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The Effects of Grafting on Plant, Fruit and Seed Quality in Cantaloupe (*Cucumis melo* L. var. *cantalupensis*) Melons

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Abstract: Grafting techniques are being used to improve economically important horticultural crops including *Cucumis melo* L. This 2-year study was carried out at Cukurova University, Adana, Turkey. This study aimed to evaluate the effects of grafting using different rootstocks on plant, fruit and seed quality in cantaloupe melons. The double haploid (DH) female (H27) and male (H4) parental lines of Solmaz F_1 (*Cucumis melo* L. var. *cantalupensis*) variety developed by Cukurova University Faculty of Agriculture were used as scion and three commercial interspecific hybrid *Cucurbita* (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) varieties, Nun-9075 F_1 (Nunhems), Ares F_1 (ITU) and TZ-148 (Clause) were used as rootstocks. The parental lines were also self grafted and ungrafted parents were used as the control group. The grafted and ungrafted parents were crossed during pollination. Graft combinations and control were compared for performances in measured parameters such as the main stem length (cm), main stem diameter (mm), node number, harvest time (day), fruit weight (g), fruit length (cm), fruit diameter (cm), fruit cavity length (cm), fruit cavity diameter (cm), fruit flesh thickness (cm), fruit rind thickness (mm), total soluble solids (TSS, %), fruit flesh productivity (%), number of full and empty seeds (number/fruit), 1000 seeds weight (g), seed germination rate (%) and time (day), seed emergence rate (%), and time (day). Most of the plant, fruit and seed parameters have been positively affected by grafting. The use of commercial interspesific *Cucurbita* hybrid rootstocks resulted in high values compared to the control group however, harvest time, fruit cavity length and diameter, fruit rind thickness and fuit flesh productivity parameters were not statistically significant between rootstocks. Considering seed emergence and germination rate *Cucurbita* hybrid rootstocks performed lower values than self grafted and ungrafted control. The current study concludes that grafting plays a crucial role in plant growth, fruit and seed characters in cantaloupe melons. Statistically significant differences were mostly observed based on evaluated parameters.

Keywords: *Cucumis melo* L.; cantaloupe; hybrid; grafting; seed production

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1. Introduction

Melon (*Cucumis melo* L.), a species of the *Cucurbitaceae* family, is one of the most important vegetable crops since ancient times, and is cultivated in the warm season [1–3].

Melon's origin has been discussed for a long time and is still unclear. Due to the number of wild *Cucumis* specimens, and followed by subsequent taxonomy and molecular data, Africa was thought to be the area where melon was domesticated [2,4,5]. In the year of 2020, 28.5 M tons of melons were grown in the world. China is the world's first melon producer with 13.8 million tons and followed by Türkiye with 1.7 M tons of melon [6].

Grafting is a combination of two plant parts as a single plant by combining them with certain techniques. The use of grafted seedlings is spreading day by day and depends on the establishment of suitable methods and the development of strong rootstocks through breeding [7–9]. The benefits of grafting in plants are based on economizing and facilitating

agriculture including increase hybrid vigor, prevent soil-borne diseases and pests when there is a genetic deficiency for disease management [10], increase efficiency, raise the yield and quality, increasing environment protection when using different chemicals like pesticides, expanding the production area (arid and saline areas, hot-cold areas etc.), broadening the production seasons including heat, cold, and etc [11–15].

In melon, *Cucurbita* interspecific hybrids (*Cucurbita maxima* × *Cucurbita moschata*) are widely used as rootstock. Some rootstocks that have been studied but not yet used commercial including *Cucumis metuliferus*, *Luffa cylindrica*, *Benincasa* hispida, and *Lageneria sicerena* [16]. The main purpose of grafting in melons is to provide resistance to soil-borne diseases (*Monosporascus cannonballus*, *Fusarium oxysporum f.* sp. *melonis* (*Fom*) and *Stagonosporopsis* spp. and root-knot nematodes (*Meloidogyne incognita* and *M. Javanica*) [12,17–19] to increase the yield, quality, aroma and carotenoid contents, salinity and drought tolerance, nutrient intake and tolerance to nutrient deficiency [20–23]. According to the various studies also it has been determined that rootstock-scion combinations affect pH, flowering, sugar, color, carotenoid content and fruit surface [24–30]. Melons like other cucurbit plants require relatively higher temperatures than other species, seedlings grafted onto *Cucurbita* rootstocks were used for cultivation at low soil temperatures and earliness [31]. Furthermore, grafted seedlings have increased in melons, and have been limited especially in cantaloupe melons due to low rootstock-scion compatibility [32].

Production and fruit quality decreases as rootstock and scion can not be matched in grafting system. Therefore, the selection of combination should be done in the best way [23]. For instance, in melons grafted onto *Cucurbita ficifolia*, the transfer of photosynthetic substances from scion to the rootstock is prevented due to the incompatible rootstock-scion combination [33,34]. In the selection of the appropriate rootstocks, biotic and abiotic stress conditions of plants are considered [30,35], for instance, resistance/tolerance to soil-borne pathogens like *Fusarium oxysporum f.* sp. *melonis* [35–37], salinity tolerance [38,39], tolerance to low and high soil temperatures [40–43]. It has been observed that RNA, protein, and small molecules can be transported from the rootstock to the scion and directly affect the scion physiology [30].

Currently, in melons, the most common used grafting method is F1 hybrid which ensures healthy dominant genes in a single genotype [44]. The F1 varieties are technically superior in case of arising yield, earliness, quality, uniformity, length of vegetation period, disease and pest tolerance, shorter time to produce new varieties, and high adaptability [23]. The F1 hybrid seeds are obtained by the hand pollination of a female parent by male parent. It is a time consuming and expensive seed production method. In hybrid seed production, high quality and quantity is desired, however in some occasions low amount and empty seeds are acquired and it results in time and financial losses.

