International Journal of
Agriculture, Environment and Food Sciences
e-ISSN: 2618-5946 https://dergipark.org.tr/jaefs

DOI: https://doi.org/10.31015/2025.2.14 Int. J. Agric. Environ. Food Sci. 2025; 9 (2): 409-419

Effect of low nitrogen stress on plant growth traits of double haploid melon (*Cucumis melo* var. *cantalupensis*) lines with different low nitrogen Tolerances

Alim Aydın[1], Halit Yetişir[2]

[1]Department of Horticulture, Faculty of Agriculture, Kırşehir Ahi Evran University, Kırşehir, Türkiye
[2]Department of Horticulture, Faculty of Agriculture, Erciyes University, Kayseri, Türkiye

Article History
Received: March 20, 2025
Accepted: May 13, 2025
Published Online: June 15, 2025

Article Info
Type: Research Article
Subject: Vegetable Growing and Treatment

Corresponding Author
Alim Aydın
✉ alim.aydin@ahievran.edu.tr

Author ORCID
[1]https://orcid.org/0000-0002-9424-5556
[2]https://orcid.org/0000-0001-6955-9513

Available at
https://dergipark.org.tr/jaefs/issue/91914/1662309

Abstract

In recent years, excessive nitrogen (N) fertilizer application has adversely affected the ecosystem. Additionally, inefficient fertilizer use can diminish soil fertility and result in the loss of organic matter. Limiting access to N fertilizer leads to increased prices, which consequently results in reduced crop productivity. Developing/breeding nitrogen-efficient plants is another strategy to enhance N uptake and efficiency in crops. The aim of this study was to assess the genotypic differences of 27 double haploid (DH) melon genotypes under low nitrogen (0.3 mM) conditions based on biomass parameters in hydroponic growth conditions. Significant differences were determined among the genotypes in all the parameters investigated. At low nitrogen levels, the highest stem fresh weight was recorded in genotypes C19 (48.53 g/plant) and D10 (42.57 g/plant), while the highest leaf fresh weight was observed in genotypes C8 (51.57 g/plant) and C19 (51.37 g/plant). In plants subjected to low N, the highest stem dry weight was found in genotypes E13 and C19, whereas the lowest was recorded in genotypesB9 and C5 with 2.10 g/plant. Under low nitrogen conditions, genotypes I7 and CA7 exhibited the highest root fresh and dry weights, respectively. The average shoot/root ratio of melon genotypes under low nitrogen conditions was 1.40, with the highest ratio in genotype B5 (2.69) and the lowest in genotype I7 (0.76). Melon genotypes had an average root length of 4000.92 cm under low nitrogen conditions, with genotype I7 having the longest root with 8194.43 cm and genotype B5 having the shortest root with 1795.34 cm. Under low nitrogen stress, genotypes displayed significant variation in plant growth. In terms of shoot fresh weight, there was a two-fold difference between susceptible and tolerant genotypes, while for root fresh weight, the difference was four-fold. This indicates that tolerance to nitrogen is attributed to changes in the root system rather than the shoot system.

Keywords: Melon, Low nitrogen, Nitrogen efficiency, Hydroponic culture

Cite this article as: Aydin, A., Yetisir, H. (2025). Effect of low nitrogen stress on plant growth traits of double haploid melon (*Cucumis melo* var. *cantalupensis*) lines with different low nitrogen Tolerances. International Journal of Agriculture, Environment and Food Sciences, 9 (2): 409-419. https://doi.org/10.31015/2025.2.14

INTRODUCTION

Melon is an important species of the *Cucurbitaceae* family. The global melon production is 29.541.294 tons, with China being the largest producer at 14.454.741.3 tons, followed by India with 1.498.000 tons and Türkiye with 1.403.214 tons (FAO, 2024). The yield per hectare in China is 36.4 ton, while in Türkiye it is 25.3 ton. Melon yield varies from country to country and from different growing regions within the same country. Yield is highly dependent on climate, soil, moisture, plant nutrition, disease and pest control, variety, and many other factors (Gorski, 2019). In recent years, chemical fertilizers are the most important input sources that directly affect plant growth and crop yield in both high-input and low-input agricultural systems, and among these sources, nitrogen is

the most needed and widely used nutrient element in crop production (Ulas et al., 2012, 2019; Goyal & Huffaker, 2015; Yam et al., 2020).

Nitrogen is one of the most important macronutrients that promotes crop growth and yield by playing multiple roles in biochemical and physiological functions in plant development such as synthesis of amino acids, proteins and enzymes (Ma et al., 1997; Souri & Dehnavard, 2018; Xiong et al., 2018; Janpen et al., 2019). It has been reported that insufficient N in vegetable species leads to reduced leaf number, leaf size, leaf chlorophyll content, reduced fruit yield and biomass, and delayed plant development and fruit production associated with a decrease in photosynthetic rate (Castellanos et al., 2011; Peña-Fleitas et al., 2015; Souri & Dehnavard, 2018; Xiong et al., 2018; Cavalcante et al., 2019). High N fertilization increased vegetative growth in plants, but yield losses associated with N over-fertilization have been detected in crop plants such as lettuce, pineapple, watermelon, cherry, and strawberry (Neilsen et al., 2007; Andriolo et al., 2011; Peña-Fleitas et al., 2015). In addition, excess N can be toxic to plants by altering their biochemistry and accumulating in plants, resulting in an imbalance of different nutrients and poor fruit quality (Fernández-Escobar et al., 2006; Goyal & Huffaker, 2015). It has been shown by many researchers that there are large differences between genotypes of the same species, especially in nitrogen efficiency (N-uptake and N-utilization) (Ruiz et al., 2006; Hoque et al., 2010; Ulas et al., 2012; Inkham et al., 2021 This genotypic variation serves as a tolerance mechanism against various biotic and abiotic stresses (salt, pH, nutrient deficiency, heavy metals, etc.) that adversely affect plant growth, and has allowed the yield and quality of the plant to increase even under adverse environmental conditions (Coskun, 2023; Coskun, 2025). A genotype is considered nitrogen-efficient if it produces a yield higher than the average of other genotypes under very low nitrogen conditions (Graham, 1984). Conversely, a genotype that responds positively to additional nitrogen under high nitrogen conditions and achieves a higher yield than other genotypes is also characterized as a nitrogen-efficient genotype (Balcha, 2014; Ulas et al., 2019). Improving nitrogen use efficiency (NUE) of crops is important for sustainable agricultural input and crop production (Xu et al., 2011; Xiong et al., 2018). Low N utilization by plants indicates that uptake is inefficient or higher than the plant needs (Anas et al., 2020). Crops such as rice, wheat, and maize require large amounts of N for healthy growth and higher yields (Linquist et al., 2012). Therefore, varieties with higher NUE should be a priority for breeders developing new varieties (Balyan et al., 2016; Mălinaş et al., 2022). For this purpose, determining the nitrogen efficiency of existing genetic resources constitutes the first stage of the breeding studies to be initiated. The aim of this study was to determine the genotypic differences of melon genotypes in low nitrogen (0.3 mM) application according to biomass parameters under hydroponic conditions.

