table 2). The highest root yield (39.04 and 38.13 t $fed^{-1}$) and recoverable sugar yield (5.87 and 5.77 t $fed^{-1}$) were produced from cultivating sugar beet at 15 cm intra-row distances and 50 cm inter-row distance in the first and second growing seasons, respectively. Cultivating sugar beet at narrower inter-row distanes, such as 45 cm, has been reported to produce higher root and recoverable sugar yields because they help to compensate for poor plant establishment (Anonymous 1995). These results were clearly observed in our study where planting sugar beet at 10 and 50 cm intra- and inter-row distances resulted in the higher, root and recoverable sugar yields. Besides, Rice (1999) reported that there was a fall in root and sugar yields in response to planting sugar beet at wider distances. The obtained results are partially similar to those reported by Khozaei et al. (2020).

The interaction between inter- (50 cm, 60 cm) and intra- (10 cm, 15 cm) row planting distances revealed significant effects on SL% and SLY in both growing seasons (Table 6). The lowest sugar loss% (2.52 and 2.50%) and sugar loss yield (0.73 and 1.11 t $fed^{-1}$) in the first and second growing seasons, respectively, were produced from planting sugar beet at the narrow intra- and inter-row distances of 10 and 50 cm, respectively.

Increasing the intra-row planting distances from 10 to 15 cm was in favor of increasing sugar loss yield (from 0.74 and 1.26 to 1.08 and 2.17 t $fed^{-1}$ in the first and second growing seasons, respectively). As expected, and because of its lower potassium content, the variety Husam exhibited the lowest sugar loss% values of 2.38 and 2.47% in the first and second growing seasons, respectively. However, the monogerm variety Garrot produced the highest sugar loss yield (1.13 and 2.18 t $fed^{-1}$) in the first and second growing seasons, respectively.

The interaction between inter-row planting distances and the four sugar beet varieties exhibited significant effects on SL% and SLY (Table 7). The multigerm variety Husam was superior in sugar loss% (2.33 and 2.48%) and sugar loss yield (0.67 and 1.26 t $fed^{-1}$), in the first and second growing seasons respectively, when cultivated at 50 cm inter-row planting distances (Table 7). The interaction between intra-row planting distances and the four evaluated sugar beet varieties revealed significant effects on SL5 and SLY (Table 8). The multigerm variety Husam planted at 10 cm intra-row distances produced the highest values of sugar loss% (2.19 and 2.47%) and sugar loss yield (0.51 and 1.00 t $fed^{-1}$) in the first and second growing seasons, respectively (Table 8).

The results presented in Tables 9 and 10 showed the effects of the interactions between inter- and intra-row planting distances with the four sugar beet varieties on SL% and SLY. The results showed that Husam variety planted at 10 and 50 cm intra- and inter-row distances, respectively, produced the lowest sugar loss% values of 2.14 and 2.34%, in the first and growing seasons, respectively. Meanwhile, the highest values of sugar loss% were produced from both the Nimaless and Garrot varieties planted at 15 and 60 cm intra- and inter-row distances, respectively (Table 9).

The interaction between inter-row planting distances and the four sugar beet varieties exhibited significant effects on RY and RSY (Table 2). Superiority in root and recoverable sugar yields was scored for the monogerm variety Garrot planted at 50 cm inter-row distance by producing the highest root (39.85 and 39.15 t $fed^{-1}$) and recoverable sugar (5.84 and 5.80 t $fed^{-1}$) yields in the first and second growing seasons, respectively.

The interaction between intra-row planting distances and the four evaluated sugar beet varieties revealed significant effects on RY and RSY (Table 8). The variety Garrot cultivated at 15 cm intra-row planting distance produced the highest root yield of 44.57 and 43.98 t $fed^{-1}$ and recoverable sugar yield of 6.21 and 6.35 t $fed^{-1}$ in the first and second growing seasons, respectively. The effect of two intra-row planting distances between plants, i.e., 10 and 15 cm, sugar loss% and sugar loss yield. The results revealed that increasing the intra-row planting distances from 10 to 15 cm significantly increased sugar loss% and sugar loss yield (Table 4). Sugar loss% was increased as the intra-row planting distances was increased from 10 (2.58 and 52%) to 15 cm (2.76 and 2.53%) in the first and second growing seasons, respectively. These results are in agreement with those reported by Beata et al. (2018) and Khaiti (2012).