Though there have been several studies performed on grating in melons [2,17,45,46], there has been no study which carried out an the evaluation of the effects of grafted seedlings on hybrid seed production. The current research is based on the hypothesis that grafting melons onto different rootstocks affects plant growth, fruit quality, and seed quality. The present study, therefore, focused on the determination of the effects of grafting cantaloupe melons onto different rootstocks on plant growth, fruit, and seed quality.

2. Materials and Methods

This study was carried out in 2018 and 2019 in the plastic greenhouse at the Research Application Area of Horticulture Department (latitude 37°1′48.63″ N, longitude 35°22′3.74″ E, altitude 56 m), and the seed analysis were performed in the Seed Technology Laboratory of Department of Horticulture, at Cukurova University, Adana, Turkey.

2.1. Plant Material

The DH female (H27) and male (H4) parents of Solmaz F_1 (*Cucumis melo* L. var. *cantalupensis*) varieties have developed by Cukurova University, Faculty of Agriculture were used as scion while three commercial interspecific hybrid *Cucurbita* (*Cucurbita maxima*

Duchesne × *Cucurbita moschata* Duchesne) varieties, Nun-9075 F_1 (Nunhems), Ares F_1 (ITU) and TZ-148 (Clause) were used as rootstocks in this study Table 1. A total of 400 healthy seedlings including the plants of the scion, rootstocks varieties and grafted combination (ten plants from each genotype/variety) used in this study were planted in a plastic greenhouse of double rows with (100–50) × 50 cm spacing distances within four repetitions. The seed sowing, grafting, and all required maintenance for the grafted seedlings were performed at the nursery of Antalya Tarım Productive, Consultant and Marketing Co. in Antalya. Plants were grown in a completely randomized design and all plant cultivation, maintenance, diseases, and pests control processes were applied.

Table 1. Plant material use in the experiment.

H27 (DH Female Parent Scion)	H4 (DH Male Parent Scion)
Nun-9075 F_1 (Nunhems)/H27	NUN-9075 F_1 (Nunhems)/H4
Ares F_1 (ITU)/H27	ARES F_1 (ITU)/H4
TZ-148 (Clause)/H27	TZ-148 (Clause)/H4
H27/H27	H4/H4
Control-H27 (ungrafted)	Control-H4 (ungrafted)

Nun-9075 F_1 (Nunhems), Ares 103 F_1 (ITU) and TZ-148 (Clause) were used as rootstocks, and with/H27 and/H4 indicate parent scions.

2.2. Pollination

Female flowers of H27 line and male flowers of H4 line for each graft combination and control were closed with clips in the afternoon of the day before anthesis and pollination was done the next day between 6:00 and 9:00 a.m. A H4 male parent was used for pollen provision to all other graft combinations and control. And only one fruit was allowed for every plant.

2.3. Analyzed Parameters

Plant measurements, harvesting, fruit and seed analysis were conducted after two months after transplanting. Plant growth measurements were made on main stem length (cm) by using a measuring tape, diameter of the main stem (mm), was measured by using a digital vernier caliper (Mitutoyo CD-15D), and number of nodes were counted from the base to the tip of the main stem length. Five plants were measured in each replication. Fruits were harvested having completely dried stipule and tendrils on the same node [47]. The 3 fruits of each replication were taken for fruit analysis regarding of mean fruit weight (g) by weighing balance, fruit length (cm), fruit diameter (cm), fruit flesh thickness (cm), fruit rind thickness (mm), fruit cavity length (cm) and diameter (cm), total soluble solids (TSS %) was determined by using digital hand refractometer (ATAGO Pocket Refractometer, Japan), number of full and empty seeds (number/fruit), full seeds and 1000 seeds weight (g) were weighed by digital balance. Seed were germinated and emergenced in the incubator at 25 °C.

2.4. Seed Analysis

To avoid the damage of seeds, the selected fruits were shallow cut longitudinally and the seeds were extracted by hand and putting them into plastic bags covered well. Every replicate was put in a separate container and kept in room of the high temperature for 4 days to be fermented. After fermentation, seeds were washed with clean water. The well-washed seeds were placed on very fine wire mesh and left on racks at 25 °C to dry. Some of the well-dried seeds from selected fruits in each replication were counted and weighed for seed number per fruit and weight of 1000 seeds determination and used in other seed quality analyses.

In the seed quality experiments, seeds were analyzed for germination and emergence rates. Before, all seeds tested the seed sterilization steps were performed by using 3% sodium hypochlorite for 10 min [48]. In the seed germination test (between filter paper) in petri dishes within 4 replications, 10 seeds of each replicate were used. Seeds were placed between blot paper in petri dishes, slightly moistened, and stored in the incubator (Memmert, Germany) at 25 °C. Germinated seeds were counted daily and removed, and

finally germination percentage and germination rate were calculated. The collected inert sand was sterilized in an autoclave at 121 °C for 1 h, and then left to cool in preparation for the seed emergence test. For each graft combination and control, seeds were sown in a plastic tray of 45 cm × 30 cm × 8.5 cm within 4 replications, and 10 seeds of each replicate were used and left on the shelves at room temperature. Thus, emerged seeds were counted by appearing of the protruding plumule above the surface.

2.5. Statistical Evalation

The SAS based JMP 8.1 statistics package program was used to evaluate the obtained data. The results were compared with LSD test at 5% significance level. Comparisons that yielded *** = $p \leq 0.001$, ** = $p \leq 0.01$ and * = $p \leq 0.05$ were considered to be statistically significant. All percentages were transformed to arcsin values for variance analysis.