MATERIALS AND METHODS

Plant Material

The study was conducted in the R&D greenhouse of Kırşehir Ahi Evran University in 2023. In the hydroponic culture test, 27 double haploid (DH) melon genotypes were used as plant material and Çıtırex, Altınbaş, Margot and Isovac melon varieties were used as controls (Table 1). DH melon genotypes were selected from the genotypes produced in project number TOGTAG-1430. DH melon lines were developed by induction with irradiated pollen from genetic resources collected from protected melon cultivation areas in Türkiye (Sarı et al., 1999). The authors are grateful to the project coordinator Prof. Dr. Nebahat SARI for her support in providing seeds. The genotypes were grown in Kırşehir and seeds were produced by selfing.

Table 1. List of plant melon genotypes used in the study.

Code	Description	Code	Description
C13	Double Haploid	D25	Double Haploid
C10	Double Haploid	I5	Double Haploid
G34	Double Haploid	B5	Double Haploid
E13	Double Haploid	C19	Double Haploid
H14	Double Haploid	D5	Double Haploid
D10	Double Haploid	C8	Double Haploid
E25	Double Haploid	E21	Double Haploid
C7	Double Haploid	E34	Double Haploid
G7	Double Haploid	B9	Double Haploid
E19	Double Haploid	H5	Double Haploid
E8	Double Haploid	C5	Double Haploid
K2	Double Haploid	MO	Margot (Diploid)
G20	Double Haploid	ISO	Isovac (Diploid)
I7	Double Haploid	GA7	Altınbaş (Diploid)
H1	Double Haploid	CA7	Çıtırex (Diploid)
G35	Double Haploid		

Sowing Seeds and Growing Seedlings

The melon seeds used in the hydroponic culture test were sown in multipots filled with peat:perlite (2:1) mixture with an electrical conductivity of 0.4 dS/m and a pH of 5.8. Fifty seeds of each genotype were planted. After germination, the seedlings were grown in a greenhouse at 24/18˚C (day/night) and 60% relative humidity.

Hydroponic Culture Low Nitrogen Application

The roots of the seedlings at the 2-3 true leaf stage were washed with tap water and cleaned from the growing medium and then planted in 130 liter plastic pots with 14 plants in each pot. The top surface of the pots was covered with composite and the plants were placed in the holes on the composite with equal spacing. The pots were placed on the growing tables at 40 cm distances. The growing solution was regularly aerated with an air pump. The composition of the water culture nutrient solution in the experiment was 1125 µM $Ca(N0_3)_2$, 375 µM $(NH_4)_2SO_4$ (Low-nitrogen: 0.3 mM N), 750 µM K_2SO_4, 650 µM $MgSO_4$, 500 µM KH_2PO_4, 10 µM H_3BO_3, 0. 5 µM $MnSO_4$, 0.5 µM $ZnSO_4$, 0.4 µM $CuSO_4$, 0.4 µM $MoNa_2O_4$, and 80 µM Fe EDDHA (modified Hoaglan solution). The electrical conductivity (EC) of the solution was kept at 1.80 dS/m and pH between 6.5-7. The experiment was carried out according to the random plots experimental design with 3 replications and 4 plants (two pots) in each replicate. The study was conducted under controlled greenhouse conditions (22-24°C day /16-18°C night and 60% relative humidity) for 30 days.

Parameters Investigated in the Hydroponic Culture Experiment

Root and shoot fresh and dry weight

After harvesting, fresh weights (g/plant) of roots, shoots and leaves were determined using a digital weighing scale with an accuracy of 0.01. To determine dry weights, plant organs were dried in an oven at 65°C until they reached constant weight and then weighed.

Shoot/root ratio

Root/shoot ratio was calculated by dividing the root dry weight by the shoot dry weight (stem and leaves) with the following formula. Shoot/root ratio= (stem dry weight+leaf dry weight)/root dry weight).

Root length and volume

At the end of the experiment, the harvested plant parts were separated into roots, leaf and stems, the fresh weight of the root was recorded and the whole root was cut into small pieces of 1 cm with scissors. Then, all of these small cut root pieces were placed in the tray of a special scanner connected to a computer and some water was added to spread the roots homogeneously in the tray. Afterwards, the scanner was closed and the root length (cm) and volume (cm^3) of the root morphological parameters were calculated with a special root imaging program (WinRhizo Regular LA2400, Regent Instruments).

Leaf area

After determining the number of leaves of the harvested plants, the total leaf area of each genotype was determined in cm^2 using the LI 3100 C Model leaf area measuring device.

Statistical Analysis

The data obtained from the study were analyzed by one-way analysis of variance (ANOVA) using SPSS 18.0 statistical software (IBM, Chicago, IL, USA) at 5% significance level and the difference between the means was determined by Duncan multiple comparison test. In addition to this the data were analyzed by principal component analysis and cluster analysis using XLSTAT Software (XLSTAT, USA) statistical program.

RESULTS

The results of stem and leaf (fresh and dry) weights of 31 different melon genotypes tested using a low nitrogen dose (0.3 mM) of hydroponics nutrient solution are given in Table 2. Stem and leaf fresh and dry weights were significantly affected by genotypes. At low nitrogen dose, the average stem fresh weight was 36.40 g/plant, while the highest stem fresh weight was measured in genotypes C19 (48.53 g/plant) and D10 (42.57 g/plant). Genotypes C5 (21.57 g/plant) and B9 (22.57 g/plant) had the lowest stem fresh weight. Under low N conditions, leaf fresh weight ranged from 51.57 g/plant to 26.00 g/plant. The highest leaf fresh weight was measured in genotypes C8 and C19 (51.57 and 51.37 g/plant, respectively) and the lowest in genotype G7 (26.00 g/plant). Similar to the fresh weights, significant differences in dry weight were determined among the genotypes with low N application. The highest stem dry weight was recorded in plants of E13 and C19, while the lowest was 2.10 g/plant in genotypes B9 and C5. Under low N conditions, the average leaf dry weight was 3.88 g/plant, while the highest leaf dry weight was 6.57 g/plant in genotype C19 and the lowest in genotypes B9 (3.60 g/plant), GA7 (3.63 g/plant) and E34 (3.77 g/plant) (Table 2).