**Table 8** Mean values of all studied traits as affected by the interaction between intra-row planting distances and sugar beet varieties in the 2019/2020 and 2020/2021 growing seasons.

| Trait | Inter-row planting distance | 10 cm | | | | 15 cm | | | | $LSD_{0.05}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Variety | Nimaless | Garrot | Husam | Karam | Nimaless | Garrot | Husam | Karam | |
| Sucrose% | 2019/2020 | 17.35 | 17.71 | 20.18 | 19.11 | 16.73 | 16. 90 | 18.78 | 18.29 | 0.14 |
| | 2020/2021 | 17.23 | 17.43 | 19.63 | 18.99 | 16.97 | 16.96 | 18.79 | 18.54 | 0.26 |
| Na% | 2019/2020 | 1.38 | 1.49 | 1.67 | 1.55 | 1.12 | 1.19 | 1.59 | 1.47 | 0.07 |
| | 2020/2021 | 1.35 | 1.49 | 1.58 | 1.48 | 1.29 | 1.25 | 1.55 | 1.53 | 0.02 |
| K% | 2019/2020 | 5.79 | 5.49 | 4.18 | 5.01 | 5.89 | 5.43 | 4.53 | 5.58 | 0.07 |
| | 2020/2021 | 4.84 | 4.92 | 4.37 | 4.66 | 5.27 | 5.16 | 4.78 | 5.13 | 0.12 |
| α-amino-N% | 2019/2020 | 1.38 | 1.20 | 1.52 | 1.44 | 1.46 | 1.39 | 1.49 | 1.56 | 0.02 |
| | 2020/2021 | 1.44 | 1.27 | 1.47 | 1.42 | 1.54 | 1.46 | 1.50 | 1.50 | 0.02 |
| Qz% | 2019/2020 | 77.44 | 76.67 | 78.94 | 78.48 | 77.21 | 75.81 | 76.59 | 77.14 | 0.20 |
| | 2020/2021 | 78.64 | 78.32 | 80.84 | 79.29 | 78.34 | 76.54 | 77.67 | 78.14 | 0.54 |
| RY (t $fed^{-1}$) | 2019/2020 | 32.47 | 34.08 | 23.27 | 24.55 | 43.85 | 44.57 | 32.43 | 31.23 | 0.23 |
| | 2020/2021 | 30.58 | 33.10 | 24.23 | 24.87 | 43.27 | 43.98 | 32.85 | 32.00 | 0.33 |
| RS% | 2019/2020 | 14.48 | 14.83 | 17.99 | 16.68 | 13.82 | 13.96 | 16.20 | 15.50 | 0.09 |
| | 2020/2021 | 14.74 | 14.83 | 17.16 | 16.48 | 14.45 | 14.43 | 16.33 | 15.98 | 0.26 |
| SL% | 2019/2020 | 2.89 | 2.88 | 2.19 | 2.36 | 2.75 | 2.93 | 2.57 | 2.79 | 0.15 |
| | 2020/2021 | 2.49 | 2.60 | 2.47 | 2.51 | 2.53 | 2.53 | 2.47 | 2.57 | 0.02 |
| RSY (t $fed^{-1}$) | 2019/2020 | 4.71 | 5.05 | 4.19 | 4.11 | 6.05 | 6.21 | 5.25 | 5.09 | 0.08 |
| | 2020/2021 | 4.51 | 4.89 | 4.15 | 4.10 | 6.21 | 6.35 | 5.09 | 5.11 | 0.12 |
| SLY (t $fed^{-1}$) | 2019/2020 | 0.93 | 0.95 | 0.51 | 0.58 | 1.27 | 1.31 | 0.83 | 0.92 | 0.07 |
| | 2020/2021 | 1.44 | 1.57 | 1.00 | 1.02 | 2.68 | 2.79 | 1.57 | 1.63 | 0.04 |

**Effect of inter- and intra-row planting distances on sugar loss**

The ANOVA results revealed significant effects of all the studied factors on sugar loss (SL)% and sugar loss yield (SLY)in both growing seasons. The results revealed that increasing the inter-row distance is associated with a significant increase in sugar loss% and sugar loss yield. Data in Table 3 showed that sugar loss (SL%) and sugar loss yield (SLY) were decreased in response to increasing the inter-row planting distance from 50 to 60 cm from 2.58 and 2.53%, and 0.90, 1.77 t $fed^{-1}$, to 2.53 and 2.51% and 1.77 and 1.66 t $fed^{-1}$, respectively. The observed changes in the quality related traits in response to increasing the inter-row planting distance (e.g., increasing SL% and SLY) could be ascribed to that the higher effect of inter-row distances on sucrose content compared to its effect on root yield.

