

VARIATION IN PHOTOSYNTHETIC PARAMETERS DURING THE GROWTH AND DEVELOPMENTAL PHASES OF MELON PLANTS

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Abstract

This article examines the variability in the dynamics of key photosynthetic parameters in two promising melon (*Cucumis melo* L.) cultivars—Nihal and Khurshud—cultivated under open-field conditions in the Absheron region. The study evaluates several physiological and biochemical indicators, including leaf surface area, photosynthetic potential (PP), net photosynthetic productivity (NPP), specific leaf surface density (SLSD), plastid pigment concentrations, the coefficient of economic efficiency of photosynthesis (CEEP), overall economic efficiency (CEE), and the accumulation of both crude and dry biomass. The findings indicate that SLSD and total biomass (crude and dry) progressively increase from the onset of the vegetative stage through to fruit formation and mass ripening. The early-maturing cultivar Gunash exhibited the most pronounced increases during the initial fruit formation stage, whereas in the mid-maturing cultivar Sadaf, these increases peaked during the mass ripening phase. Substantial variation in NPP, SLSD, and CEE was observed throughout plant ontogenesis, with maximum values recorded during the mass ripening period in both cultivars. Furthermore, chlorophyll and carotenoid accumulation in melon leaves followed a tri-phasic peak pattern, with the timing of each peak being cultivar-specific.

Keywords: melon, promising varieties, photosynthetic indicators, plastid pigments, growth and development process.

Introduction

Melon fruits, particularly those of the barberry plant, are recognized for their rich nutritional profile and valuable therapeutic and preventive properties. Although barberry fruits—botanically classified as "false" berries and belonging to the Berberidaceae family—are not true fruits in a strict botanical sense, they are commonly treated as such in everyday usage. The nutritional and health benefits of barberry are largely attributed to its chemical composition, which is approximately 90% water and contains a wide array of essential vitamins (including E, PP, A, B1, B2, B5, B9, β -carotene, and vitamin C), as well as microelements such as iron, silicon, zinc, iodine, copper, fluorine, and cobalt. It also includes mono- and disaccharides, organic acids, both saturated and unsaturated fatty acids, and dietary fiber [1–4]. Due to this comprehensive chemical makeup, barberry is considered an

important component of the human diet. Its bioactive constituents support immune function, enhance nervous system stability, aid digestion, improve cardiovascular and circulatory health, and contribute positively to hair and skin condition. Additionally, they facilitate detoxification and promote skin elasticity and overall vitality. The growth and development of fruit-bearing crops, including melons and other vegetables, are strongly influenced by external environmental factors such as light, water availability, temperature, and soil properties. Among these, water supply has been shown to play a particularly significant role. Studies demonstrate that increasing water availability by 18% during the growing season results in more vigorous plant growth and yield improvements of 25–30% [5, 6]. Furthermore, enhancing irrigation during the fruit formation and ripening stages led to measurable increases in plant height (by 17.2%), leaf surface area (by 20.7%), and overall biomass (by 12.5%). Increased water availability also promoted root development, with root mass observed to be 6.6% greater at a water input of 2300 m³/ha compared to 1795 m³/ha [7]. Additionally, a deeper placement (by 1–3 cm) of the primary root mass under higher moisture conditions allowed for more effective utilization of residual soil moisture, particularly under surface drying conditions. For melon cultivation, optimal irrigation ranges from 5000 to 7000 m³/ha [8]. The biological development cycle of the melon plant includes several distinct phases: seed germination, seedling establishment, scion formation, development of male and female flowers, pollination, and fruit growth and maturation. Key factors influencing these stages include ambient temperature, humidity, soil nutrient availability, light conditions, agronomic practices, cultivar selection, and other management interventions [9, 10]. According to existing literature, achieving optimal levels of photosynthetic indicators—such as leaf area, crop photosynthetic potential, net photosynthetic productivity, specific leaf mass per area, and plastid pigment concentration—is critical for ensuring high yields and fruit quality. These parameters can be effectively optimized through targeted agronomic measures, including precise nutrient and water management strategies [11, 12]. Moreover, researchers have reported strong positive correlations between leaf area, photosynthetic potential, and crop yield in various species. For example, correlation coefficients have been reported as $r = 0.98$ and 0.95 in watermelon, 0.90 and 0.85 in potato, 0.85 and 0.80 in eggplant, and 0.87 and 0.82 in table beet, respectively [1, 13].

Research objective.