Genotype variation was found significant for root development under low nitrogen stress. The average root fresh weight was 55.22 g/plant, while the average root dry weight was 2.48 g/plant. Genotypes I7 and CA7 had the highest root fresh and dry weights, respectively, under low nitrogen conditions. Genotypes B5 and B9 had the lowest root fresh weight, while genotypes B5, C10 and B9 had the lowest root dry weight. Under low nitrogen

conditions, the average shoot/root ratio of melon genotypes was 1.40, the highest shoot/root ratio was determined in genotype B5 (2.69) and the lowest ratio was determined in genotype I7 with 0.76 (Table 3).

Table 2. Stem and leaf (fresh and dry) weights of melon genotypes under low N conditions in the hydroponic culture.

Genotype	Stem Fresh Weight (g/plant) Mean±SE	Leaf Fresh Weight (g/plant) Mean±SE	Stem Dry Weight (g/plant) Mean±SE	Leaf Dry Weight (g/plant) Mean±SE
B5	28.27±3.50e-i	38.03±2.45a-h	2.90±0.40j-l	4.40±0.61e-h
B9	22.57±7.60hi	31.53±5.39d-h	2.10±0.87k	3.60±0.69h
C10	37.17±2.40b-d	29.40±7.17f-h	4.83±0.57a-e	4.03±0.25gh
C13	38.93±1.21b-d	40.50±2.94a-g	3.73±0.57c-j	4.97±0.40b-h
C19	48.53±3.19a	51.37±5.34a	5.57±0.45ab	6.57±0.83a
C5	21.57±1.16i	33.40±1.04b-h	2.10±0.20k	3.80±0.10gh
C7	36.87±1.16b-f	46.83±0.99ab	4.43±0.15b-h	5.30±0.10a-g
C8	38.07±0.85b-d	51.57±1.80a	4.40±0.20b-h	6.17±0.15a-c
CA7	41.13±2.40a-c	45.23±3.16a-d	4.77±0.21a-e	5.80±0.44a-e
D10	42.57±0.35ab	35.70±1.81b-h	4.20±0.20c-j	4.23±0.15f-h
D25	32.47±0.81c-g	31.13±1.53e-h	3.40±0.17g-l	4.03±0.32gh
D5	36.40±5.03b-f	34.30±11.33b-h	3.40±0.56g-l	4.50±1.14d-h
E13	40.90±2.69a-c	32.00±3.04c-h	6.00±0.40a	4.00±0.46gh
E19	31.77±7.16c-h	27.03±3.52gh	4.53±1.16b-g	4.33±0.25e-h
E21	38.63±3.36b-d	43.10±2.16a-f	4.07±0.31c-j	4.57±0.59d-h
E25	37.17±0.29b-d	39.43±3.95a-h	5.07±0.40a-c	4.77±0.49c-h
E34	34.63±2.61b-f	30.93±1.79e-h	3.57±0.47e-k	3.77±0.15h
E8	36.33±1.53b-f	43.33±1.53a-e	4.17±0.21c-j	4.50±0.00d-h
G20	27.50±0.99f-i	45.37±1.58a-c	3.53±0.06e-k	6.00±0.36a-d
G34	35.90±1.25b-f	35.13±0.67b-h	3.97±0.21c-j	3.87±0.21gh
G35	32.67±0.80c-f	39.70±2.19a-h	3.00±0.30i-l	4.63±0.31d-h
G7	29.87±7.23d-i	26.00±14.11h	3.83±0.42c-j	4.50±0.36d-h
GA7	23.20±1.00g-i	37.43±3.27b-h	2.33±0.29kl	3.63±0.46h
H1	32.60±0.70c-g	37.13±1.76b-h	3.10±0.20h-l	4.17±0.38f-h
H14	34.70±0.76b-f	36.77±2.12b-h	3.70±0.17d-j	4.07±0.06gh
H5	34.77±0.47b-f	40.03±1.57a-g	3.53±0.49e-j	4.53±0.15d-h
I5	31.30±0.44d-h	38.80±1.56a-h	3.17±0.12h-l	4.47±0.35e-h
I7	38.33±0.31b-d	47.03±1.25ab	4.23±0.15b-j	6.33±0.46ab
İSO	40.97±1.07a-c	34.87±2.14b-h	4.33±0.42b-i	4.97±1.04b-h
K2	4538±1.31e-i	34.13±1.63b-h	3.43±0.32f-l	4.10±0.00f-h
MO	38.87±1.22b-d	39.73±1.10a-g	5.00±0.44a-d	5.60±0.53a-f
Mean	34.60	37.97	4.65	3.88
Min	21.57	26.00	2.10	3.60
Max	48.53	51.57	6.00	6.57
p value	0.001	0.008	0.001	0.006

Means that do not share a letter are significantly different. ISO: Isovac, MO: Margot, GA7: Altınbaş, CA7: Cıtırex. SE: Standart Error. $P \leq 0.01$: Very strong evidence, the result is considered very significant. $P \leq 0.05$: Strong evidence, the result is considered significant. $P > 0.05$: Insufficient evidence, the result is not significant.

The average leaf area of melon genotypes grown at low nitrogen (0.3 mM) dose under hydroponics conditions was 1439.67 cm^2. The highest leaf area was found in genotypes C19 (2044.67 cm^2) and E25 (1964.67 cm^2), while the lowest leaf area was measured in genotypes B9 (946.00 cm^2) and D25 (1154.00 cm^2). Melon genotypes had an average root length of 4000.92 cm under low N conditions, the longest root length was found in genotype I7 with 8194.43 cm and the shortest root length was recorded in genotype B5 with 1795.34 cm. The average root volume under low N conditions was determined as 2.91 cm3, while the highest root volume was measured in genotype I7 (5.92 cm^3), and the lowest root volume was determined in genotype B5 (1.30 cm^3) as in root length (Table 4).

