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Technical evaluation of transplanters' performance for potted seedlings

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Abstract: This research was conducted to evaluate the performance of disc, carrousel and dibble-type transplanters for potted tomato and watermelon seedlings in field conditions. Intra row distance, transplantation depth, the gripping force of seedlings to the soil, vertical position, damage of seedling and seedling survival rate were determined to evaluate performance of transplanters. The disc and carrousel-type transplanters place the seedlings into furrow and the dibble-type transplanter places the seedlings into the holes. According to field experiment results, distribution uniformity of intra row distance of dibble and carrousel-type transplanters were very well with the coefficient of variations between 3.52% and 5.55%. The highest transplantation depth was obtained when the carrousel-type transplanter was used. The disc and carrousel-type transplanters placed the seedlings into furrow, increasing the gripping force between seedlings and soil. The angle between the seedlings and vertical plane was under the 30° for all transplanters used. Only the disc-type transplanter damaged seedlings over 3%. The survival rate of seedlings for all transplanters were higher than 90% and this rate is acceptable for transplanting vegetable seedlings.

Key words: Seedling, tomato, transplanting, transplanters, watermelon

1. Introduction

Agriculture has become a sector where traditional and modern methods are used, as well-advanced technologies are included. The widespread use of mechanization in agriculture is one of the most important outputs of the use of technology in agriculture and it plays an important role in decreasing the production costs and increasing the profitability of enterprises, especially in agricultural production, reducing labour use and saving time. Turkey still lies behind developed countries in terms of the use of agricultural machinery. While the use of agricultural machinery is common for soil preparation, sowing, spraying, and harvesting, the use of it is not common for other agro technological processes in developing countries.

Most of the vegetable seeds are sown directly into the soil, while some seeds, such as of tomatoes, peppers and tobacco, are sown in pillows, soil pots, or soil blocks before planting into the field. Once the seeds are germinated, the seedlings have to grow until they reach the proper size for transplanting and strength enough for transportation, then they are transplanted for growth and maturation (Kumar and Raheman, 2008; Ren et al., 2022; Sharma and Khar 2022).

Many vegetables (tomato, pepper, eggplant) are started growing from seeds indoors, and then transplanted into the field. The seeds of these plants need a very large growing area, are sensitive to various adverse effects, and therefore require special care. During germination and initial cultivation period, they require adequate temperature, sufficient moisture and abundant nutrients. These conditions can only be achieved in controlled environments. Later the seedlings of these plants are transplanted into the parcels in the field. One of the benefits of this method is the prolonged growth period of vegetables, especially those affected by adverse weather conditions in the spring.

Turkey is one of the largest vegetable producers in the world. It is known, that 72% of the total vegetable production is performed by developing countries. The transplanting operation is one of the most labour intensive in vegetable production (Kumar and Raheman, 2008). It is mostly done by hand in Turkey and in the majority of developing countries and causes large investments in labour, time, and cost. Manual transplanting is not only time-consuming, but also a tedious method. In manual transplanting, a farmer may be able to plant six seedlings per minute, 360

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seedlings per hour, and works constantly leaning while transplanting. Moreover, during the transplanting period, usually there is a labour shortage. This results in increased labour wages and a delayed transplanting operation. Therefore, the need for a structurally simple, functionally accurate, and economically feasible vegetable transplanter is obvious in the vegetable growing areas of Turkey and other countries.

For seedlings to grow well in the soil, proper seedling habitat must be prepared before transplanting. This preparation is done by soil tillage. Cay and Aykas (2012, 2013) compared two conventional, two reduced and three direct transplanting methods used in tomato production. Disc-type furrow opener was modified and new rippled discs were mounted on the conventional carrousel-type transplanter to make successful transplanting into the direct transplanting plots covered by plant residues. As a result of these researches, the most suitable method was the conventional tillage method. However, the direct transplanting method with cover cropping may be an alternative to conventional tillage methods. Kumar and Raheman (2011) developed a paper pot seedling transplanter powered by a 9.75 kW walk-behind type hand tractor. The field capacity of the vegetable transplanter was 0.026 ha h^{-1}. It assured savings of 68% of labour and 80% of the time when compared to conventional manual transplanting. The soil covering efficiency of the developed vegetable transplanter was about 81% and the quality of transplanting was satisfactory. Javidan and Mohammadzamani (2019) designed a tomato transplanter with a conical distributor cup (funnel). The row distance of seedlings, transplantation depth, vertical position of seedlings and the amount of physical damage to seedlings were determined for field conditions. The most appropriate forward speed was 2 km h^{-1} and transplantation depth was 5 cm. The results indicated that increasing the forward speed and transplantation depth, increased deviations from the adjusted seedling spacing, physical damage and vertical angle of seedlings. The lowest performance of the transplanter was observed at the depth of 10 cm and the forward speed of 3 km h^{-1}.