3. Results

3.1. Plant Measurements

All data for plant analysis such as main stem length (cm), main stem diameter (mm), and number of nodes are presented in Table 2. The longest main stem was obtained from Nun9075/H27 combination with 350.07 cm. Also, in combination average Nun9075/H27 found to be the superior (270.93 cm). In terms of main stem diameter average, the thickest plant was observed from Ares/H4 graft combination with 9.06 cm followed by Nun9075/H4 combination with 8.99 cm. Based on number of node Ares/H4 and Ares/H27 have the highest values (38.67 mm, 38.92 mm) respectively in second year, while Ares/H27 showed the highest number of nodes in the graft combination average with 34.04.

Table 2. Main stem length, main stem diameter and node number in both years.

Graft Combinations	Main Stem Lenght (cm)			Main Stem Diameter (mm)			Node Number		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H4 (Control)	124.92 k	252.44 ef	188.68 F	7.82 fgh	8.02 e–h	7.97 BC	18.89 g	33.33 cde	26.11 D
H4/H4	186.17 ij	268.00 de	227.08 C	8.27 c–h	7.88 fgh	8.07 BC	29.67 ef	33.89 bcd	31.78 ABC
H27 (Control)	119.44 k	273.11 cde	196.28 EF	6.14 i	7.63 gh	6.89 D	19.67 g	37.50 ab	28.08 D
H27/H27	176.33 j	283.44 cd	229.89 C	7.43 h	7.75 gh	7.59 C	27.33 f	34.89 abc	31.11 BC
TZ 148/H4	195.17 hij	242.83 f	219.00 CD	8.90 a–e	8.11 d–h	8.51 AB	29.08 f	28.83 f	28.96 CD
TZ 148/H27	204.11 hi	292.56 c	248.33 B	7.88 fgh	8.40 b–g	8.14 BC	37.58 ab	28.33 f	32.96 AB
Ares/H4	195.00 hij	217.00 gh	206.00 DE	9.04 a–d	9.09 abc	9.06 A	29.17 f	38.67 a	33.92 AB
Ares/H27	189.33 ij	321.92 b	255.63 AB	8.61 b–f	9.25 ab	8.93 AB	29.17 f	38.92 a	34.04 A
Nun9075/H4	203.22 hi	238.44 fg	220.83 CD	9.56 a	8.43 b–g	8.99 A	30.42 def	35.78 abc	33.10 AB
Nun9075/H27	191.78 ij	350.07 a	270.93 A	8.68 a–f	8.55 b–g	8.61 AB	29.11 f	33.56 b–e	31.33 ABC
Year avg.	178.55 B	273.98 A		8.24	8.31		26.98 B	35.29 A	
$N_{(Year)}$ ***: 16.30; $N_{(Genotype)}$ ***: 16.30; $N_{(Genotype \times year)}$ ***: 16.30			$N_{(Year)}$: NS, $N_{(Genotype)}$ ***: 0.66; $N_{(Genotype \times year)}$ ***: 0.66				$N_{(year)}$ ***: 2.89; $N_{(Genotype)}$ ***: 2.89; $N_{(Genotype \times year)}$ ***: 2.89		

N: Significant; NS: Not Significant; ***: $p \leq 0.001$: shows difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

3.2. Fruit Analysis

Fruit traits such as fruit weight (g), fruit length (cm), fruit diameter (cm), fruit cavity length (cm) fruit cavity diameter (cm), fruit flesh thickness (cm), fruit rind thickness (mm), total soluble solids (TSS %), and fruit flesh productivity (%) for graft combinations and control group in both years are presented in Tables 3–6. The harvest time was non-significant among the combination averages and found to be between 29.42 and 30.90 days, however the fruits were harvested earlier in the second year. According to combination averages, the heaviest fruits were obtained from Nun9075/H27 × H4 combination with 1508.13 g. While the year and genotype interaction was statistically important, 1700 g average fruit weight was produced by Nun9075/H27 × H4 graft combination in the second

year (Table 3). The longest and widest fruits were observed in second year as 12.88 cm and 14.16 cm respectively. Based on average fuit length TZ 148/H27 × H4 (12.75 cm), Nun9075/H27 × Nun9075/H4 (12.68 cm), Ares/H27 × H4 (12.64 cm), Nun9075/H27 × H4 (12.61 cm) TZ 148/H27 × TZ 148/H4 (12.60 cm) graft combinations were superior, however the year and genotype interaction was not statistically significant (Table 3). Considering fruit diameter TZ 148/H27 × TZ 148/H4 combination had the highest value (13.08 cm) followed by TZ 148/H27 × H4 combination (13.01 cm). Moreover, the interaction of year and genotype was nonsignificant for flesh thickness, the mean value was obtained in the second year by 3.49 cm and was mentioned as the thickest flesh. The highest combination average was obtained from TZ 148/H27 × H4 (3.31 cm) TZ 148/H27 × TZ 148/H4 (3.27 cm) and Nun9075/H27 × H4 (3.21 cm) respectively. The acerage fruit rind thickness was 7.77 mm in the second year. Also in the same year the thickest rind (9.05 mm) was determined from Ares/H27 × Ares/H4 graft combination (Table 4).

Table 3. Harvest time, Fruit weight and Fruit length of different graft combinations in both years.