These results are in harmony with those previously reported by Brar et al. (2015) and Bayat et al. (2019).

Increasing the intra-row planting distances from 10 to 15 cm was in favor of increasing sugar loss yield (from 0.74 and 1.26 to 1.08 and 2.17 t fed$^{-1}$ in the first and second growing seasons, respectively). As expected, and because of its lower potassium content, the variety Husam exhibited the lowest sugar loss% values of 2.38 and 2.47% in the first and second growing seasons, respectively. However, the monogerm variety Garrot produced the highest sugar loss yield (1.13 and 2.18 t fed$^{-1}$) in the first and second growing seasons, respectively. The interaction between inter- (50 cm, 60 cm) and intra- (10 cm, 15 cm) row planting distances revealed significant effects on SL% and SLY in both growing seasons (Table 6). The lowest sugar loss% (2.52 and 2.50%) and sugar loss yield (0.73 and 1.11 t fed$^{-1}$) in the first and second growing seasons, respectively, were produced from planting sugar beet at the narrow intra- and inter-row distances of 10 and 50 cm, respectively.

The interaction between inter-row planting distances and the four sugar beet varieties exhibited significant effects on SL% and SLY (Table 7). The multigerm variety Husam was superior in sugar loss% (2.33 and 2.48%) and sugar loss yield (0.67 and 1.26 t fed$^{-1}$), in the first and second growing seasons respectively, when cultivated at 50 cm inter-row planting distances (Table 7). The interaction between intra-row planting distances and the four evaluated sugar beet varieties revealed significant effects on SL5 and SLY (Table 8). The multigerm variety Husam planted at 10 cm intra-row distances produced the highest values of sugar loss% (2.19 and 2.47%) and sugar loss yield (0.51 and 1.00 t fed$^{-1}$) in the first and second growing seasons, respectively (Table 8).

The results presented in Tables 9 and 10 showed the effects of the interactions between inter- and intra-row planting distances with the four sugar beet varieties on SL% and SLY. The results showed that Husam variety planted at 10 and 50 cm intra- and inter-row distances, respectively, produced the lowest sugar loss% values of 2.14 and 2.34%, in the first and growing seasons, respectively. Meanwhile, the highest values of sugar loss% were produced from both the Nimaless and Garrot varieties planted at 15 and 60 cm intra- and inter-row distances, respectively (Table 9). The results presented in Tables 9 and 10 showed the effects of the interactions between inter- and intra-row planting distances with the four sugar beet varieties on the ten studied yield and quality traits. The results showed that Husam variety planted at 10 and 50 cm intra- and inter-row distances, respectively, produced the highest values of sucrose content (20.43 and 19.87%) and recoverable sugar% (18.29 and 17.42%), in the first and growing seasons, respectively. Meanwhile, the variety Nimaless cultivated at 15 and 60 cm intra- and inter-row distances, respectively, produced the lowest values of sucrose content and recoverable sugar% (Tables 9 and 10).

**Table 9** Mean values of sucrose%, Na%, K%, α-amino-N% and Qz% as affected by the interaction among intra- and inter-row planting distances and sugar beet varieties in the 2019/2020 and 2020/2021 growing seasons.