In this study, firstly, a method to evaluate the performance of transplanters was developed and then the performance of different types of transplanters designed for transplanting into holes or furrows was compared. The disc and carrousel-type transplanters place the seedlings into furrow and the dibble-type transplanter places the seedlings into holes (Kumar and Raheman, 2008). While the disc-type transplanters were designed for transplanting bare root seedlings, such as tobacco, it is also can be used for transplanting of some potted vegetable seedlings. Carrousel and dibble-type transplanters are more expensive therefore, disc-type transplanters are more common in Turkey and many developing countries. The carrousel and dibble-type transplanters were designed for transplanting either bare or potted root seedlings. It should be acknowledged that the scientific researches that investigate the transplanting performance of disc, carrousel, and dibble-type transplanters are rather limited.

As demand for potted seedlings for vegetable production in Turkey has increased, research is needed to determine the accurate type of transplanters. The main objective of this research was to compare different types of transplanters suitable for Turkey conditions and evaluate the work performance of potted seedlings in the field.

2. Materials and methods

2.1. Description of transplanters

The following transplanters were tested in this research:

1) disc-type transplanter designed for transplanting bare root seedlings into furrow,

2) carrousel-type transplanter designed for transplanting bare or potted root seedlings into furrow,

3) dibble-type transplanter designed for transplanting bare or potted root seedlings into the holes.

The potted tomato and watermelon seedlings were used for all experiments. These vegetables are mostly produced from potted seedlings in the Antalya region of Turkey. The characteristics of the tomato and watermelon seedlings are given in Table 1. Transplanting operation was completed in one day. Both tomato and watermelon seedlings were available on the same day of transplanting. The forward speed of all types of transplanters was 1.8 km h^{-1}. This forward speed is within the limits recommended by machine manufacturers and various research results (Onal, 2017; Kumar and Raheman, 2008; Karayel and Aytem, 2013).

The disc-type transplanter was equipped with elastic discs not to damage the seedlings. The seedlings were placed by the operator between the discs opened at the top. The discs are mounted at a certain angle relative to each other (Figure 1). The spacing between the seedlings in furrow is determined by the operator by placing marks on the discs.

Carrousel and dibble-type transplanters were designed to eliminate the problem of synchronization between the operator and the metering mechanism of transplanters and the stressful work of operator. The operator only feeds the magazine with seedlings and all subsequent operations are performed by the transplanter. The distance between the seedlings can be adjusted by changing the transmission ratio of the magazine drive (Onal 2017). In the carrousel transplanters, the seedlings placed by the operator in the magazine are transplanted into the furrow by free fall of seedlings. The placed seedlings into furrow are compressed by the press wheels (Figure 2).

Table 1. Characteristics of seedlings used in field experiments.

Characteristics	Tomato seedlings	Watermelon seedlings
Age of seedlings (day)	23–25	21–23
Leaf stage	4–5	4–5
Average height (mm)	145	140

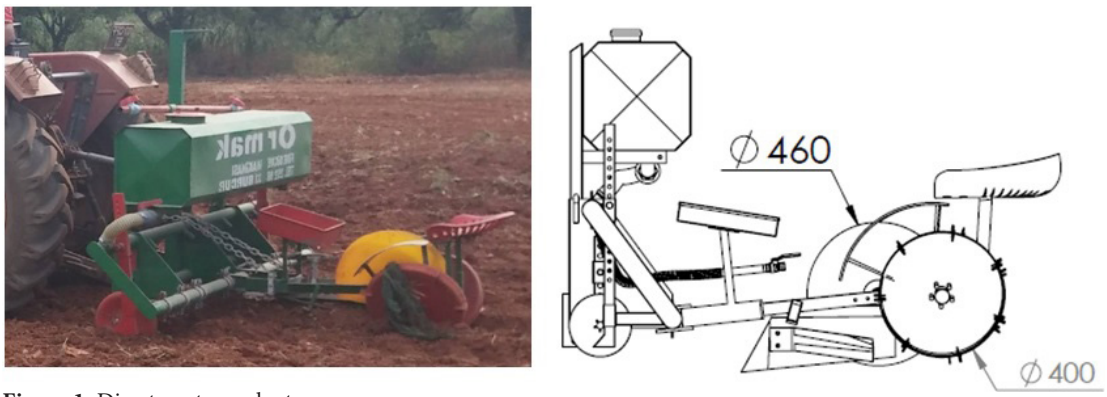


Figure 1. Disc-type transplanter.