Graft Combinations	Harvest Time (day)			Fruit Weight (g)			Fruit Length (cm)		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H27 × H4	32.38	29.42	30.90	1141.85 hi	1400.00 de	1270.93 DE	9.67	12.35	11.01 C
H27/H27 × H4	32.08	29.11	30.60	1079.86 i	1271.85 e	1175.86 E	11.16	11.81	11.48 BC
H27/H27 × H4/H4	31.88	29.67	30.77	1084.34 i	1260.00 de	1172.17 E	10.87	12.24	11.55 BC
TZ 148/H27 × H4	31.75	28.08	29.91	1278.89 fgh	1460.00 de	1369.44 BCD	12.63	12.87	12.75 A
TZ 148/H27 × TZ 148/H4	30.58	28.92	29.75	1352.16 d–g	1560.00 abc	1456.08 AB	12.47	12.88	12.60 A
Ares/H27 × H4	30.75	28.70	29.50	1238.66 gh	1628.89 ab	1433.77 AB	10.92	13.08	12.64 A
Ares/H27 × Ares/H4	32.25	28.75	30.50	1081.11 i	1486.67 cd	1283.89 CD	11.57	13.30	12.11 AB
Nun9075/H27 × Nun9075/H4	32.33	28.71	30.52	1207.78 ghi	1557.78 bc	1382.78 BC	11.66	13.71	12.68 A
Nun9075/H27 × H4	30.58	28.25	29.42	1316.25 efg	1700.00 a	1508.13 A	12.19	13.65	12.61 A
Year avg.	31.62 A	28.79 B		1197.88 B	1480.58 A		11.46 B	12.88 A	
$N_{(year)}$ ***: 1.13; $N_{(Genotype)}$: NS; $N_{(Genotype \times year)}$: NS				$N_{(year)}$ ***: 103.65; $N_{(Genotype)}$ ***: 103.65; $N_{(Genotype \times year)}$: NS			$N_{(year)}$ ***: 0.99; $N_{(Genotype)}$ **: 0.99; $N_{(Genotype \times year)}$: NS		

N: Significant; NS: Not Significant; ***: $p \leq 0.001$; **: $p \leq 0.01$: shows difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

Table 4. Fruit diameter, fruit flesh thickness and fruit rind thickness of different graft combinations in both years.

Graft Combinations	Fruit Diameter (cm)			Fruit Flesh Thickness (cm)			Fruit Rind Thickness (mm)		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H27 × H4	9.66	14.14	11.90 B	2.03	3.24	2.63 C	5.12 d	8.30 ab	6.71
H27/H27 × H4	10.81	13.05	11.93 B	2.33	3.02	2.67 BC	5.72 d	5.92 cd	5.82
H27/H27 × H4/H4	10.85	14.05	12.45 AB	2.58	3.35	2.96 ABC	4.94 d	7.88 ab	6.41
TZ 148/H27 × H4	11.83	14.19	13.01 A	2.88	3.74	3.31 A	4.68 d	7.82 ab	6.25
TZ 148/H27 × TZ 148/H4	11.67	14.50	13.08 A	2.83	3.71	3.27 A	5.04 d	8.00 ab	6.52
Ares/H27 × H4	11.23	14.46	12.85 A	2.59	3.43	3.01 ABC	4.75 d	8.08 ab	6.42
Ares/H27 × Ares/H4	10.54	14.11	12.33 AB	2.44	3.40	2.92 ABC	4.71 d	9.05 a	6.88
Nun9075/H27 × Nun9075/H4	10.88	14.27	12.58 AB	2.46	3.62	3.04 AB	5.02 d	7.32 bc	6.13
Nun9075/H27 × H4	10.95	14.63	12.79 A	2.54	3.88	3.21 A	4.97 d	7.62 b	6.29
Year Avg.	10.94 B	14.16 A		2.52 B	3.49 A		4.99 B	7.77 A	
$N_{(year)}$ ***: 0.82; $N_{(Genotype)}$ *: 0.82; $N_{(Genotype \times year)}$: NS				$N_{(year)}$ ***: 0.39; $N_{(Genotype)}$ **: 0.39; $N_{(Genotype \times year)}$: NS			$N_{(year)}$ ***: 0.93; $N_{(Genotype)}$: NS; $N_{(Genotype \times year)}$ **: 0.93		

NS: Not Significant; ***: $p \leq 0.001$; **: $p \leq 0.01$; *: $p \leq 0.05$: shows difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

Table 5. Fruit cavity length and fruit cavity diameter of different graft combinations in both years.

Graft Combinations	Fruit Cavity Length (cm)			Fruit Cavity Diameter (cm)		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H27 × H4	6.00	7.53	6.77	4.90 e	6.41 a	5.66
H27/H27 × H4	7.45	6.92	7.19	5.60 cd	6.11 a–d	5.85
H27/H27 × H4/H4	7.07	6.67	6.87	5.48 de	5.95 a–d	5.71
TZ 148/H27 × H4	8.45	7.43	7.95	6.08 a–d	5.69 cd	5.89
TZ 148/H27 × TZ 148/H4	8.06	7.04	7.55	5.73 bcd	6.38 ab	6.05
Ares/H27 × H4	8.42	7.25	7.84	6.08 a–d	6.20 abc	6.14
Ares/H27 × Ares/H4	7.54	7.65	7.59	5.80 a–d	5.81 a–d	5.81
Nun9075/H27 × Nun9075/H4	7.80	7.28	7.54	5.94 a–d	6.03 a–d	5.98
Nun9075/H27 × H4	7.76	7.54	7.65	5.59 cd	5.88 a–d	5.73
Year Avg.	7.62	7.26		5.69 A	6.05 A	
$N_{(year)}$: NS; $N_{(Genotype)}$: NS; $N_{(Genotype \times year)}$: NS				$N_{(year)}$ **: 0.46; $N_{(Genotype)}$: NS; $N_{(Genotype \times year)}$ *: 0.46		

N: Significant; NS: Not Significant; **: $p \leq 0.01$; *: $p \leq 0.05$: shows difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

Table 6. The TSS and fruit flesh productivity of different graft combinations in both years.

