

The Effect of Developmental Stages on the Photosynthetic Parameters of the Melon

Pengaruh Tahap Perkembangan terhadap Parameter Fotosintesis Melon

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ABSTRACT

This study explores the fluctuations in key photosynthetic parameters in two high-potential melon (*Cucumis melo* L.) cultivars—Gunash and Sadaf—grown in open-field conditions in the Absheron region. The research analyzes a range of physiological and biochemical traits, such as leaf area, photosynthetic potential (PP), net photosynthetic productivity (NPP), specific leaf surface density (SLSD), concentrations of plastid pigments, the coefficient of economic photosynthetic efficiency (CEEP), overall economic efficiency (CEE), and the accumulation of both fresh and dry biomass. Results show a steady rise in SLSD and biomass (both crude and dry) from the vegetative phase to fruit development and full ripening. The early-ripening Gunash cultivar displayed the highest gains during early fruit formation, while the mid-ripening Sadaf cultivar reached peak values during full ripening. Significant differences in NPP, SLSD, and CEE were found throughout the plant's life cycle, with peak values observed at the mass ripening stage in both varieties. Additionally, levels of chlorophyll and carotenoids in the leaves showed a three-phase peak pattern, with each phase varying by cultivar.

Keywords: Melon, High-Potential Cultivars, Photosynthetic, Plastid Pigments

ABSTRAK

Penelitian ini mengkaji fluktuasi parameter fotosintesis utama pada dua varietas melon berpotensi tinggi (*Cucumis melo* L.)—Gunash dan Sadaf—yang ditanam di lahan terbuka di wilayah Absheron. Penelitian ini menganalisis berbagai sifat fisiologis dan biokimia, seperti luas daun, potensi fotosintesis (PP), produktivitas fotosintesis bersih (NPP), densitas permukaan daun spesifik (SLSD), konsentrasi pigmen plastida, koefisien efisiensi fotosintesis ekonomi (CEEP), efisiensi ekonomi keseluruhan (CEE), serta akumulasi biomassa segar dan kering. Hasil menunjukkan peningkatan yang stabil dalam SLSD dan biomassa (baik segar maupun kering) dari fase vegetatif hingga pembentukan buah dan pematangan penuh. Varietas Gunash yang matang awal menunjukkan peningkatan tertinggi selama pembentukan buah awal, sementara varietas Sadaf yang matang tengah mencapai nilai puncak selama pematangan penuh. Perbedaan signifikan dalam NPP, SLSD, dan CEE ditemukan sepanjang siklus hidup tanaman, dengan nilai puncak teramati pada tahap pematangan massal pada kedua varietas. Selain itu, tingkat klorofil dan karotenoid pada daun menunjukkan pola puncak tiga fase, dengan setiap fase bervariasi menurut varietas.

Kata Kunci: Melon, Varietas Berpotensi Tinggi, Fotosintesis, Pigmen Plastida

INTRODUCTION

Melon fruits, including those from the barberry plant, are highly regarded for their dense nutritional content and significant therapeutic and preventive benefits. While barberries—classified botanically as "false" berries from the Berberidaceae family—are not true fruits in the strict botanical sense, they are widely accepted in everyday language. Their health-promoting properties stem from their diverse chemical composition: roughly 90% water and a rich mix of essential vitamins (such as E, PP, A, B1, B2, B5, B9, β -carotene, and C), as well as trace elements like iron, silicon, zinc, iodine, copper, fluorine, and cobalt. They also contain sugars (mono- and disaccharides), organic acids, various fatty acids (saturated and unsaturated), and dietary fiber (Allahverdiyev et al., 2020; Emelyanova, 2014; Halimova & Kim, 2014; Koleboshina, 2011). Thanks to this complex composition, barberries play a valuable role in human nutrition. Their bioactive compounds help regulate the immune system, support the nervous system, enhance digestion, and contribute to cardiovascular and circulatory health. In addition, they promote detoxification, improve skin tone and elasticity, and support healthy hair and overall vitality.