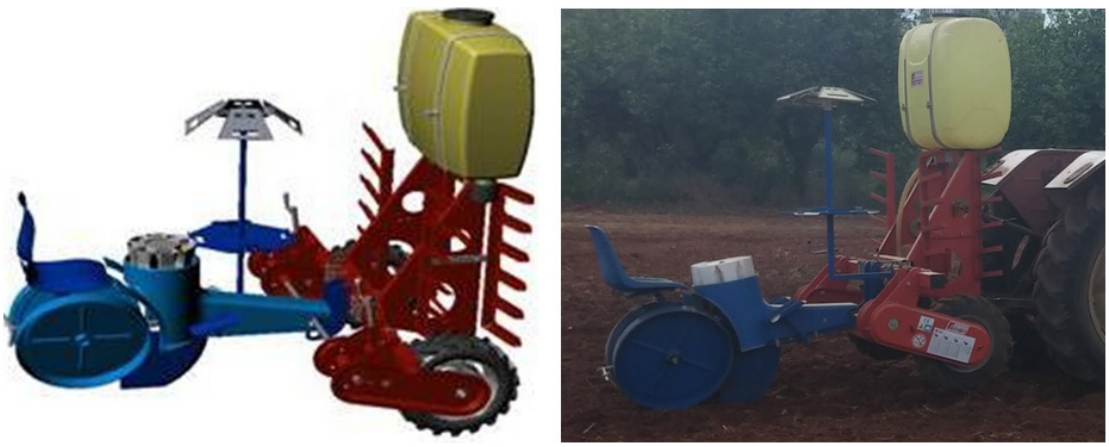


Figure 2. Carrousel-type transplanter.

In the dibble-type transplanter, the seedlings were placed in the small funnel by the operator. When the lower part of the articulated funnel with seedling falls into the soil, the lower part of the funnel opens and leaves the seedling in the soil (Figure 3).

Carrousel and dibble-type transplanters allow the operator to locate several seedlings fast and then to have a short time to pull out or remove seedlings from cell tray rather than having to maintain exact timing for each seedling for disc-type transplanter. Carrousel and dibble-type transplanting units are usually used for transplanting pot seedlings in a semiautomatic vegetable transplanters.

2.2. Experimental design

Experiments were carried out according to a randomized complete plot design and the F test for analysis of variance was applied to estimate statistically significant differences between the means of treatments. Duncan's Multiple-Range Test was applied to detect significantly different treatment means within dependent variables. The experimental field was divided into four plots and the treatments shown in Figure 4 were randomly applied to the plots. The dimensions of each plot are 12 m × 20 m.

Seedling bed was prepared using the conventional tillage method (including ploughing, disc harrowing, and



Figure 3. Dibble-type transplanter.

Manual transplanting of tomato seedlings (Reference parcel)	Transplanting of tomato seedlings using disc-type transplanter	Transplanting of tomato seedlings using carrousel-type transplanter	Transplanting of tomato seedlings using dibble-type transplanter

Manual transplanting of watermelon seedlings (Reference parcel)	Transplanting of watermelon seedlings using disc-type transplanter	Transplanting of watermelon seedlings using carrousel-type transplanter	Transplanting of watermelon seedlings using dibble-type transplanter

Figure 4. Transplanting methods of potted root seedlings.

levelling) before transplanting. To determine the planting quality of the transplanters (performance of transplanters), the measurements were made after transplanting operation, the results obtained from these measurements were evaluated statistically.