Graft Combinations	TSS (%)			Fruit flesh Productivity (%)		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H27 × H4	10.35 bcd	9.19 bcd	9.77 C	60.34 (51.01) def	68.44 (55.87) a–d	64.40 (53.44)
H27/H27 × H4	10.41 bcd	10.26 bcd	10.33 BC	65.73 (54.21) bcd	67.49 (55.27) a–d	66.60 (54.74)
H27/H27 × H4/H4	10.48 bc	10.17 bcd	10.33 BC	56.26 (48.65) ef	75.38 (60.70) a	65.82 (54.68)
TZ 148/H27 × H4	13.42 a	9.94 bcd	11.68 A	55.46 (48.27) f	66.34 (54.59) bcd	60.90 (51.43)
TZ 148/H27 × TZ 148/H4	12.98 a	8.94 d	10.96 AB	67.24 (55.13) bcd	72.97 (58.74) ab	70.10 (56.94)
Ares/H27 × H4	12.46 a	10.64 b	11.55 A	72.55 (58.61) abc	65.72 (54.21) bcd	69.13 (56.41)
Ares/H27 × Ares/H4	12.68 a	9.14 cd	10.90 AB	60.96 (51.43) def	63.99 (53.16) c–f	62.47 (52.29)
Nun9075/H27 × Nun9075/H4	12.83 a	9.86 bcd	11.34 AB	65.14 (53.84) b–e	68.38 (55.83) a–d	66.75 (54.84)
Nun9075/H27 × H4	12.48 a	9.43 bcd	10.96 AB	64.24 (53.32) b–f	68.79 (56.09) a–d	66.51 (54.71
Year avg.	12.01 A	9.73 B		63.10 (52.72) B	68.61 (56.05) A	
$N_{(year)}$ ***: 1.04; $N_{(Genotype)}$ **: 1.04; $N_{(Genotype \times year)}$ **: 1.04				$N_{(year)}$ ***: 6.35; $N_{(Genotype)}$: NS; $N_{(Genotype \times year)}$ *: 6.35		

N: Significant; NS: Not Significant; ***: $p \leq 0.001$; **: $p \leq 0.01$; *: $p \leq 0.05$: shows difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

There was no significant difference found in the mean of fruit cavity length, it varied between 6.77 cm and 7.95 cm among the graft combinations. The year and year × genotype interaction were also found nonsignificant. Higher mean fruit cavity diameter (6.05 cm) was obtained in the second year. Although, there was no significant difference between combinations, the highest fruit cavity diameter (6.41 cm) was in H27 × H4 graft combination in the second year (Table 5). In terms of total solible solid (TSS), avarage was 12.01% in the first year. Highest TSS (11.68%) was obtained from TZ 148/H27 × H4 and followed by Ares/H27 × H4 (11.55%) graft combinations. Based on year and genotype interaction, Nun9075/H27 × H4 (12.48%), Nun9075/H27 × Nun9075/H4 (12.83%); Ares/H27 × Ares/H4 (12.68%); Ares/H27 × H4 (12.46%); TZ 148/H27 × TZ 148/H4 (12.98%) and TZ 148/H27 × H4 (13.42%) graft combinations were demonstrated the highest TSS values in the study. The mean fruit flesh productivity was higher in the second yer than inthe first year (Table 6).

3.3. Seed Analysis

According to the number of full seeds per fruit, both years were highlighted to be nonsignificant. The highest combination average was 433.31 from H27/H27 × H4, while the lowest was 211. 81 from Nun9075/H27 × Nun9075/H4 combinations. On the other hand, the year and genotype interaction was statistically important; the highest number of full seeds (514.38) was determined in the first year from H27/H27 × H4/H4 graft combination (Table 7). The highest number of empty seeds (174.42) was obtained in the first year, while Nun 9075/H27 × Nun9075/H4 combination resulted in highest values both in combination average and year × genotype interaction (291.69, 386.67 seeds respectively).

Table 7. Number of full seeds and empty seeds obtained of different graft combinations in both years.

Graft Combinations	Number of Full Seeds			Number of Empty Seeds		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H27 × H4	166.25 i	470.67 ab	318.46 B	311.67 b	69.06 fg	190.12 BC
H27/H27 × H4	462.50 abc	404.11 bcd	433.31 A	44.92 g	62.15 fg	79.04 DE
H27/H27 × H4/H4	514.38 a	325.42 fg	419.89 A	57.08 g	101.00 efg	53.53 E
TZ 148/H27 × H4	403.92 bcd	249.78 h	326.85 B	177.94 c	171.56 cd	174.75 C
TZ 148/H27 × TZ 148/H4	349.25 def	293.83 fgh	321.54 B	165.78 cd	155.56 cde	160.67 C
Ares/H27 × H4	427.78 bc	408.26 bcd	418.02 A	142.33 cde	75.44 fg	96.00 D
Ares/H27 × Ares/H4	270.18 gh	333.22 efg	301.70 B	116.56 def	290.33 b	216.33 B
Nun9075/H27 × Nun9075/H4	78.78 j	344.83 def	211.81 C	386.67 a	196.71 c	291.69 A
Nun9075/H27 × H4	398.44 cde	396.68 cde	397.56 A	167.31 cd	185.08 c	176.19 C
Year avg.	341.28	358.53		174.42 A	145.21 B	
$N_{(year)}$: NS; $N_{(Genotype)}$ ***: 49.16; $N_{(Genotype \times year)}$ ***: 49.16				$N_{(year)}$ **: 40.14; $N_{(Genotype)}$ ***: 40.14; $N_{(Genotype \times year)}$ ***: 40.14		

N: Significant; ***: $p \leq 0.001$; **: $p \leq 0.01$; shows difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

Due to the weight of full seeds, the heaviest seeds (11.19 g) were obtained in second year from H27/H27 × H4/H4 graft combination. Based on year average, full seed weight (10.31 g) was higher in the second year than in the first year (8.19 g). The highest value (13.49 g) for the year × genotype interaction was found also in second year from H27 × H4 graft combination. The 1000 seeds weight was affected by the year, genotype and year and genotype interactions. The average seed weight was 28.21 g in the second year, while the heaviest seed weight (29.21 g) were determined from TZ 148/H27 × H4 graft combination The year × genotype interaction was found significant and the heaviest seeds (31.32 g) were obtained in the first year from the TZ 148/H27 × H4 graft combination (Table 8).