The growth and productivity of fruit-bearing crops—such as melons and various vegetables—are heavily influenced by environmental conditions like light exposure, water supply, temperature, and soil characteristics. Among these, water availability stands out as a critical factor. Research has shown that increasing water supply during the growing period by 18% can enhance plant growth and raise yields by 25–30% (Koleboshina et al., 2019; Koleboshina et al., 2016). More targeted irrigation during the fruit-setting and ripening phases led to notable increases in plant height (by 17.2%), leaf area (by 20.7%), and total biomass (by 12.5%). Higher water input also stimulated root growth, with a 6.6% increase in root mass observed at 2300 m³/ha compared to 1795 m³/ha (Krunina et al., 2016). Additionally, greater soil moisture promoted deeper root development by 1–3 cm, enhancing the plant's ability to absorb remaining soil moisture in drier surface conditions. For melon cultivation, optimal irrigation levels are generally between 5000 and 7000 m³/ha (Kornilov et al., 2021). Melons follow a distinct biological development cycle that includes seed germination, seedling emergence, vine growth, flower development (male and female), pollination, fruit development, and ripening. Each stage is influenced by ambient temperature, humidity, soil fertility, light intensity, cultivar characteristics, and specific agricultural practices (Malueva et al., 2018; Barykin, 2009). According to current research, optimizing key photosynthetic parameters—like leaf surface area, crop photosynthetic potential, net photosynthetic productivity, specific leaf mass per area, and pigment concentration in plastids—is essential for achieving high-quality yields. These indicators can be improved through effective agronomic management, particularly with accurate nutrient and water control strategies (Bezuglov, 2006; Yusifov, 2004). Strong correlations have been found between these photosynthetic traits and yield performance across different crops. For example, studies have reported correlation coefficients of $r = 0.98$ and 0.95 for watermelon, 0.90 and 0.85 for potato, 0.85 and 0.80 for eggplant, and 0.87 and 0.82 for table beet (Allahverdiyev et al., 2020; Vecher & Goncgarik, 1973).

This research aimed to determine effective methods for enhancing fruit crop cultivars' growth, development, and productivity by analyzing various photosynthetic indicators throughout different stages of plant development. The study focused on parameters such as leaf area, overall photosynthetic capacity, net photosynthetic productivity (NPP), specific leaf surface density (SLSD), the efficiency coefficient of photosynthesis (CEEP), general economic efficiency (CEE), plastid pigment concentrations in leaves, and the distribution of moisture and dry matter across different plant parts.

MATERIALS AND METHODS

The study investigated two promising fruit crop cultivars—Gunash (No. 80) and Sadaf (No. 81)—submitted for registration in 2021 to the State Service for Plant Variety Registration and Seed Control under the Ministry of Agriculture of Azerbaijan. Field trials took place on the soils of the Absheron Auxiliary Farm affiliated with the Vegetable Science Research Institute (VSRİ AF). Since the soils in Absheron, including those at VSRİ AF, have low organic matter content and insufficient mineral nutrients, 20 tons per hectare of organic manure and two-thirds of the planned mineral fertilizers (excluding nitrogen) were applied during autumn ploughing. The fertilizer regime was designed based on N₈₀P₈₀K₆₀ in terms of active ingredients. The remaining nitrogen, phosphorus, and potassium fertilizers were split into two applications—20 days after planting and at the start of fruit development—using the compound fertilizer ammofoska (N₂₀P₂₀K₂₀).

The experimental plots measured 20 meters long by 2.8 meters wide, with 70 cm spacing between and within rows. Each plot covered an average area of 56 m², and each treatment was replicated thrice. Leaf surface

area was measured using an L1-3000C portable leaf area meter during the study. Photosynthetic potential (PP) was calculated by multiplying the average leaf area (LA) by the duration of the growing season (T_v):

$$PP = LA \times T_v \quad (1)$$

During different stages of the growing period, net photosynthetic productivity (NPP) was determined using the formula (Vecher & Goncharik, 1973):

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

where B_1 and B_2 are the plant's total dry biomass (t/ha) at the start and end of the observation period; L_1 and L_2 are the green leaf area (m^2/ha) at the start and end; and n is the number of days in the period. The specific leaf area density (SDLS), expressed in mg/cm^2 , is defined as the dry leaf mass per unit leaf area:

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

where m is the dry mass of leaves (mg) and L is the leaf surface area (cm^2).

The coefficient of economic efficiency of photosynthesis (CEEP) represents the ratio of dry fruit biomass (P_m) to the combined dry biomass of leaves, stems, and petioles (M_v) (Ermakov et al., 1987):

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

The coefficient of economic efficiency (CEE) is calculated as the ratio of dry fruit biomass (P_m) to the total dry biomass of the plant (P_{tot}) (Vecher & Goncharik, 1973):

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

Dry biomass distribution between vegetative and generative organs was studied by Gavrilenko et al. (1975), while plastid pigment content in leaves was analyzed by Gavrilenko et al. (1975).