2.3. Intra row distance of seedlings

The seedlings were transplanted in a 20 m-long furrow and at least 6 rows of tomatoes and 12 rows of watermelons were transplanted for each treatment. Transplanters were adjusted according to seedling spacing recommendations by the producer of seedling. Theoretical spacing between the tomato seedlings was 50 cm for disc and carrousel-type transplanters and 51 cm for dibble-type transplanters. For watermelon transplanting, it was 100 cm for disc and carrousel-type transplanters and 102 cm for dibble-type transplanters. The distance between each seedling was measured and average seedling spacing and coefficient of variation of these spacings were calculated. The coefficient of variation of seedling spacings over the row was evaluated according to Table 2 (Ministry of Agriculture and Forestry, 1999; Karayel and Aytem, 2013).

2.4. Transplantation depth

The depths of the seedlings roots incorporated into the soil were measured in the vertical plane. Depth measurements were made on randomly removed 30 seedlings for each row. From these measured values, the average planting depth and the coefficient of variation of the planting depth was calculated. According to Karayel and Aytem (2013), the coulter of the transplanter should be able to open the furrow or hole up to a depth of 15 cm and the average coefficient of variation of transplanting depth should be not more than 15%.

2.5. The gripping force of seedlings in the soil

Each of the seedlings was pulled from the furrow to determine the amount of compression of the seedlings in the soil, and soil adhesion force of the seedlings was measured approximately 10 days after transplanting. Thirty random seedlings from each row were pulled upwards in the upright position and the force required to remove them from the soil was measured. The minimum pulling force required to remove the seedlings from the soil should be over 3 N for an acceptable transplanting (Ministry of Agriculture and Forestry, 1999; Karayel and Aytem, 2013). The penetration resistance of the soil for the top 100 mm was 1.3 MPa.

2.6. Vertical position of seedlings in soil

The vertical positions of the seedlings were determined by measuring the vertical angle of 30 seedlings randomly chosen from each row. Thus, it was assessed whether the transplanting equipment was opened at the exact time. For an acceptable transplanting quality, the vertical angle of seedlings should not exceed 30° (Ministry of Agriculture and Forestry, 1999; Karayel and Aytem, 2013).

2.7. Damage of seedlings

The damaged ones of 30 seedlings randomly selected after transplantation were identified. Transplanters should not

Table 2. Evaluation of intra-row distance of transplanting (according the Ministry of Agriculture and Forestry, 1999, Karayel and Aytem 2013).

Coefficient of variation of seedling spacing – CV (%)	Evaluation
≤5	Very good
5.1–10	Good
10.1–15	Moderate
15.1–20	Sufficient
>20	Insufficient

cause more than 3% of seedlings damage. Breakage of more than one leaf or other parts of the seedling are considered as damage (Ministry of Agriculture and Forestry, 1999; Karayel and Aytem, 2013).

2.8. Survival rate of seedlings

The seedling survival rate was calculated by dividing the living seedlings by the total transplanted seedlings for each row. Living seedlings were counted four days after transplanting. The seedling survival rate should not be less than 90% for acceptable transplanting quality (Ministry of Agriculture and Forestry, 1999; Karayel and Aytem, 2013).

3. Results and discussion

3.1. Comparison of intra row distance of seedlings

The spacing between the adjacent seedlings of transplanted tomato and watermelon seedlings were measured in the row and statistical analysis was carried out to compare the measured spacings. Mean seedling spacing and the coefficient of variation are presented in Table 3.

According to the results of the statistical analysis, the differences between the adjacent tomato and watermelon seedlings spacing were statistically significant. This difference may be caused by the operator in the disc-type transplanter and the transmission ratio in carrousel and dibble-type transplanters, which cannot be adjusted to provide equal seedling spacing.

The coefficient of variation of seedling spacing is an important indicator of uniform distribution of seedlings resulting equal growing area per plant. Uniform seedling spacing results in better germination and emergence and increases the yield by minimizing competition between plants for available light, water, and nutrients. The lowest coefficient of variation was obtained for the dibble-type transplanter (Table 3). The coefficient of variations for carrousel and dibble-type transplanters were between 3.52% and 5.55% and it can be stated as good or very good transplanting quality according to Karayel and Aytem (2013). Dihingia et al. (2016) and Javidan and Mohammadzamani (2019) stated that transplanting mechanisms (seedling distributor) of carrousel and dibble-type transplanters are driven by the land wheel of transplanters. Therefore, the metering mechanisms are fixed in a certain seedling spacing (independent of forward speed). This situation provided more uniform seedling spacing for carrousel and dibble-type transplanters than the disc-type transplanter.