Principal component analysis (PCA) was used to classify melon genotypes based on biomass parameters in hydroponics. According to the analysis, two principal components (99.85% according to PC1 and 1.14% according to PC2) accounted for about 99% of the total variation. According to the PCA graphs, the genotypes on the left side of the red arrow in graph b produced less biomass under low nitrogen conditions than the genotypes on the right side of the arrow (Figure 1). Genotype C19 had the highest leaf area and shoot biomas in region I. of the graph (b), while genotype I7 had the highest root parameters in region IV. of the graph (b).

Table 3. Root (fresh and dry) weight and shoot/root ratio of melon genotypes under low N conditions in the hydroponic culture.

Genotype	Root Fresh Weight (g/plant) Mean±SE	Root Dry Weight (g/plant) Mean±SE	Shoot/Root RatioMean±SE
C13	24.63±2.23j	1.40±0.17k	2.69±0.11a
C10	36.50±12.48ij	1.57±0.55i-k	1.52±0.21b-f
G34	38.67±10.11h-j	1.53±0.55jk	1.77±0.27b-d
E13	70.83±11.62b-d	3.00±0.53b-f	1.15±0.25e-h
H14	57.07±6.49c-i	3.00±0.53b-f	1.76±0.19b-d
D10	37.87±1.86h-j	1.90±0.17f-k	1.45±0.07b-f
E25	63.07±4.91b-g	3.07±0.32b-e	1.33±0.10c-g
C7	67.63±5.49b-e	3.30±0.10a-c	1.33±0.07c-g
G7	82.13±15.65b	3.77±0.32ab	1.07±0.18f-h
E19	53.67±3.50d-i	1.93±0.12f-k	1.46±0.13b-f
K2	62.77±5.65b-g	2.87±0.12b-g	1.02±0.11f-h
G20	60.23±13.14b-h	2.60±0.70c-j	1.17±0.06e-h
I7	62.03±2.46b-g	2.33±0.21c-k	1.18±0.04e-h
H1	52.07±4.61d-i	2.63±0.15c-j	1.15±0.29e-h
G35	52.63±11.55d-i	2.60±0.61c-j	1.59±0.27b-e
D25	56.17±5.99c-i	2.17±0.23d-k	1.37±0.14c-g
I5	36.73±2.71ij	1.87±0.38g-k	1.80±0.25bc
B5	41.30±0.00f-j	2.60±0.00c-j	1.93±0.04b
C19	77.87±6.76bc	3.23±0.46a-d	0.94±0.10gh
D5	60.07±1.69b-h	2.23±0.15c-k	1.18±0.04e-h
C8	57.4±4.37c-i	2.27±0.25c-k	1.26±0.06d-h
E21	43.73±13.62f-j	1.90±0.27f-k	1.32±0.30c-g
E34	40.43±7.04g-j	2.07±0.23e-k	1.52±0.18b-f
B9	57.8±2.80c-i	2.37±0.25c-k	1.21±0.06e-h
H5	51.17±0.81d-i	1.73±0.21h-k	1.40±0.07c-g
C5	45.33±1.19e-j	2.20±0.36c-k	1.65±0.01b-e
E8	50.27±4.22d-i	2.70±0.44b-h	1.40±0.10c-g
GA7	112.43±6.49a	4.33±0.40a	0.76±0.04h
CA7	52.47±4.88d-i	2.67±0.12b-i	1.46±0.19b-f
MO	43.40±3.12f-j	1.77±0.12g-k	1.44±0.10b-g
İSO	63.60±4.17b-f	3.27±0.15a-d	1.24±0.11e-h
Mean	55.22	2.48	1.40
Min	24.63	1.40	0.76
Max	112.43	4.33	2.69
p value	0.001	0.001	0.001

Means that do not share a letter are significantly different. ISO: Isovac, MO: Margot, GA7: Antınbaş; CA: Cıtırex. SE: Standart Error. P ≤ 0.01: Very strong evidence, the result is considered very significant. P ≤ 0.05: Strong evidence, the result is considered significant. P > 0.05: Insufficient evidence, the result is not significant.

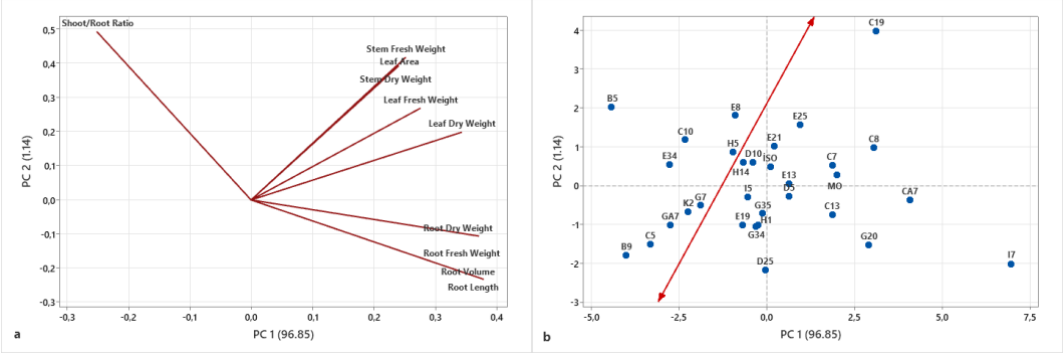

Figure 1. Two-dimensional PCA plot of melon genotypes with biomass traits under hydroponics low N conditions. ISO: Isovac, MO: Margot, GA7: Altınbaş, CA7: Cıtırex.

Cluster analysis was performed to determine the relationship between 31 melon genotypes using biomass parameters in hydroponics (Figure 2). In the dendrogram graph, 2 main clusters were formed, cluster I included

genotype I7, which had the highest values in terms of root parameters, while cluster II included 30 genotypes that were 35% similar to each other. Cluster II, which was 35% similar to each other, was divided into 2 sub-clusters. In the sub-cluster of cluster II with 63% similarity, genotypes with high values in terms of biomass parameters under low nitrogen conditions were located, while in the sub-cluster with 73% similarity, genotypes with low values in terms of biomass parameters were located.

Table 4. Leaf area, root volume, and diameter of melon genotypes under low N conditions in the hydroponic culture.