RESULT AND DISCUSSION

Considering the fundamental importance of photosynthesis for the growth and productivity of autotrophic organisms like melon plants, a detailed study was carried out during the 2021–2022 growing seasons to assess key photosynthetic parameters in two melon cultivars. The study focused on leaf surface area development throughout the vegetative period, photosynthetic potential (PP), net photosynthetic productivity (NPP), chlorophyll content index (CCI), photosynthetic efficiency coefficient (PEC), production efficiency coefficient (PEC), plastid pigment concentrations in leaves, and the distribution and dynamics of total moisture and dry biomass during plant growth. The goal was to uncover similarities and differences in these parameters across various developmental stages.

Results showed that leaf surface area and PP exhibited similar trends in both cultivars during the vegetative cycle. These values were lowest at the seedling stage, increased steadily during active growth, and peaked at different times for each cultivar. The early-ripening Gunash reached its maximum leaf area and PP at the technical ripeness of the first fruits (5.26 thousand m^2/ha and 620.9 thousand $m^2 \cdot day/ha$, respectively), while the mid-ripening Sadaf peaked later during mass ripening (7.46 thousand m^2/ha and 932.4 thousand $m^2 \cdot day/ha$). After peaking, both parameters declined in both cultivars.

A notable observation was the sharp increase in leaf area and PP between the seedling and male flower formation stages—rising by 13.86 and 21.80 times in Gunash and 8.88 and 13.84 times in Sadaf, respectively. In Sadaf, this rapid increase continued through the female flower formation phase before following a pattern similar to Gunash. Among the parameters analyzed, CCI was an important indicator of plant adaptation to abiotic stresses such as drought and heat. In Gunash, CCI rose steadily throughout the season, reaching a peak of 77.89 mg/cm^2 at the end. Conversely, Sadaf showed a more variable pattern: CCI increased linearly up to pollination and early fruit development, with a maximum of 9.27 mg/cm^2 , then declined to 7.77 mg/cm^2 , before sharply rising about 3.2-fold to 24.83 mg/cm^2 at the start of fruit ripening. Towards the later stages, CCI decreased again to around 15.12–15.32 mg/cm^2 .

The dynamics of NPP, photosynthetic efficiency coefficient (CEP), and production efficiency coefficient (PEC) showed common trends and cultivar-specific differences. The largest variations in NPP occurred during the seedling, pollination, and early fruit formation stages. In Gunash, two NPP peaks were recorded—first at male flower formation (3.69 $g/m^2 \cdot day$) and again during pollination/early fruit set (12.64 $g/m^2 \cdot day$). This was followed by a sharp decline to negative values (-8.64 $g/m^2 \cdot day$), indicating temporary reduced photosynthetic activity. Subsequently, NPP increased dramatically at the onset of technical ripeness (62.85 $g/m^2 \cdot day$), reaching a maximum of 80.37 $g/m^2 \cdot day$ during mass ripening (see Table 1).

By the end of the growing season, the photosynthetic efficiency coefficient (CEP) decreased approximately 2.43-fold, largely due to leaf yellowing and senescence. Unlike Gunash, whose first CEP peak appeared earlier,

Sadaf showed its initial maximum CEP during pollination and early fruit formation (16.29 g/m²·day). Both cultivars experienced a sharp decline in CEP transitioning to the first fruit formation stage (0.90 g/m²·day in Sadaf). However, at the onset of technical maturity of the first fruits, Sadaf's CEP surged sharply, paralleling Gunash, reaching its highest value during mass ripening (93.23 g/m²·day). Notably, unlike Gunash, Sadaf's CEP dropped steeply at the end of the season, even becoming negative (-6.25 g/m²·day).

CEP and the production efficiency coefficient (PEC) dynamics showed cultivar-specific differences mainly toward the season's end. Gunash displayed a sharp decline in CEP and PEC, whereas Sadaf's CEP continued to rise and PEC remained relatively stable. Peak CEP and PEC values for Gunash were 3.056 and 0.751, respectively, during mass ripening, while Sadaf's maxima occurred at season's end (3.426 and 0.772–0.783), reflecting their distinct productivity profiles.