| Inter-row distance | Intra-row distance | variety | Sucrose% | | Na% | | K% | | α-amino-N% | | Qz% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 |
| 50 cm | 10 cm | Nimaless | 17.73 | 17.38 | 1.42 | 1.28 | 5.41 | 4.63 | 1.39 | 1.51 | 77.93 | 79.08 |
| | | Garrot | 18.05 | 17.81 | 1.52 | 1.49 | 5.35 | 4.97 | 1.08 | 1.21 | 77.83 | 78.93 |
| | | Husam | 20.43 | 19.87 | 1.69 | 1.64 | 4.35 | 4.22 | 1.34 | 1.34 | 79.27 | 81.85 |
| | | Karam | 19.38 | 19.18 | 1.59 | 1.51 | 4.89 | 4.64 | 1.40 | 1.37 | 79.21 | 79.36 |
| | 15 cm | Nimaless | 16.89 | 17.10 | 1.16 | 1.29 | 5.61 | 5.00 | 1.38 | 1.50 | 77.86 | 78.91 |
| | | Garrot | 17.08 | 17.08 | 1.21 | 1.22 | 5.36 | 4.85 | 1.30 | 1.40 | 76.58 | 77.53 |
| | | Husam | 19.19 | 18.56 | 1.60 | 1.53 | 4.61 | 4.67 | 1.58 | 1.56 | 77.06 | 77.86 |
| | | Karam | 18.54 | 18.46 | 1.50 | 1.55 | 5.51 | 4.90 | 1.66 | 1.56 | 77.47 | 79.75 |
| 60 cm | 10 cm | Nimaless | 16.98 | 17.09 | 1.33 | 1.42 | 6.17 | 5.05 | 1.36 | 1.36 | 76.95 | 78.20 |
| | | Garrot | 17.36 | 17.04 | 1.47 | 1.50 | 5.63 | 4.87 | 1.31 | 1.32 | 75.50 | 77.70 |
| | | Husam | 19.93 | 19.39 | 1.66 | 1.53 | 4.01 | 4.52 | 1.69 | 1.59 | 77.74 | 79.82 |
| | | Karam | 18.84 | 18.80 | 1.51 | 1.45 | 5.14 | 4.67 | 1.48 | 1.48 | 78.61 | 79.22 |
| | 15 cm | Nimaless | 16.58 | 16.83 | 1.08 | 1.29 | 6.16 | 5.53 | 1.55 | 1.58 | 76.55 | 77.77 |
| | | Garrot | 16.71 | 16.84 | 1.18 | 1.27 | 5.50 | 5.46 | 1.47 | 1.51 | 75.04 | 75.55 |
| | | Husam | 18.36 | 19.02 | 1.58 | 1.58 | 4.45 | 4.89 | 1.39 | 1.44 | 76.12 | 77.47 |
| | | Karam | 18.04 | 18.62 | 1.45 | 1.50 | 5.64 | 5.36 | 1.45 | 1.43 | 76.81 | 76.54 |
| LSD0.05 | | | 0.20 | 0.37 | 0.10 | 0.03 | 0.09 | 0.17 | 0.01 | 0.03 | 0.28 | 0.77 |

**Table 10** Mean values of root yield, recoverable sugar%, sugar loss%, recoverable sugar and sugar loss yields as affected by the interaction among intra- and inter-row planting distances and sugar beet varieties in the 2019/2020 and 2020/2021 growing seasons.

| Inter-row distance | Intra-row distance | Variety | RY (t fed$^{-1}$) | | RS% | | SL% | | RSY (t fed$^{-1}$) | | SLY (t fed$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 | 2019/2020 | 2020/2021 |
| 50 cm | 10 cm | Nimaless | 32.97 | 31.30 | 14.95 | 14.95 | 2.81 | 2.43 | 4.94 | 4.67 | 0.93 | 1.46 |
| | | Garrot | 34.67 | 33.37 | 15.25 | 15.20 | 2.79 | 2.61 | 5.28 | 5.06 | 0.91 | 1.69 |
| | | Husam | 24.00 | 24.43 | 18.29 | 17.42 | 2.14 | 2.34 | 4.39 | 4.25 | 0.51 | 1.03 |
| | | Karam | 24.90 | 25.03 | 17.05 | 16.65 | 2.34 | 2.53 | 4.24 | 4.17 | 0.58 | 1.04 |
| | 15 cm | Nimaless | 44.53 | 43.27 | 14.03 | 14.54 | 2.52 | 2.58 | 6.24 | 6.29 | 1.27 | 2.53 |
| | | Garrot | 45.03 | 44.93 | 14.23 | 14.57 | 2.85 | 2.52 | 6.40 | 6.54 | 1.28 | 2.65 |
| | | Husam | 33.13 | 31.90 | 16.68 | 16.05 | 2.51 | 2.52 | 5.52 | 5.11 | 0.83 | 1.59 |
| | | Karam | 33.47 | 32.40 | 15.90 | 15.86 | 2.6 | 2.63 | 5.31 | 5.13 | 0.89 | 1.66 |
| 60 cm | 10 cm | Nimaless | 31.97 | 29.87 | 14.02 | 14.54 | 2.96 | 2.55 | 4.48 | 4.35 | 0.94 | 1.42 |
| | | Garrot | 33.50 | 32.83 | 14.40 | 14.45 | 2.96 | 2.59 | 4.820 | 4.72 | 0.99 | 1.45 |
| | | Husam | 22.53 | 24.03 | 17.69 | 16.89 | 2.24 | 2.50 | 3.99 | 4.05 | 0.50 | 0.97 |
| | | Karam | 24.20 | 24.70 | 16.32 | 16.31 | 2.38 | 2.50 | 3.98 | 4.03 | 0.58 | 0.99 |
| | 15 cm | Nimaless | 43.17 | 43.27 | 13.60 | 14.25 | 2.98 | 2.49 | 5.86 | 6.14 | 1.27 | 2.72 |
| | | Garrot | 44.10 | 43.03 | 13.69 | 14.29 | 3.02 | 2.64 | 6.03 | 6.1 | 1.33 | 2.93 |
| | | Husam | 31.73 | 30.57 | 15.72 | 16.61 | 2.63 | 2.41 | 4.97 | 5.08 | 0.83 | 1.55 |
| | | Karam | 32.23 | 31.60 | 15.11 | 16.10 | 2.94 | 2.51 | 4.86 | 5.09 | 0.95 | 1.61 |
| | $LSD_{0.05}$ | | 0.32 | 0.46 | 0.12 | 0.36 | 0.21 | 0.03 | 0.11 | 0.17 | 0.09 | 0.06 |