Genotype	Leaf Area (cm^2) Mean±SE	Root Length (cm) Mean±SE	Root Volume (cm^3) Mean±SE
C13	1237.00±75.80b-d	1795.34±162.50j	1.3±0.1174.00j
C10	946.00±41.10d	2660.21±909.00ij	1.92±0.65ij
G34	1305.33±139.70a-d	2818.13±737.00h-j	2.04±0.53h-j
E13	1396.67±25.20a-d	5162.51±847.00b-d	3.73±0.61b-d
H14	2044.67±185.00a	4159.16±473.00c-i	3±0.34c-i
D10	1203.33±77.80cd	2759.82±135.60h-j	1.99±0.098h-j
E25	1530.67±19.80a-d	4596.46±358.00b-g	3.32±0.26b-g
C7	1668.67±55.00a-d	4929.29±400.00b-e	3.56±0.29b-e
G7	1472.33±109.30a-d	5986.09±1141.00b	4.32±0.82b
E19	1373.67±114.50a-d	3911.36±255.00d-i	2.82±0.18d-i
K2	1154.00±18.10cd	4574.60±412.00b-g	3.3±0.29b-g
G20	1767.33±144.90a-c	4389.96±957.00b-h	3.17±0.69b-h
I7	1289.33±94.70b-d	4521.15±179.00b-g	3.26±0.19b-g
H1	1258.33±16.17b-d	3794.75±336.00d-i	2.74±0.24d-i
G35	1518.00±3.46a-d	3836.05±842.00d-i	2.77±0.61d-i
D25	1964.67±883.00ab	4093.57±437.00c-i	2.96±0.32c-i
I5	1297.67±96.50a-d	2677.22±197.00ij	1.93±0.14ij
B5	1500.00±0.00a-d	3010.05±0.00f-j	2.17±0.00f-j
C19	1557.33±49.20a-d	5675.12±493.00bc	4.1±0.36bc
D5	1223.67±26.50b-d	4377.81±122.90b-h	3.16±0.089b-h
C8	1418.67±101.40a-d	4183.46±319.00c-i	3.02±0.23c-i
E21	1386.00±24.20a-d	3187.40±993.00f-j	2.3±0.72f-j
E34	1329.00±109.10a-d	2946.88±513.00g-j	2.13±0.37g-j
B9	1390.67±97.80a-d	4212.61±204.00c-i	3.04±0.15c-i
H5	1797.67±853.00a-c	3729.16±58.09d-i	2.69±0.04d-i
C5	1530.00±42.90a-d	3304.01±86.30e-j	2.39±0.06e-j
E8	1479.33±75.60a-d	3663.56±308.00d-i	2.65±0.22d-i
GA7	1689.33±25.30a-d	8194.43±473.00a	5.92±0.34a
CA7	1297.67±31.20a-d	3823.90±356.00d-i	2.76±0.26d-i
MO	1201.33±26.70cd	3163.10±228.00f-j	2.28±0.16f-j
ISO	1401.33±82.20a-d	4635.33±304.0b-f	3.35±0.22b-f
Mean	1439.67	4024.92	2.91
Min	946.00	1795.34	1.30
Max	2044.67	8194.43	5.92
p value	0.001	0.001	0.001

Means that do not share a letter are significantly different. ISO: Isovac, MO: Margot, GA7: Altınbaş, CA7: Cıtırex. SE: Standart Error. $P \leq 0.01$: Very strong evidence, the result is considered very significant. $P \leq 0.05$: Strong evidence, the result is considered significant. $P > 0.05$: Insufficient evidence, the result is not significant.

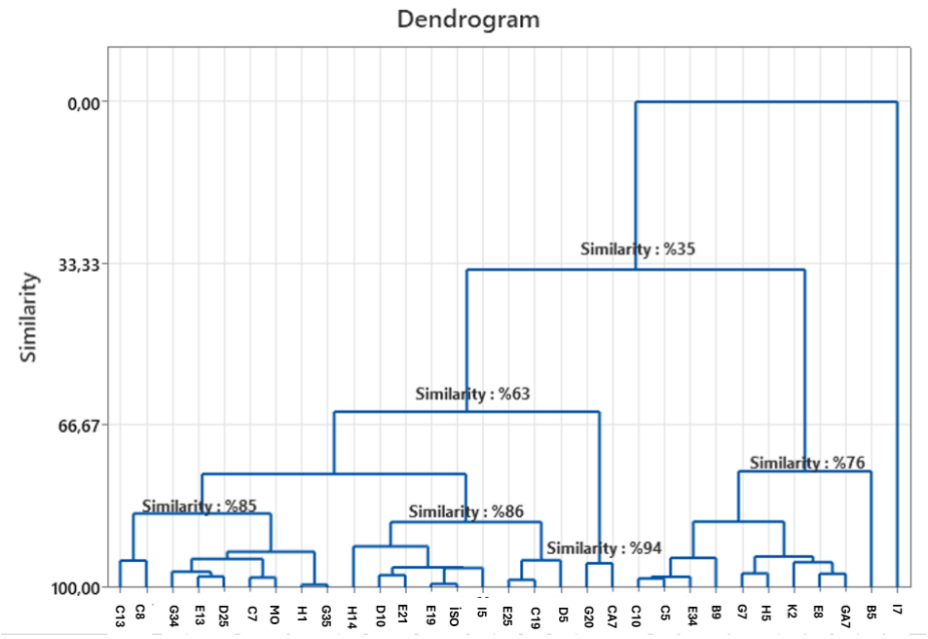

Figure 2. Dendrogram plot of melon genotypes with biomass traits under hydroponics low N conditions. ISO: Isovac, MO: Margot, GA7: Altınbaş, CA7: Cıtırex.

Regresyon analysis was performed to determine the relationship between stem, leaf, and root parameters of melon genotypes grown under low nitrogen conditions (Table 5). Since the significance level between root fresh weight, root length and root volume and stem fresh weight is $p<0.05$, the established regression (R^2) model is significant. According to the regression analysis results made for the prediction of the relationship, it is seen that root fresh weight, root length and root volume have a positive and weak effect on stem fresh weight. The R^2 value expressed as the explanatory power of all models was calculated as 0.187 ($R=0.433$; $R^2= 0.187$). This value shows that 18.7% of the stem fresh weight variable is explained by the independent variables in the model, namely root fresh weight, 18.7% by root length and 18.7% by root volume. 20.4% of the stem fresh weight variable is explained by the independent variable root dry weight. Since the significance level between root fresh weight, root dry weight, root length and root volume parameters and leaf fresh weight and leaf dry weight is $p<0.01$, the established regression model is significant. According to the results of the regression analysis performed to predict the relationship between these parameters, it is seen that the root fresh weight, root dry weight, root length and root volume parameters have a positive and strong effect on the leaf fresh weight and leaf dry weight parameters. Additionally, positive correlation (R) was found between all root parameters and stem fresh weight and leaf area parameters at 0.05 significance level, while positive correlation was found with leaf fresh and dry weight parameters at 0.01 level.