Table 1. Dynamics of changes in photosynthetic indicators in fruit varieties during the growing period (average for 2021–2022 years)

Development phases	Leaf surface area, min m ² /ha	Photosintetic potential min m ² ·min/h·a	SDLS, mq/sm ²	PEC, q/m ² ·gün	CEEP	CEE	Pigments of plastids, mq/100 q in wet mass					
							Xlorofil a	Xlorofil b	Karotinoidlar	Σ pigmentlar	xla/xlb	Σxl/karotinoid
80-Gunash												
Seedling phase (formation of 4-5 leaves)	0,22	9,1	3,07	2,86	-	-	112,8	35,8	33,1	181,7	3,15	4,49
Formation of male flowers	3,05	198,4	6,47	3,69	-	-	122,1	38,8	28,1	189,0	3,15	5,73
Formation of female flowers	3,75	273,4	6,53	1,18	-	-	110,1	35,0	28,0	173,1	3,15	5,18
Fertilization and the formation of the first fruits	5,08	411,1	7,23	12,64	0,223	0,169	117,5	41,6	31,0	190,1	2,83	5,13
Formation of the first fruits	5,19	422,2	8,05	-8,64	0,469	0,312	108,9	40,5	30,0	179,4	2,69	4,98
Technical maturity of the first fruits	5,26	620,9	18,62	62,85	2,486	0,709	92,0	34,0	28,0	154,0	2,71	4,50
Mass maturation	2,85	356,4	48,66	80,37	3,056	0,751	91,1	33,8	33,3	158,2	2,70	3,75
End of vegetation	2,66	353,5	77,89	33,13	1,440	0,599	100,5	37,5	26,8	164,8	2,68	5,15
81-Sadaf												
Seedling phase (formation of 4-5 leaves)	0,24	10,0	1,96	1,80	-	-	135,3	45,3	44,5	225,1	2,99	4,06
Formation of male flowers	2,13	138,4	5,75	2,76	-	-	146,8	47,3	34,3	228,4	3,10	5,66
Formation of female flowers	4,16	303,4	6,86	11,30	-	-	137,0	46,0	32,0	215,0	2,98	5,72
Fertilization and the formation of the first fruits	4,85	392,5	9,27	16,29	0,286	0,221	117,3	44,0	28,0	189,3	2,67	5,76
Formation of the first fruits	4,64	431,9	7,77	0,90	0,803	0,440	123,3	47,3	30,5	201,1	2,61	5,59
Technical maturity of the first fruits	5,18	575,5	24,83	39,35	2,493	0,711	94,3	27,8	30,8	152,9	3,39	3,96
Mass maturation	7,46	932,4	15,12	93,23	3,023	0,783	82,8	31,0	26,8	140,6	2,67	4,25
End of vegetation	6,13	815,8	15,32	-6,25	3,426	0,772	97,0	40,5	31,8	169,3	2,40	4,32

Table 1 highlights clear cultivar differences in total plastid pigments and chlorophyll content. Gunash's chlorophyll content fluctuated with alternating peaks until early fruit formation, declined toward ripening, then reached a final maximum (138.0 mg/100 g fresh weight) at the season's end. Sadaf exhibited a second chlorophyll peak during early fruit formation (170.6 mg/100 g), followed by a similar decline and a third peak at season's end (137.5 mg/100 g). Plastid pigment contents differed from early fruit formation to mass ripening: Gunash decreased, while Sadaf had a second peak (201.1 mg/100 g). Both followed similar trends, culminating in a third peak (169.3 mg/100 g) at the season's end. Both cultivars shared a tri-phasic pattern in total plastid pigment dynamics, with higher chlorophyll and pigment concentrations during early growth stages (seedling to early fruit formation) compared to later phases. Chlorophyll a and b followed similar patterns, showing three peaks with higher levels during early vegetative stages.

Carotenoids, which absorb short-wavelength light (420–452 nm), displayed distinct trends. The first carotenoid peak occurred at the seedling stage (33.1 mg/100 g in Gunash and 44.5 mg/100 g in Sadaf). Subsequent peaks differed by cultivar: Gunash peaked again during pollination/early fruit formation (31.0 mg/100 g), whereas Sadaf peaked during technical maturity (30.8 mg/100 g). The third peak appeared at mass ripening in Gunash (33.3 mg/100 g) and at season's end in Sadaf (31.8 mg/100 g). Ontogenetic changes in the chlorophyll a/b ratio (xl.a/xl.b) and total chlorophyll/carotenoid ratio (Σxl./carotenoid) showed cultivar-specific patterns. Gunash maintained a stable high xl.a/xl.b ratio (3.15) from seedling to female flower formation, then gradually declined and stabilized around 2.68–2.71 until season's end. Sadaf exhibited two peaks—at male flower formation (3.10) and early fruit maturity (3.39)—with the lowest ratio (2.40) at season's end, reflecting reduced need for long-wavelength light

(660–700 nm).