The objective of this study was to identify effective strategies for optimizing the growth, development, and yield of fruit plant cultivars by examining a range of photosynthetic parameters across different ontogenetic stages. These parameters included leaf surface area, crop photosynthetic potential, net photosynthetic productivity (NPP), specific leaf surface density (SLSD), the coefficient of economic efficiency of photosynthesis (CEEP), overall economic efficiency (CEE), the content of plastid pigments in leaves, and the distribution of total moisture and dry biomass among various plant organs.

Materials and Methods.

The study focused on two promising fruit crop cultivars— Nihal (No. 80) and Khurshud (No. 81)—which were submitted in 2021 to the State Service for Plant Variety Registration and Seed Control under the Ministry of Agriculture of the Republic of Azerbaijan. Field experiments were conducted on the soils of the Absheron Auxiliary Farm of the “Vegetable Science Research Institute” Public Legal Entity (VSRI AF). As the soils of Absheron, including those at VSRI AF, are characterized by low humus content and insufficient mineral nutrient levels, 20 t/ha of organic manure and two-thirds of the planned dose of mineral fertilizers (excluding nitrogen) were incorporated during autumn plowing. The fertilization regime was based on a formulation of $N_{80}P_{80}K_{60}$ in terms of active ingredients. The remaining portions of nitrogen, phosphorus, and potassium were applied in two split doses—twenty days after planting and at the onset of fruit formation—using the compound fertilizer ammofoska ($N_{20}P_{20}K_{20}$).

The experimental design included plots measuring 20 meters in length and 2.8 meters in width, with 70 cm inter-row and intra-row spacing. The average area of a single experimental plot was 56 m², and each treatment was replicated three times. During the study, the leaf surface area was measured using an L1-3000C portable leaf area meter. The photosynthetic potential (PP) was calculated as the product of the average leaf surface area (LA) and the duration of the vegetation period (T_v):

$$PP = LA \times T_v$$

$$PP = La \cdot Tv \quad (1)$$

During various phases of the vegetation period, the net photosynthetic productivity (NPP) was calculated using the following formula [13]:

$$NPP = (B_2 - B_1) / ((L_1 + L_2) / 2 \cdot 0.5n)$$

Here, B_1 and B_2 represent the total dry biomass of the plant (t/ha) at the beginning and at the end of the observation period, respectively; L_1 and L_2 denote the green leaf area (m²/ha) at the beginning and end of the period; and n is the number of days in the observation period.

The specific density of leaf area (SDLS) is defined as the dry mass per unit leaf area and is expressed in mg/cm²:

$$SDLS = m / L \quad (3)$$

Here m is the dry mass of leaves, mg; L is the leaf surface area of a plant, cm².

The coefficient economic of economic efficiency of photosynthesis (CEEP) is the ratio of the dry biomass of fruits (P_m) to the combined dry biomass of leaves, stems, and petioles (M_v) [14].

$$CEEP = P_m / M_v \quad (4)$$

The coefficient of economic efficiency (FEC) is the ratio of the dry biomass of fruits (P_m) to the total dry biomass of the plant (P_{db}) [13].

$$CEE = P_m / P_{ugb} \quad (5)$$

The amount of dry biomass in vegetative and generative organs was studied by A. I. Yermakova [15], while the amount of plastid pigments in leaves was examined by Gavrilenko V. F. and others [16].

Results and discussion of research.

Given the central role of photosynthesis in the growth and productivity of autotrophic organisms, including melon plants, a comprehensive study was conducted during the 2021–2022 growing seasons to evaluate key photosynthetic parameters in two melon cultivars. The parameters examined included the dynamics of leaf surface area expansion throughout the vegetative period, photosynthetic potential (PP), net photosynthetic productivity (NPP), chlorophyll content index (CCI), photosynthetic efficiency coefficient (PEC), production efficiency coefficient (PEC), the concentration of plastid pigments in leaves, and the distribution and dynamics of total moisture and dry biomass during plant development. The study aimed to identify both commonalities and differences in these parameters across developmental phases. The results indicated that the trends in leaf surface area and photosynthetic potential followed similar patterns in both cultivars over the course of the vegetative cycle. These metrics were lowest during the seedling stage, increased steadily during active growth, and reached peak values at different stages for each variety. In the early-ripening Nihal cultivar, the maximum values were recorded at the technical ripeness stage of the first fruits (5.26 thousand m²/ha and 620.9 thousand m²·day/ha for leaf area and PP, respectively). In contrast, the mid-ripening Khurshud cultivar reached its peak during the mass ripening phase (7.46 thousand m²/ha and 932.4 thousand m²·day/ha). Following these peaks, both parameters declined in both cultivars. A notable feature observed in both varieties was the pronounced increase in these indicators during the transition from the seedling phase to the male flower formation stage—by 13.86 and 21.80 times in Nihal, and by 8.88 and 13.84 times in Khurshud, for leaf area and PP, respectively. In Khurshud, this rapid growth extended through to the female flower formation stage, after which the developmental pattern mirrored that of Nihal. Among the indicators evaluated, the chlorophyll