Table 5. Regresyon between stem, leaf and root parameters.

Parameters	Stem Fresh Weight			Leaf Fresh Weight			Stem Dry Weight			Leaf Dry Weight			Leaf Area		
	R	R^2	p	R	R^2	p	R	R^2	p	R	R^2	p	R	R^2	p
Root Fresh Weight	0.433	0.187	0.015	0.514	0.264	0.003	0.380	0.144	0.035	0.691	0.478	0.000	0.390	0.152	0.030
Root Dry Weight	0.451	0.204	0.011	0.649	0.421	0.000	0.391	0.153	0.030	0.809	0.654	0.000	0.396	0.157	0.027
Root Length	0.433	0.187	0.015	0.514	0.264	0.003	0.380	0.144	0.035	0.691	0.478	0.000	0.390	0.152	0.030
Root Volume	0.433	0.187	0.015	0.514	0.264	0.003	0.380	0.144	0.035	0.691	0.478	0.000	0.390	0.152	0.030

DISCUSSION

Under low nitrogen stress, significant changes in growth and development occur in most plant species. Previous studies have shown that plant adaptation to nutrient stress is mainly due to morphological changes and significantly suppresses plant growth (Zhao et al., 2005; J. Wang et al., 2019). In the present study, the responses of melon genotypes to low nitrogen stress in terms of biomass development were significantly different from each other. Since there is a positive correlation between root development and leaf and stem development, the genotypes with the highest root fresh and dry weight, root length, and volume had higher stem and leaf fresh and dry weight and leaf area than the other genotypes under low nitrogen conditions. Wahocho et al. (2017) reported that low nitrogen conditions reduced vegetative growth in two melon cultivars and the cultivars were affected differently by low nitrogen stress. Reducing nitrogen fertilization had a low effect on fruit marketable yield in tomato (-7.5%), but a significant effect on plant vegetative Growth (Bénard et al., 2009). In general, previous studies have reported that increasingly high N application has a negative effect on fruit quality and that reducing N application to a level that does not reduce yields can be achieved commercially in terms of quality and economically (less fertilizer input). In the case of prolonged N deficiency, plant leaves turn yellow, brown and die, eventually reducing the production and quality of agricultural products. According to the current literature, N deficiency-induced leaf chlorosis and reduced plant growth have been reported in many plants, including rice (Shin et al., 2018), potato (Wei et al., 2015), maize (Ning et al., 2018), sunflower (Agüera et al., 2010), tobacco (Wang et al., 2013), rapeseed (Pant et al., 2009), Arabidopsis (Scheible et al., 2004) and wheat (Cartelat et al., 2005). It has also been reported that limiting nitrogenous fertilizer to a level that does not reduce yield and plant growth has positive effects on fruit quality (Bénard et al., 2009; Wahocho et al., 2017). The results of this study confirmed previous studies and showed that there is a significant genetic variation and that low nitrogen conditions reduce plant growth in melon.

Approximately 199 million tons of NPK (Nitrogen-Phosphate-Potassium) were produced in the world in 2015, and nitrogen-based fertilizers accounted for the largest share at 57%. World nitrogen fertilizer production was 114 million tons in 2015, 52% of which was provided by China, India and the USA. In the same year, of the total NPK exports of 90.6 million tons, 38% of nitrogen (41 million tons) and 47% of phosphorus (17.5 million tons) were provided by China and Russia, and 51% of potassium (32.3 million tons) were provided by Canada and Russia. Nitrogen constitutes 43% of the total NPK imports of 88.5 million tons in the world. Of the 38.5 million tons of nitrogen imports, 36% was provided by the USA, India and Brazil. NPK fertilizer consumption, which increased by 20% compared to 2005, was approximately 184 million tons as of 2015; China ranked first with a consumption of 51 million tons. Türkiye increased its consumption amount, which was 2 million in 2005, by 7% in 2015 to 2.2 million tons (equivalent to 5.5 million tons in physical fertilizer consumption) (Tagem, 2018). Since nitrogen use and export are high in Türkiye, breeding of nitrogen-using plants is important for reducing the budget allocated to nitrogen in plant nutrition and for sustainable agriculture. For all these reasons, determining the responses of genotypes to low nitrogen conditions is important both economically and in terms of fruit quality.

CONCLUSION

It was found that low nitrogen doses in melon genotypes inhibited plant growth, yet the genotypes exhibited varied responses to low nitrogen conditions. Melon, which has a monoecious and andromoncios flower structure, has created great genetic diversity by cross-pollination with other melon species over the years. In this study, the genotypic differences of a population consisting of a limited number of DH melon genotypes against low nitrogen stress were revealed. Two and four-fold differences were detected in terms of shoot and root biomasses, respectively. The researchers believe that higher variation can be detected if larger populations are studied in terms of nitrogen use efficiency. It is thought that the determination of nitrogen-efficient genotypes in our study and similar studies will help develop high-quality melon varieties suitable for sustainable melon production in future research. Evaluation of the responses of genotypes showed superior characteristics in this screening experiment regarding vegetative growth, nitrogen use efficiency, yield and quality under varying nitrogen doses in the field or greenhouse environment will make this study meaningful.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The authors state there is no competing interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the text, figures, and tables are original and that they have not been published before.

REFERENCES

Agüera, E., Cabello, P., & de la Haba, P. (2010). Induction of leaf senescence by low nitrogen nutrition in sunflower (*Helianthus annuus*) plants. *Physiologia Plantarum 138* (3), 256–267. https://doi.org/10.1111/J.1399-3054.2009.01336.X

Anas, M., Liao, F., Verma, K. K., Sarwar, M. A., Mahmood, A., Chen, Z. L., Li, Q., Zeng, X. P., Liu, Y., & Li, Y. R. (2020). Fate of nitrogen in agriculture and environment: agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. *Biological Research 53* (1), 1–20. https://doi.org/10.1186/S40659-020-00312-4

Andriolo, J. L., Erpen, L., Cardoso, F. L., Cocco, C., Casagrande, G. S., & Jänisch, D. I. (2011). Nitrogen levels in the cultivation of strawberries in soilless culture. *Horticultura Brasileira 29* (4), 516–519. https://doi.org/10.1590/S0102-05362011000400012