The lowest Na contents in the beet root juice of 1.08 and 1.22% resulted from the Nimaless variety planted at 15 and 60 cm intra- and inter-row distances, and the variety Garrot planted at 15 and 50 cm intra- and inter-row distances in the first and second growing seasons, respectively. Meanwhile, planting the variety Husam at 10 and 50 cm intra- and inter-row distances produced the highest Na content of 1.69 and 1.64% in the first and second growing seasons, respectively. The desirable (lowest) contents of K in the beet root juice resulted from planting the variety Husam at 10 and 60 cm intra- and inter-row distances in the first growing season (4.01%), while in the second growing season the lowest K contents (4.22 and 4.22%) were produced from the variety Husam at 10 cm intra-row distance either under 50 and 60 cm inter-row distances. The Garrot variety cultivated at 10 and 50 cm intra- and inter-row planting distances produced the lowest α-amino-N (1.08 and 1.21%) in the first and second growing seasons, respectively. The highest quality index values of 79.27 and 81.85% in the first and second growing seasons, respectively, resulted from planting the Husam variety at 10 The obtained results may be due to that increasing intra-row planting distances led to increasing root mass and consequently, increasing the root juice impurities. Besides, the association between decreasing the sugar percentage and higher root yield under higher intra-row planting distances could be explained by the dilution effect (Shaheen et al. 2017). The results presented in Table 5 reveal significant variations among the four evaluated varieties, i.e., Nimaless and Garrot, Husam and Karam, in RY and RSY. The monogerm variety Garrot produced the highest root yield of 39.33 and 38.54 t fed$^{-1}$) and recoverable sugar yield (5.63 and 5.62 t fed$^{-1}$) in the first and second growing seasons, respectively. The superiority of the Garrot variety in these particular traits might be attributed to its genetic make-up that enabled to maximize light interception, enhance its photosynthetic capacity and partitioning more photoassimilates towards increasing storage root growth.

The interaction between inter- (50 cm, 60 cm) and intra- (10 cm, 15 cm) row planting distances revealed significant effects on RY and RSY in both growing seasons (Table 2). The highest root yield (39.04 and 38.13 t fed$^{-1}$) and recoverable sugar yield (5.87 and 5.77 t fed$^{-1}$) were produced from cultivating sugar beet at 15 cm intra-row distances and 50 cm inter-row distance in the first and second growing seasons, respectively.

Cultivating sugar beet at narrower inter-row distanes, such as 45 cm, has been reported to produce higher root and recoverable sugar yields because they help to compensate for poor plant establishment (Anonymous 1995). These results were clearly observed in our study where planting sugar beet at 10 and 50 cm intra- and inter-row distances resulted in the higher, root and recoverable sugar yields. Besides, Rice (1999) reported that there was a fall in root and sugar yields in response to planting sugar beet at wider distances. The obtained results are partially similar to those reported by Khozaei et al. (2020).