Owing to the seed emergence time (day) and rate (%), the results indicated that the earliest seed emergence time (2.46 days) was found from H27/H27 × H4/H4 graft combination in the second year. The latest seed emergence time (5.23 days) was obtained from TZ 148/H27 × H4 graft combinations in second year (Tables 9 and 10). Our results revealed that H27/H27 × H4/H4 graft combination showed earliest seed emergence and high germination rate (87.1%) (Tables 9 and 10).

Table 8. Full seed weight and weight of 1000 seeds of different graft combinations in both years.

Graft Combinations	Full Seed Weight (g)			1000 Seeds Weight (g)		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H27 × H4	2.78 i	13.49 a	8.14 D	15.54 h	30.30 ab	22.92 C
H27/H27 × H4	11.06 bcd	10.97 b–e	11.01 A	24.19 fg	27.25 b–f	25.72 B
H27/H27 × H4/H4	11.42 bc	10.96 b–e	11.19 A	22.44 g	30.28 ab	26.37 B
TZ 148/H27 × H4	12.08 ab	8.71 fgh	10.39 AB	31.32 a	27.10 b–f	29.21 A
TZ 148/H27 × TZ 148/H4	9.30 d-h	7.76 h	8.53 CD	26.40 c-f	28.58 abc	27.50 AB
Ares/H27 × H4	8.37 gh	10.65 b–e	9.51 BC	26.24 efg	26.14 c–f	25.39 B
Ares/H27 × Ares/H4	7.94 h	9.20 e–h	8.57 CD	24.22 fg	27.93 b–e	26.07 B
Nun9075/H27 × Nun9075/H4	0.51 j	9.81 c–g	5.15 E	25.21 d–g	28.30 a–d	17.00 D
Nun9075/H27 × H4	10.31 b–f	11.30 bc	10.80 AB	5.71 i	28.01 bcd	26.61 B
Year avg.	8.19 B	10.31 A		22.19 B	28.21 A	
$N_{(year)}$ ***: 1.30; $N_{(Genotype)}$ ***: 1.30; $N_{(Genotype \times year)}$ ***: 1.30				$N_{(year)}$ ***: 2.34; $N_{(Genotype)}$ ***: 2.34; $N_{(Genotype \times year)}$ ***: 2.34		

N: Significant; ***: $p \leq 0.001$shows difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

Table 9. Seed emergence time and emergence rate of different graft combinations in both years.

Graft Combinations	Seed Emergence Time (day)			Seed Emergence Rate (%)		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H27 × H4	3.77 cd	2.80 fg	3.29 BCD	98.00 (84.27) abc	96.00 (82.09) abc	97.00 (83.18) A
H27/H27 × H4	3.21 def	2.72 fg	2.96 DE	96.00 (82.09) abc	98.00 (85.94) ab	97.00 (84.01) A
H27/H27 × H4/H4	3.19 def	2.46 g	2.83 E	99.00 (87.16) a	94.00 (77.97) bcd	96.50 (82.57) A
TZ 148/H27 × H4	4.22 bc	5.23 a	4.72 A	88.00 (75.79) cd	25.33 (30.16) j	58.67 (52.98) D
TZ 148/H27 × TZ 148/H4	4.25 bc	2.69 fg	3.48 BC	88.00 (69.90) de	64.00 (53.17) gh	76.00 (61.53) C
Ares/H27 × H4	4.44 b	2.80 fg	3.46 BC	82.67(65.89) ef	77.33 (61.62) efg	80.00 (63.75) C
Ares/H27 × Ares/H4	2.96 efg	2.48 g	2.88 DE	96.00 (82.09) abc	76.44 (61.11) efg	86.22 (71.60) B
Nun9075/H27 × Nun9075/H4	3.72 cd	3.54 de	3.63 B	76.00 (60.74) fg	36.00 (36.85) i	56.00 (48.79) D
Nun9075/H27 × H4	3.05 efg	3.24 def	3.15 CDE	97.00 (81.39) abc	58.00 (49.68) h	77.50 (65.53) BC
Year avg.	3.65 A	3.11 B		91.63 (76.59) A	69.46 (59.84) B	
$N_{(year)}$ ***: 0.45; $N_{(Genotype)}$ ***: 0.45; $N_{(Genotype \times year)}$ ***: 0.45				$N_{(year)}$ ***: 5.04; $N_{(Genotype)}$ ***: 5.04; $N_{(Genotype \times year)}$ ***: 5.04		

N: Significant; ***: $p \leq 0.001$show difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

Table 10. Seed germination time and rate of different graft combinations in both years.