Balcha, A., & Balcha, A. (2014). Effect of Phosphorus Rates and Varieties on Grain Yield, Nutrient Uptake and Phosphorus Efficiency of Tef [Eragrostis tef (Zucc.) Trotter]. *American Journal of Plant Sciences 5* (3), 262–267. https://doi.org/10.4236/AJPS.2014.53035

Balyan, H. S., Gahlaut, V., Kumar, A., Jaiswal, V., Dhariwal, R., Tyagi, S., Agarwal, P., Kumari, S., & Gupta, P. K. (2016). Nitrogen and Phosphorus Use Efficiencies in Wheat: Physiology, Phenotyping, Genetics, and Breeding. *Plant Breeding Reviews 40*, 167–234. https://doi.org/10.1002/9781119279723.CH4

Bénard, C., Gautier, H., Bourgaud, F., Grasselly, D., Navez, B., Caris-Veyrat, C., Weiss, M., & Génard, M. (2009). Effects of low nitrogen supply on tomato (*Solanum lycopersicum*) fruit yield and quality with special emphasis on sugars, acids, ascorbate, carotenoids, and phenolic compounds. *Journal of Agricultural and Food Chemistry 57* (10), 4112–4123. https://doi.org/10.1021/JF8036374

Cartelat, A., Cerovic, Z. G., Goulas, Y., Meyer, S., Lelarge, C., Prioul, J. L., Barbottin, A., Jeuffroy, M. H., Gate, P., Agati, G., & Moya, I. (2005). Optically assessed contents of leaf polyphenolics and chlorophyll as indicators of nitrogen deficiency in wheat (*Triticum aestivum* L.). *Field Crops Research 91* (1), 35–49. https://doi.org/10.1016/J.FCR.2004.05.002

Castellanos, M. T., Cabello, M. J., Cartagena, M. del C., Tarquis, A. M., Arce, A., & Ribas, F. (2011). Dinâmica do crescimento e da produtividade do melão em resposta ao fertilizante nitrogenado. *Scientia Agricola 68* (2), 191–199. https://doi.org/10.1590/S0103-90162011000200009

Cavalcante, V. S., Prado, R. de M., Vasconcelos, R. de L., Almeida, H. J. de, & Silva, T. R. da. (2019). Growth and Nutritional Efficiency of Watermelon Plants Grown under Macronutrient Deficiencies. *HortScience 54* (4), 738–742. https://doi.org/10.21273/HORTSCI13807-18

Coşkun, Ö. F. (2023). The effect of grafting on morphological, physiological, and molecular changes induced by drought stress in cucumber. *Sustainability*, 15(1), 875. https://doi.org/10.3390/su15010875

Coşkun, Ö. F. (2025). Association mapping for drought tolerance in watermelons (*Citrullus lanatus* L.). *Horticulturae*, 11(2), 193. https://doi.org/10.3390/horticulturae11020193

FAO. (2024). Food and Agriculture Organization of the United Nations. Retrieved on February 1, 2025, from https://www.fao.org/faostat/en/#data/QCL.

Fernández-Escobar, R., Beltrán, G., Sánchez-Zamora, M. A., García-Novelo, J., Aguilera, M. P., & Uceda, M. (2006). Olive Oil Quality Decreases with Nitrogen Over-fertilization. *HortScience 41* (1), 215–219. https://doi.org/10.21273/HORTSCI.41.1.215

Gorski, S. F. (2019). Melons. Detecting Mineral Nutrient Deficiencies in Tropical and Temperate Crops, 283–293. https://doi.org/10.1201/9780429035258-26

Goyal, S. S., & Huffaker, R. C. (2015). Nitrogen Toxicity in Plants. *Nitrogen in Crop Production*, 97–118. https://doi.org/10.2134/1990.NITROGENINCROPPRODUCTION.C6

Graham, P. H. (1984). Plant Factors Affecting Nodulation and Symbiotic Nitrogen Fixation in Legumes. *Biological Nitrogen Fixation* 75–98. https://doi.org/10.1007/978-1-4613-2747-9_4

Hoque, M. M., Ajwa, H., Othman, M., Smith, R., & Cahn, M. (2010). Yield and Postharvest Quality of Lettuce in Response to Nitrogen, Phosphorus, and Potassium Fertilizers. *HortScience 45* (10), 1539–1544. https://doi.org/10.21273/HORTSCI.45.10.1539

Inkham, C., Panjama, K., Seehanam, P., & Ruamrungsri, S. (2021). Effect of nitrogen, potassium and calcium concentrations on growth, yield and nutritional quality of green oak lettuce. *Acta Horticulturae*, 1312, 409–415. https://doi.org/10.17660/ACTAHORTIC.2021.1312.59

Janpen, C., Kanthawang, N., Inkham, C., Tsan, F. Y., & Sommano, S. R. (2019). Physiological responses of hydroponically-grown Japanese mint under nutrient deficiency. *PeerJ (9)*, e7751. https://doi.org/10.7717/PEERJ.7751/TABLE-2

Linquist, B., Van Groenigen, K. J., Adviento-Borbe, M. A., Pittelkow, C., & Van Kessel, C. (2012). An agronomic assessment of greenhouse gas emissions from major cereal crops. *Global Change Biology 18* (1), 194–209. https://doi.org/10.1111/J.1365-2486.2011.02502.X

Ma, Q., Longnecker, N., & Dracup, M. (1997). Nitrogen Deficiency Slows Leaf Development and Delays Flowering in Narrow-leafed Lupin. *Annals of Botany 79* (4), 403–409. https://doi.org/10.1006/ANBO.1996.0361

Mălinaş, A., Vidican, R., Rotar, I., Mălinaş, C., Moldovan, C. M., & Proorocu, M. (2022). Current Status and Future Prospective for Nitrogen Use Efficiency in Wheat (*Triticum aestivum* L.). *Plants 11* (2), 217. https://doi.org/10.3390/PLANTS11020217/S1

Neilsen, G., Kappel, F., & Neilsen, D. (2007). Fertigation and Crop Load Affect Yield, Nutrition, and Fruit Quality of 'Lapins' Sweet Cherry on Gisela 5 Rootstock. *HortScience 42* (6), 1456–1462. https://doi.org/10.21273/HORTSCI.42.6.1456

Ning, P., Yang, L., Li, C., & Fritschi, F. B. (2018). Post-silking carbon partitioning under nitrogen deficiency revealed sink limitation of grain yield in maize. *Journal of Experimental Botany 69* (7), 1707–1719. https://doi.org/10.1093/jxb/erx496