3.2. Comparison of transplantation depth

As a result of experiments using potted root tomato and watermelon seedlings, the transplanting depth values of disc, carrousel and dibble-type transplanters were compared by performing an analysis of variance. According to the results of the analysis shown in Table 4, the effect of the transplanters on the depth was significant and the highest depth of transplanting was obtained for the carrousel-type transplanter. The coulter used in the carrousel-type transplanter caused the transplanting depth to be higher

Table 3. Comparison of intra-row distances of transplanters.

Transplanters	Seedling spacing (cm)	Coefficient of variation (%)	Deviation from theoretical seedling spacing (cm)	Evaluation
Tomato seedlings				
Disc-type	49.76[c]	20.77	0.24	Insufficient
Carrousel-type	53.15[b]	5.55	3.15	Good
Dibble-type	54.25[a]	4.83	3.25	Very good
Watermelon seedlings				
Disc-type	98.88[c]	14.50	1.12	Moderate
Carrousel-type	105.86[b]	4.23	5.86	Very good
Dibble-type	107.83[a]	3.52	5.83	Very good

[a, b, c] Seedling spacings within a group followed by different letter are significantly different, according Duncan's multiple range test ($p < 0.05$).

Table 4. Comparison of transplanting depths of transplanters.

Transplanters	Transplanting depth (mm)	Coefficient of variation (%)
Tomato seedlings		
Disc-type	74.46[c]	11.4
Carrousel-type	88.18[a]	10.6
Dibble-type	83.25[b]	9.7
Watermelon seedlings		
Disc-type	78.88[c]	12.5
Carrousel-type	91.86[a]	10.2
Dibble-type	87.83[b]	9.5

[a, b, c] Transplanting depths within a group followed by different letter are significantly different, according Duncan's multiple range test ($p < 0.05$)

than that of the disc and dibble-type transplanters. The lowest coefficient of variation was obtained for the dibble-type transplanter. According to Karayel and Aytem (2013), the coulters of the transplanters must place the seedlings at a depth of up to 15 cm depending on the size and variety of the seedlings. Javidan and Mohammadzamani (2019) suggest that a vegetable transplanter with conical distributor cup (dibble-type transplanter) must place the seedlings at a depth of up to 13 cm. The coefficient of variation determining the uniformity of the transplanting depth should not exceed 15%. The variation coefficients in Table 4 are below 15% and are within acceptable limits.

3.3. Comparison of the gripping force of seedlings in the soil

The results of the gripping force of tomato and watermelon seedlings were compared by analysis of variance and the data are presented in Table 5. According to the results of the analysis, the effect of the transplanters on the gripping force of seedlings is statistically significant ($p < 0.05$). It was determined that the disc and carrousel-type transplanters placing the seedling into the soil by opening the furrow increase the gripping force of seedlings. For acceptable transplanting quality according to Karayel and Aytem (2013), it is desirable that the seedlings transplanted by the machine are pressed and compressed in such a way that it is not rooted out from the soil when pulled with a force under the 3 N. The values in Table 5 are above 3 N and are within acceptable limits.

3.4. Comparison of the vertical position of seedlings in the soil

According to the results of the statistical analysis presented in Table 6, it was estimated that disc and carrousel-type transplanters increased the vertical angle of the seedlings.

Table 5. Effect of transplanters to seedling gripping force in the soil.

Transplanters	Seedling gripping force (N)
Tomato seedlings	
Disc-type	16.3[a]
Carrousel-type	16.1[a]
Dibble-type	11.2[b]
Watermelon seedlings	
Disc-type	15.8[a]
Carrousel-type	17.1[a]
Dibble-type	11.9[b]

[a, b] Seedling gripping forces within a group followed by different letter are significantly different, according Duncan's multiple range test ($p < 0.05$)

Table 6. Effect of transplanters to vertical seedling position.

Transplanters	Vertical seedling position (°)
Tomato seedlings	
Disc-type	17.8[a]
Carrousel-type	15.2[a]
Dibble-type	11.1[b]
Watermelon seedlings	
Disc-type	18.8[a]
Carrousel-type	17.1[a]
Dibble-type	11.6[b]

[a, b] Vertical seedling position within a group followed by different letter are significantly different, according Duncan's multiple range test ($p < 0.05$)

It is because these transplanters open the furrow and place the seedling into the furrow. Placing the seedling into the holes by the dibble-type transplanter decreased the vertical angle of the seedlings. Javidan and Mohammadzamani (2019) obtained similar results for dibble-type transplanters while transplanting tomato seedlings at the depth of 10 cm. They also reported that the speed and depth factors have a significant effect on the vertical angle of the transplanted seedlings.