Graft Combinations	Seed Germination Time (day)			Seed Germination Rate (%)		
	1st Year	2nd Year	Comb. Avg.	1st Year	2nd Year	Comb. Avg.
H27 × H4	5.34 bcd	3.20 g	4.27 CDE	99.00 (87.16) a	98.00 (85.94) ab	98.50 (86.55) A
H27/H27 × H4	5.73 a	3.40 fg	4.56 B	97.00 (83.05) a-d	95.00 (77.28) cd	96.00 (80.16) B
H27/H27 × H4/H4	5.28 bcd	3.16 g	4.22 DE	99.00 (87.16) a	97.00 (83.05) a-d	98.00 (85.11) AB
TZ 148/H27 × H4	5.21 cd	3.64 f	4.43 BCD	94.00 (77.98) bcd	45.33 (42.29) h	69.67 (60.14) EF
TZ 148/H27 × TZ 148/H4	5.57 ab	3.34 fg	4.46 BC	90.00 (74.62) de	63.55 (52.95) g	76.78 (63.78) DE
Ares/H27 × H4	5.45 abc	3.64 f	4.54 B	98.67 (85.50) abc	65.67 (54.19) g	83.16 (69.85) C
Ares/H27 × Ares/H4	5.57 ab	4.26 e	4.91 A	93.00 (75.80) de	74.67 (59.82) fg	83.83 (67.81) CD
Nun9075/H27 × Nun9075/H4	5.19 cd	3.42 fg	4.31 CDE	85.33 (67.55) ef	44.44 (57.53) g	64.89 (54.68) F
Nun9075/H27 × H4	5.09 d	3.27 g	4.18 E	71.00 (41.82) h	98.00 (84.27) abc	84.50 (70.90) C
Year avg.	5.38 A	3.48 B		91.89 (77.37) A	75.7 (64.62) B	
$N_{(year)}$***: 0.22; $N_{(Genotype)}$ ***: 0.22; $N_{(Genotype \times year)}$ **: 0.22				$N_{(year)}$ ***: 5.12; $N_{(Genotype)}$ ***: 5.12; $N_{(Genotype \times year)}$ ***: 5.12		

N: Significant; ***: $p \leq 0.001$; **: $p \leq 0.01$: show difference according to LSD comparison. Different uppercase letters were used for Combination average and The year average. Different lowercase letters were used for Genotype × year interaction.

4. Discussion

Previously, distinct studies have stated that rootstocks have a positive effect on plant length and leaf number, depending on the scion genotype, and that when the root structure of the rootstock was strong, the stem thickness and plant length increased [49]. In the recent study, the result obtained from grafting 9 different rootstocks to the Kırkağaç 589 genotype have shown that the longest plants were ungrafted control plants and plants grafted onto interspecies hybrid "TZ 148" rootstock (457.8 and 456.3 cm, respectively), whereas the shortest plants have been determined as 301.8 cm in grafted plant on loofah rootstock with white seeds [16]. Generally, plants were affected by the rootstock used in the experiment [30,50]. According to this study's results, grafted plants had higher values compared to the control group. The Nun9075/H27 combination had the longest (270.93 cm) plants in the average graft combination.

Interspecific hybrid Cucurbita rootstocks have thick and long hypocotyledons that facilitate grafting, and although their emergence rates are high, they may cause a delay in flowering and maturation because of their vigor [51]. Moreover, in a study performed, Galia melon cv. Arava was grafted onto hybrid squash rootstock Strong Tosa; the first female flower formation was delayed by 8–9 days, and it has been reported that the harvest times were 38 days in ungrafted plants and 39 days in self-grafted plants [52]. Currently, in a study using a total of 9 different melon cultivars, consisting of 6 hybrid melon cultivar candidates and 3 control cultivars, the harvest time varied between 57 and 72 days, and it was stated that grafting had no effect on the harvest time, thus the only variation was observed based on the growing seasons [53]. This means that the rootstocks and scions used in the study do not alter the harvest time because optimum harvest maturity is crucial for obtaining high-quality fruits during that period and is challenging to be determined between crops and even within melon species [54]. Various studies have reported that fruit weight, fruit flesh thickness, fruit length, and diameter were positively correlated with rootstocks [55,56].

In general, the *Cucumis melo* and *Cucurbita* interspecific rootstocks have little or no effect on the scion's fruit weight [57]. The United Nation Economic Commission for Europe (UNECE) reported the size of Galia melon fruit ant its diameter [58]. Due to the results of the study performed in 2018, the 9 different rootstocks were used for 589 melon cultivars and their fruit weights have been ranged between 1096 and 4375 (g) [16]. Beside this, two pure lines were grafted onto Canay F1 melon cultivars and their fruit weights have been varied in range of 670 and 990 (g) [59]. Furthermore, by using 7 different rootstocks for Falez and Galia melon cultivars, the fruit weights of the Galia melon cultivars remained between 1009 and 1241 (g). Kırkağaç type Sinem 45 F1 and Sürmeli F1 melon cultivars were grafted onto three *Cucurbita* hybrid (*C. maxima* Duch. × *C. moschata* Duch.) Ares F1, Nun 9075 F1 and TZ 148 F1 rootstocks to investigate the effect of grafting on yield and quality. The results indicated that fruit weight was 4200 g and was not affected by grafting. Self-grafted plants had higher values that ranged from 6.5 to 7 kg [52]. In the study carried out by Soteriou et al. [51] using the interspecific hybrid "TZ 148" as rootstock in Galia melons, there was no effect observed on fruit weight. In this study, in accordance with other studies, fruit seed cavity and diameter were not affected by grafting, nevertheless, fruit weights variation were determined in a combination of H4 scion to Nun9075 rootstock (Nun9075/H4).

According to Karabulut et al. [16], grafted plants had lower values (21.5 cm) in fruit length than ungrafted plants (23.1 cm). Although rootstocks did not have any effect on fruit diameter when using TZ 148 as rootstocks. Moreover, based on melon studies, fruit length ranged between 20.30 cm and 29.9 cm, and fruit diameter ranged between 15.69 cm and 16.68 cm, and it was found that grafting was not effective on these parameters [22]. Compare this to Namli et al. [60], where fruit length varied between 34.98 cm and 21.33 cm and fruit diameter was in the range of 17.21 cm and 13.67 cm with Ares F1 and TZ 148 rootstocks. The present study, the results demonstrated that the longest fruit (12.88) cm and

widest fruit (14.16 cm) were observed when TZ 148/H27 cultivar was used as rootstock in second year.