content index (CCI) served as a critical marker for assessing the plants' adaptive responses to abiotic stressors such as drought and heat. In Nihal, the CCI increased linearly throughout the vegetation period, peaking at 77.89 mg/cm² at the end of the season. In contrast, Khurshud displayed a more variable trend: the CCI rose linearly until the pollination and early fruit formation phases, with an initial maximum of 9.27 mg/cm². This was followed by a decrease (to 7.77 mg/cm²), and subsequently a sharp increase—approximately 3.2-fold—coinciding with the onset of fruit ripening, when the highest value of 24.83 mg/cm² was recorded. In the later stages of development, CCI declined to a range of 15.12–15.32 mg/cm².

The dynamics of net photosynthetic productivity (NPP), the coefficient of photosynthetic efficiency (CEP), and the production efficiency coefficient (PEC) revealed both shared patterns and varietal differences. The most significant variation in NPP occurred during the seedling, pollination, and early fruit formation stages. In the Nihal cultivar, two peaks in NPP were observed—first during male flower formation (3.69 g/m²·day), and again during pollination/early fruit formation (12.64 g/m²·day). However, a sharp decline in NPP followed, with values even becoming negative (-8.64 g/m²·day), indicating a temporary reduction in photosynthetic performance. A dramatic increase in NPP was then recorded at the beginning of the technical ripeness stage (62.85 g/m²·day), with the highest value (80.37 g/m²·day) occurring during the mass ripening phase (Table 1).

Table 1.

Dynamics of photosynthetic and pigment parameters in tomato cultivars (2021–2022 mean values)

Development stage	Cultivar	Leaf area (m ² /ha)	PP (m ² ·day/ha)	SLMD (mg/cm ²)	NPP (g/m ² ·day)	Total pigments (mg/100 g FW)	Chl a/b	Chl/Carot.
Seedling (4–5 leaves)	Nihal	0.22	9.1	3.07	2.86	181.7	3.15	4.49
Seedling (4–5 leaves)	Khurshud	0.24	10.0	1.96	1.80	225.1	2.99	4.06
Male flowering	Nihal	3.05	198.4	6.47	3.69	189.0	3.15	5.73
Male flowering	Khurshud	2.13	138.4	5.75	2.76	228.4	3.10	5.66
Female flowering	Nihal	3.75	273.4	6.53	1.18	173.1	3.15	5.18
Female flowering	Khurshud	4.16	303.4	6.86	11.30	215.0	2.98	5.72
Fruit set (fertilization)	Nihal	5.08	411.1	7.23	12.64	190.1	2.83	5.13
Fruit set (fertilization)	Khurshud	4.85	392.5	9.27	16.29	189.3	2.67	5.76

First fruit formation	Nihal	5.19	422.2	8.05	-8.64	179.4	2.69	4.98
First fruit formation	Khurshud	4.64	431.9	7.77	0.90	201.1	2.61	5.59
Technical maturity	Nihal	5.26	620.9	18.62	62.85	154.0	2.71	4.50
Technical maturity	Khurshud	5.18	575.5	24.83	39.35	152.9	3.39	3.96
Mass ripening	Nihal	2.85	356.4	48.66	80.37	158.2	2.70	3.75
Mass ripening	Khurshud	7.46	932.4	15.12	93.23	140.6	2.67	4.25
End of vegetation	Nihal	2.66	353.5	77.89	33.13	164.8	2.68	5.15
End of vegetation	Khurshud	6.13	815.8	15.32	-6.25	169.3	2.40	4.32

Table presents the dynamics of key physiological and photosynthetic indicators, including leaf area, photosynthetic potential (PP), specific leaf mass density (SLMD), net photosynthetic productivity (NPP), and plastid pigment content in two melon (*Cucumis melo* L.) cultivars ('Nihal' and 'Khurshud') across different ontogenetic stages.

Overall, both cultivars exhibited a gradual increase in leaf area and photosynthetic potential from the seedling stage toward the reproductive phases, reaching their highest values during technical maturity and mass ripening. This indicates progressive development of assimilative leaf surface and enhanced photosynthetic capacity during plant ontogenesis.