According to Karayel and Aytem (2013), it has been reported that the vertical angle of the transplanted and compacted seedlings for an acceptable transplanting quality should not exceed 30°. The average angle data for all three transplanters were below 30° and are within acceptable limits for transplanting quality.

3.5. Comparison of seedling damage

According to Kumar and Raheman (2011), Karayel and Aytem (2013), and Javidan and Mohammadzamani (2019), it has been reported that transplanters should not cause more than 3% of seedlings damage. As shown in Table 7, only a disc-type transplanter damaged more than 3% of both tomato and watermelon seedlings. Placing only the leafy part of seedlings between the elastic discs of the transplanter possibly increased damage of seedlings. The reason is that the potted roots of seedlings are heavier than the leafy parts, and leaves cannot carry the weight of the potted roots. In the experiment, the lowest rate of damage was obtained in the dibble-type transplanters.

Table 7. Effect of transplanters to damage of seedlings.

Transplanters	Damage of seedlings (%)
Tomato seedlings	
Disc-type	7.8[a]
Carrousel-type	1.9[b]
Dibble-type	<0.1[c]
Watermelon seedlings	
Disc-type	8.9[a]
Carrousel-type	2.1[b]
Dibble-type	<0.1[c]

[a, b, c] Seedling damage rates within a group followed by different letter are significantly different, according Duncan's multiple range test ($p < 0.05$)

3.6. Comparison of survival rate of seedlings

To determine the survival rate of the seedlings used in the experiments in the field conditions, 30 seedlings were manually transplanted and it was found that all of these seedlings survived (the survival rate of seedlings was 100% for manual transplanting). Seedling survival rates were found to be sufficiently high (94%–98%) for all transplanters tested. The survival rate of carrousel and dibble-type transplanters was higher than that of disc-type transplanter by 2%–4%. Satpathy and Garg (2008) and Dihingia et al. (2017) reported that transplanting depth, seedling position, and seedling damage of transplanters are effective factors influencing the survival rate of seedlings. More uniform transplanting depth, lower seedling damage, and vertical angle of the seedlings using carrousel and dibble-type transplanters resulted in higher survival rates of tomato and watermelon seedlings.

The lowest value of vegetable seedling survival rate according to Karayel and Aytem (2013) should be 90%. The average survival rates of both tomato and watermelon seedlings were found to be within acceptable limits (Table 8).

Table 8. Effect of transplanters to survival rate of seedlings.

Transplanters	Survival rate of seedlings (%)
Tomato seedlings	
Disc-type	96[b]
Carrousel-type	98[a]
Dibble-type	98[a]
Watermelon seedlings	
Disc-type	94[b]
Carrousel-type	96[a]
Dibble-type	98[a]

[a, b] Survival rates within a group followed by different letter are significantly different, according Duncan's multiple range test ($p < 0.05$)

4. Conclusions

This research was conducted to determine the performance of the different types of transplanters developed for transplanting into the hole (dibble-type transplanter) or furrow (disc and carrousel-type transplanters) for potted root tomato and watermelon seedlings. The following results were obtained:

The lowest variation coefficient of seedling spacing was obtained for the dibble-type transplanter. Both carrousel and dibble-type transplanters were found to be suitable in terms of the coefficient of variation of seedling spacing. The seedling spacing uniformity of tomato seedlings, with a coefficient of variation of 20.77%, was insufficient only for the disc-type transplanter. The effect of transplanters on transplanting depth was statistically significant. The highest transplanting depth was obtained for carrousel-type transplanter.

Disc and carrousel-type transplanters opened the furrow for placing the seedlings into the soil. Therefore, it increased the gripping force of seedlings from the soil. The vertical angle of the seedling was below 30° and within acceptable limits for all tested transplanters.

Only the disc-type transplanter's damage rate was higher than the critical value of 3% in the experiment. The lowest rate of damage was obtained by the dibble-type transplanter. Average survival rates for tomato and watermelon seedlings were higher than 90% for all the transplanters tested and therefore are within acceptable limits.

Similar results were obtained for both tomato and watermelon seedlings. Only the coefficient of variations of the spacings of tomato seedling were slightly higher than those of watermelon seedling for all types of transplanters.

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