Pant, B. D., Musialak-Lange, M., Nuc, P., May, P., Buhtz, A., Kehr, J., Walther, D., & Scheible, W.-R. (2009). Identification of Nutrient-Responsive Arabidopsis and Rapeseed MicroRNAs by Comprehensive Real-Time Polymerase Chain Reaction Profiling and Small RNA Sequencing . *Plant Physiology 150* (3), 1541–1555. https://doi.org/10.1104/pp.109.139139

Peña-Fleitas, M. T., Gallardo, M., Thompson, R. B., Farneselli, M., & Padilla, F. M. (2015). Assessing crop N status of fertigated vegetable crops using plant and soil monitoring techniques. *Annals of Applied Biology 167* (3), 387–405. https://doi.org/10.1111/AAB.12235

Ruiz, J. M., Rivero, R. M., Cervilla, L. M., Castellano, R., & Romero, L. (2006). Grafting to improve nitrogen-use efficiency traits in tobacco plants. *Journal of the Science of Food and Agriculture 86* (6), 1014–1021. https://doi.org/10.1002/JSFA.2450

Sarı, N., Yücel, S., Ekiz, H., Yetişir, H., Tunalı, C. (1999). Dihaploidizasyon Yöntemi ile Örtüaltı Tarımına Elverişli ve Fusarium oxysporum f.sp. melonis'e Dayanıklı Kavun Çeşitlerinin Geliştirmesi. TÜBİTAK projesi sonuç raporu, 150.

Scheible, W. R., Morcuende, R., Czechowski, T., Fritz, C., Osuna, D., Palacios-Rojas, N., Schindelasch, D., Thimm, O., Udvardi, M. K., & Stitt, M. (2004). Genome-Wide Reprogramming of Primary and Secondary Metabolism, Protein Synthesis, Cellular Growth Processes, and the Regulatory Infrastructure of Arabidopsis in Response to Nitrogen. *Plant Physiology 136* (1), 2483. https://doi.org/10.1104/PP.104.047019

Shin, S. Y., Jeong, J. S., Lim, J. Y., Kim, T., Park, J. H., Kim, J. K., & Shin, C. (2018). Transcriptomic analyses of rice (*Oryza sativa*) genes and non-coding RNAs under nitrogen starvation using multiple omics technologies. *BMC Genomics 19* (1). https://doi.org/10.1186/S12864-018-4897-1

Souri, M. K., & Dehnavard, S. (2018). Tomato plant growth, leaf nutrient concentrations and fruit quality under nitrogen foliar applications. *Advances in Horticultural Science* 32 (1), 41–47. https://doi.org/10.13128/AHS-21894

Tagem, (2018). Gübre Sektör Politika Belgesi. Tagem Arge ve İnovasyon 2018-2022, Ankara, Türkiye, ss. 21-24

Ulas, A., Doganci, E., Ulas, F., & Yetisir, H. (2019). Root-growth Characteristics Contributing to Genotypic Variation in Nitrogen Efficiency of Bottle Gourd and Rootstock Potential for Watermelon. *Plants*, *8* (3), 77. https://doi.org/10.3390/PLANTS8030077

Ulas, A., Schulte Auf'm Erley, G., Kamh, M., Wiesler, F., & Horst, W. J. (2012). Root-growth characteristics contributing to genotypic variation in nitrogen efficiency of oilseed rape. *Journal of Plant Nutrition and Soil Science 175* (3), 489–498. https://doi.org/10.1002/JPLN.201100301

Wahocho, N. A., Maitlo, A. A., Baloch, Q. B., Kaleri, A. A., Rajput, L. B., Talpur, N. A., Sheikh, Z. A., Mengal, F. H., & Wahocho, S. A. (2017). Effect of Varying Levels of Nitrogen on the Growth and Yield of Muskmelon (*Cucumis melo* L.). *Journal of Basic & Applied Sciences 13*, 448–453. https://doi.org/10.6000/1927-5129.2017.13.74

Wang, J., Song, K., Sun, L., Qin, Q., Sun, Y., Pan, J., & Xue, Y. (2019). Morphological and Transcriptome Analysis of Wheat Seedlings Response to Low Nitrogen Stress. *Plants 8* (4), 98. https://doi.org/10.3390/PLANTS8040098

Wang, Y., Fu, B., Pan, L., Chen, L., Fu, X., & Li, K. (2013). Overexpression of Arabidopsis Dof1, GS1 and GS2 Enhanced Nitrogen Assimilation in Transgenic Tobacco Grown Under Low-Nitrogen Conditions. Plant *Molecular Biology Reporter, 31* (4), 886–900. https://doi.org/10.1007/s11105-013-0561-8

Wei, M., Zhang, A., Li, H., Tang, Z., & Chen, X. (2015). Growth and Physiological Response to Nitrogen Deficiency and Re-supply in Leaf-vegetable Sweetpotato (*Ipomoea batatas* Lam). *HortScience 50* (5), 754–758. https://doi.org/10.21273/HORTSCI.50.5.754

Xiong, Q., Tang, G., Zhong, L., He, H., & Chen, X. (2018). Response to nitrogen deficiency and compensation on physiological characteristics, yield formation, and nitrogen utilization of rice. *Frontiers in Plant Science 9*, 316347. https://doi.org/10.3389/FPLS.2018.01075/BIBTEX

Xu, Z., Zhong, S., Li, X., Li, W., Rothstein, S. J., Zhang, S., Bi, Y., & Xie, C. (2011). Genome-Wide Identification of MicroRNAs in Response to Low Nitrate Availability in Maize Leaves and Roots. *PLOS ONE, 6* (11), e28009. https://doi.org/10.1371/JOURNAL.PONE.0028009

Yam, R. S. W., Fan, Y. T., Lin, J. T., Fan, C., & Lo, H. F. (2020). Quality Improvement of Netted Melon (C*ucumis melo* L. var. *reticulatus*) through Precise Nitrogen and Potassium Management in a Hydroponic System. *Agronomy 10* (6), 816. https://doi.org/10.3390/AGRONOMY10060816

Zhao, D., Reddy, K. R., Kakani, V. G., & Reddy, V. R. (2005). Nitrogen deficiency effects on plant growth, leaf photosynthesis, and hyperspectral reflectance properties of sorghum. *European Journal of Agronomy*, *22* (4), 391–403. https://doi.org/10.1016/J.EJA.2004.06.005