Increasing the intra-row planting distances from 10 to 15 cm was in favor of increasing sugar loss yield (from 0.74 and 1.26 to 1.08 and 2.17 t fed$^{-1}$ in the first and second growing seasons, respectively). As expected, and because of its lower potassium content, the variety Husam exhibited the lowest sugar loss% values of 2.38 and 2.47% in the first and second growing seasons, respectively. However, the monogerm variety Garrot produced the highest sugar loss yield (1.13 and 2.18 t $fed^{-1}$) in the first and second growing seasons, respectively. The interaction between inter- (50 cm, 60 cm) and intra- (10 cm, 15 cm) row planting distances revealed significant effects on SL% and SLY in both growing seasons (Table 6). The lowest sugar loss yields (0.50 and 0.97 t $fed^{-1}$), in the first and second growing seasons respectively, resulted from planting the sugar beet variety Husam at 10 and 60 cm intra- and inter-row planting distances, whereas planting the variety Garrot at 15 and 50 cm intra- and inter-row planting distances yielded the highest sugar loss yields (1.28 and 2.65 t $fed^{-1}$) in the first and second growing seasons, respectively (Table 10).

## Conclusion

Under the conditions of the present work, it is recommended that planting sugar beet at narrower intra- and inter-row distances (10 and 50 cm) produced the highest values of sucrose content, recoverable sugar%, Na content, and quality index (Qz%). Besides, the lowest values of K, α-amino-N content, sugar loss% and sugar loss yield were also produced from the same planting distances. The multigerm variety Husam produced the highest values of sucrose content, Na content, α-amino-N, quality index, and recoverable sugar. On the other hand, the monogerm variety Garrot produced the highest root yield, recoverable sugar yield and sugar loss yield.

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## الملخص العربى

# استجابة اصناف بنجر السكر للتوزيع الفراغي للنباتات

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اجريت هذة الدراسة فى المزرعة البحثية بشركة الدلتا للسكر - الحامول - محافظة كفرالشيخ خلال الموسمين الزراعيين 2020/2019 و 2021/2020 وذلك لتقدير إستجابة اربعة اصناف من بنجر السكر للتوزيع الفراغي للنباتات من حيث المحصول وصفات جودة العصير. تم استخدام تصميم القطاعات كاملة العشوائية للقطع تحت المنشقة فى ثلاث مكررات. اظهرت النتائج ان زيادة مسافة الزراعة بين الخطوط من 50 الى 60 سم ادت الى انخفاض معنوي في محتوى السكر ، نسبة الصوديوم ، محصول الجذور ، نسبة السكر القابل للاستخلاص ، دليل الجودة ومن ناحية اخرى ارتبطت زيادة مسافات الزراعة بين الخطوط بزيادة كبيرة فى محتوى كلا من البوتاسيوم والفا امين نيتروجين فى عصير جذور البنجر بالإضافة الى النسبة المئوية لفقد السكر ومحصول الفاقد من السكر. ادت زيادة مسافات الزراعة داخل الخط من 10 الى 15 سم الى انخفاض معنوى فى النسبة المئوية للسكر والنسبة المئوية لمحتوى الصوديوم دليل الجودة والسكر القابل للاستخلاص ومن ناحية اخرى ادت زيادة مسافات الزراعة داخل الخط الى زيادة معنوية فى كلا من النسبة المئوية لمحتوى البوتاسيوم والالفا امين النيتروجيني ، محصول الجذور ، نسبة فقد السكر ، محصول السكر القابل للاستخلاص وكذلك محصول السكر المفقود. اعطى الصنف حسام متعدد الأجنة اعلى قيم للنسبة المئوية لمحتوى السكر (19.48%) ومحتوى الصوديوم (1.63%) و محتوى الفا امين النيتروجينى (1.50%) ودليل الجودة (79.25%) ونسبة السكر القابل للاستخلاص (17.09%) فى حين اظهر اقل نسبة فقد للسكر. من ناحية اخرى اعطى الصنف جاروت احادى الأجنة اعلى محصول للجذور (39.33 طن/فدان) ومحصول السكر القابل للاستخلاص (5.63 طن /فدان) وفقد محصول السكر (2.18 طن /فدان). بشكل عام يمكن التاكيد على ان زراعة بنجر السكر على مسافات ضيقة داخل الخطوط وبين الخطوط (10 ،50سم) اعطت اعلى قيم لمحتوى السكر نسبة السكر القابل للاستخلاص ، محتوى الصوديوم ، دليل الجودة وفى نفس الوقت اعطت قيم اقل لمحتوى البوتاسيوم والالفا امين النيتروجينى ، نسبة فقد السكر ومحصول فقد السكر.



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