The big fruit cavity is an undesirable trait that reduces the fruit quality. For instance, the length of the cavity has been varied between 12.3 and 22.67 cm, while the cavity diameter showed similar results of 6.3 and 8.28 cm. Furthermore, the average thickness of fruit flesh was 2.5 cm in ungrafted plants and 2.4 cm in grafted plants, and it changed from 1.6 cm to 2.6 cm during the use of TZ 148 rootstock [16]. On the other hand, fruit rind thickness was determined as 0.7 cm in ungrafted and 0.5 cm in grafted plants, between 0.5 and 0.9 in the use of other rootstocks [61], and 5.17 and 4.05 mm in ref. [53]. The thickness of the fruit flesh varied between 5.25 cm and 4.51 cm, and rind thickness between 2.40 and 3.22 mm [59]. These differences in fruit flesh thickness may be due to rootstock and scion, location, and environmental differences [16,46,53].

Total soluble solid is an important fruit quality criterion in melons. In a previous study, it was stated that TSS in melons is more affected by the prevailing temperature and planting dates [62]. Although TSS analysis is a practical method for determining harvest maturity, it may not always correlate with the sensory quality and sugar ratio [63]. According to UNECE standards, the juice taken from the middle of the melon fruit is good when it is in the range of 10 Brix and 8 brix, while the USDA reported that the minimum should be between 9 brix and 11 Brix for very good quality [64]. The commercially acceptable brix should be 10 or more than 10 [58]. In the study by Ünlü et al. [59], the TSS ranged between 6.67 and 14.52 for graft combinations with lower values than ungrafted plants. The fact that during the summer season (the hottest months), the uptake of water and minerals in plants slows down and the rapid ripening of the fruits reduces the rate of TSS. In the study carried out by Lecholocholo et al. [65], *Cucurbita maxima* × *Cucurbita moschata* hybrid rootstocks were grafted to 4 different melon cultivars, and TSS was found to be higher than ungrafted plants, and TSS remained below 10% in both years. In our study, different rootstocks did not affect the TSS rate. The TSS rates varied between 10.3 and 12.1 in the first year and between 10.4 and 11.6 in the second year. In their study, Yarsi et al. [46] demonstrated that TSS changed between 9.04 and 7.7 and remained between 8.7 and 7.7 in Galia melons. In melons grown in spring and autumn, higher TSS was detected compared to the summer season [66]. Furthermore, Ohletz and Loy [67] determined the TSS between 11.8 and 11.00 (%). Our results showed the TSS was not affected by grafting, and the TSS rates were in the range of 13.42 and 8.94 (%).

The germination of seeds varies depending on the plant species and variety, and environmental effects such as water, temperature, light and oxygen [68]. In the study of Karabulut et al. [16] the highest seed germination rate was found to be 100% in TZ 148 and pumpkin rootstocks, and the lowest germination rate (75%) was obtained in white seed of loofah rootstock. However, the results of our study indicated the highest germination rates that was observed from the H27 (87.16%), and self-grafted H27 (83.05%) genotypes used as rootstock. Based on the results from Edelstein and Nerson [69]' study, authors reported that fruit weight and size were positively correlated with seeds in watermelon. In the study conducted by Yetisir and Sarı, [70] by using 5 Lagenaria rootstocks were grafted onto the Crimson Tide watermelon cultivar and their seed yield was examined. The number of seeds per plant varied between 858.8 and 556.1 seeds in the first year and between 738.6 and 489.2 seeds in the second year, and more seeds were obtained in the first year. The number of seeds increased with grafting. In results of this study, the year was not a factor on the number of full seed, but the genotype and year × genotype interaction increased the number of full seeds, and the highest number of seeds (514.38 seeds) was obtained by crossing the self-grafted H27 and self-grafted H4 genotypes. In the study performed on Crimson sweet, watermelon cultivars were grafted with three different rootstocks, *Cucurbita* 'Nun9075', *Lagenaria* 'Argentario', and *Citron* watermelon 'PI296341', to investigate their fruit flesh to seed ratio. The number of seeds varied between 558.11 and 805.00 (seeds) in the first year, and between 241.25 and 483.00 (seeds) in the second year. The 1000 seed

weight was not affected by grafting and was ranged from 36.14 to 40.74 g in the first year and between 28.15 and 32.52 g in the second year.

Seed germination and emergence rates were much higher (39.3%) than the control group (30.5%), while in the graft combinations, the germination and emergence rates varied between 68.5% and 61.0% and were mentioned as low values. The highest values of germination and emergence rates observed were 97.5%, 91.0%, respectively, from watermelon varieties [71]. Seed germination day varied between 2.6 and 7.3 days; the latest germination was in the control group. Seed emergence days ranged from 10.8 to 7.1 days. Since the rootstocks improved root development, seed yield, plant strength, fruit size, and seed number increased, and the use of grafting techniques can affect the harvest day and weak lines in hybrid seed production [70]. In our study, the 1000 seed weight increased, and the heaviest seed average was obtained in 2019 (28.21 g). The TZ 148/H27 × H4 graft combination produced 29.21 g and 31.32 g in the first year. Our results also highlighted that the year × genotype interaction increased seed characteristics such as the number of full seeds, seed weight, germination, and emergence rates. Additionally, the high seeds were obtained from self-grafted hybrids.

5. Conclusions

According to the global warming that has occurred in recent years, the speed of change in the ecology system and the appearance of new diseases have increased due to the use of fertilizers and pesticides that lead to soil pollution. The use of grafted seedlings increased owing to the fact that, it provides tolerance against soil-borne diseases, protects plants against biotic and abiotic stress factors, and increases fruit yield and quality.

In this study, grafting was performed to evaluate the effects of different rootstocks using hybrid scions and their effects on the plant, fruit, and seed. Furthermore, the results showed that plant and seed parameters had been positively affected by grafting. The present study demonstrates that grafting onto different rootstocks increase the yield, weight, and number of cantaloupe melon seeds. Further studies should look into the effects of grafting on seed quality, plant growth development, and fruit in hybrid melons, as well as its variations, if this trait is to be used for melon crop improvement in the future.

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