Net photosynthetic productivity showed marked stage-dependent variation, with peak values recorded during reproductive stages. 'Khurshud' generally demonstrated higher NPP during late developmental phases, particularly at mass ripening, suggesting more efficient assimilate production and translocation toward reproductive organs compared to 'Nihal'.

Specific leaf mass density (SLMD) increased progressively with plant age in both cultivars, reflecting structural strengthening of leaves and improved adaptation to increasing physiological demands during development. 'Nihal' showed a more pronounced increase in SLMD at later stages, indicating stronger leaf structural reinforcement.

Total pigment content and pigment ratios (chlorophyll a/b and chlorophyll/carotenoids) showed moderate fluctuations across developmental stages. Slight reductions in pigment content during late ontogeny suggest the onset of natural senescence and redistribution of assimilates toward fruits.

In general, the results indicate that ontogenetic stage strongly regulates photosynthetic performance and pigment dynamics in melon plants, while cultivar-specific differences reflect variation in physiological efficiency and productivity potential, with 'Khurshud' exhibiting superior performance during reproductive development.

Conclusion.

Conclusion based on these findings:

1. Both Nihal and Khurshud cultivars exhibited similar leaf area and photosynthetic potential dynamics during vegetation, characterized by linear increases from the bud stage to mass maturity. Maximum values occurred at the technical maturity of first fruits— 5.26×10^3 m²/ha leaf area and 620.9×10^3 m²·day/ha photosynthetic potential in Nihal, and 7.46×10^3 m²/ha and 932.4×10^3 m²·day/ha, respectively, in Khurshud.

2. A notable feature in both cultivars is the sharp increase—by a factor of 8.86 to 21.80—in leaf area and photosynthetic potential during the transition from the bud phase to the flowering phase. The dynamics of specific density of leaf area (SDLA) in the Nihal cultivar followed a strictly linear pattern throughout the vegetation period, reaching a maximum of 77.89 mg/cm² at the end. In contrast, the Khurshud cultivar maintained linearity only until the pollination and first fruit formation phase, where it exhibited a first maximum, followed by a second and highest maximum of 24.83 mg/cm² during the technical maturity phase of the first fruits.

3. The accumulation patterns of total chlorophylls, plastid pigments, and individual pigments (chlorophyll a, chlorophyll b, and carotenoids) displayed similar characteristics in both cultivars. Except for carotenoids, all pigments showed an initial maximum and followed a three-peaked curve over the vegetation period. Carotenoids also exhibited three maxima; however, these occurred simultaneously during the bud phase in both cultivars. Additionally, the dynamics of the chlorophyll a/chlorophyll b (Chl a/Chl b) ratio and total chlorophyll/carotenoid ratio—important indicators of plant adaptability to environmental stresses such as drought and high temperatures—were found to be cultivar-specific.

4. The net photosynthetic productivity (NPP) dynamics differed markedly between the cultivars: Nihal exhibited a three-peaked curve, whereas Khurshud showed a two-peaked curve. A common critical feature was that the highest production efficiency coefficient (PEC) values were recorded during the pollination/first fruit formation and mass maturity phases. Divergences in the dynamics of the coefficient efficiency of photosynthesis (CEP) and PEC became evident only at the end of the vegetation period. In Nihal, both coefficients decreased sharply, whereas in Khurshud, CEP continued to increase and PEC remained nearly constant. These distinct dynamic patterns likely underpin the observed differences in yield characteristics between the cultivars.

5. In both cultivars, the maximum levels of total wet and dry biomass, including that of vegetative organs, were recorded at the end of the vegetation period. Transitioning into the first fruit formation phase triggered a sharp increase in these parameters in each cultivar. The distribution of wet and dry biomass among vegetative and reproductive organs can be categorized into three periods:

First period (bud phase): Formation of male and female flowers, characterized by a distribution pattern of stem/shoot (or leaf) – leaf (or stem/shoot) – root.

Second period: Pollination and first fruit formation, with a pattern of stem/shoot (or fruit) – leaf – fruit (or stem/shoot) – flower (or root).

Third period (end of vegetation): Technical maturity of the first fruits, characterized by a pattern of fruit – stem/shoot (or leaf) – leaf (or stem/shoot) – root – flower.

This distribution pattern further confirms the decisive role of “creative” leaves and “transmitting” stems and shoots in fruit formation and maturation, compared with other plant organs

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