Similarly, the Σx_l /carotenoid ratio varied: Gunash peaked at male flower formation (5.73), declined until mass ripening, then showed a secondary peak (5.15) at season's end. Sadaf's highest peak (5.76) was during fertilization and early fruit formation, followed by a minimum (3.96) at initial fruit maturity and a second peak (4.32) near season's end. During mass ripening, the lowest Σx_l /carotenoid ratio in Gunash (3.75) coincided with increased short-wavelength light demand in late development. As with all crops, biomass accumulation is the end product of photosynthesis in melons. Both cultivars followed similar biomass accumulation patterns, differing mainly in magnitude. Maximum moist and dry biomass were recorded at the season's end: 821.31 and 100.41 t/ha in Gunash, and 707.45 and 78.41 t/ha in Sadaf. Sharp biomass increases occurred from initial fruit maturity to season's end—5.75- and 6.71-fold in Gunash (moist and dry biomass), and 2.68- and 3.17-fold in Sadaf (Table 2).

Table 2. Dynamics of distribution of wet and dry biomass in fruit varieties by individual plant organs during the vegetation period (average for 2021-2022)

Development phases	Wet biomass, s/ha						Dry biomass, s/ha					
	general	leaves	stems	roots	flowers	fruits	general	leaves	stems	roots	flowers	fruits
80-Gunash												
Seedling phase (formation of 4-5 leaves)	1,36	0,56	0,63	0,17	-	-	0,13	0,07	0,04	0,02	-	-
Formation of male flowers	29,31	10,85	17,33	0,64	0,49	-	3,84	1,98	1,65	0,11	0,10	-
Formation of female flowers	35,43	12,73	20,92	1,20	0,58	-	4,65	2,45	1,86	0,15	0,19	-
Fertilization and the formation of the first fruits	70,70	18,92	30,19	1,59	2,10	17,90	8,80	3,67	3,02	0,23	0,39	1,49
Formation of the first fruits	80,80	22,43	34,69	1,64	0,18	21,86	8,97	3,92	3,23	0,24	0,07	1,51
Technical maturity of the first fruits	145,44	36,96	64,60	2,07	-	41,81	59,94	9,80	7,36	0,32	-	42,46
Mass maturation	697,11	42,30	65,17	2,23	-	587,41	86,99	13,87	10,51	0,34	-	62,27
End of vegetation	821,31	68,55	134,99	2,34	0,47	614,96	100,41	20,70	20,11	0,38	0,18	59,04
81-Sadaf												
Seedling phase (formation of 4-5 leaves)	1,32	0,55	0,62	0,15	-	-	0,09	0,05	0,03	0,01	-	-
Formation of male flowers	17,28	6,28	10,44	0,29	0,27	-	2,21	1,23	0,89	0,05	0,04	-
Formation of female flowers	38,32	14,33	22,36	1,96	0,57	-	5,05	2,85	1,95	0,17	0,08	-
Fertilization and the formation of the first fruits	73,36	17,95	29,59	1,88	0,32	23,62	11,37	3,61	2,46	0,23	0,11	4,96
Formation of the first fruits	131,27	18,54	30,55	2,47	1,04	78,67	14,77	4,28	3,73	0,25	0,22	6,29
Technical maturity of the first fruits	352,16	22,96	50,07	2,67	-	276,46	46,78	7,90	5,41	0,29	-	33,18
Mass maturation	656,65	32,40	63,19	3,11	1,09	556,86	81,40	11,27	8,48	0,62	0,33	60,70
End of vegetation	707,45	40,70	78,11	3,19	1,03	584,42	78,41	9,40	7,90	0,64	0,27	60,20

Organ-specific biomass dynamics mirrored overall trends, peaking at mass ripening except for flowers, which peaked in Gunash during fertilization and early fruit formation (2.10 and 0.39 t/ha) and in Sadaf during mass ripening (1.09 and 0.33 t/ha), followed by slight declines. Moist biomass distribution among vegetative and reproductive organs revealed three distinct phases: (1) male and female flower formation, (2) pollination and first fruit formation, and (3) technical maturity of first fruits/season's end. Initially, both cultivars exhibited a stem–leaf–root biomass pattern. During pollination, Gunash's pattern shifted to stem–leaf–fruit–flower (or root), while Sadaf showed a stem (or fruit)–fruit (or stem)–leaf–root–flower distribution. By the final phase, both cultivars displayed a fruit–stem–leaf–flower pattern.

CONCLUSION

The Gunash and Sadaf cultivars exhibited comparable developmental patterns in leaf area index (LAI) and photosynthetic potential, demonstrating linear growth from bud initiation through physiological maturity. Maximum values occurred at technical maturity of the first fruits: Gunash reached $5.26 \times 10^3 \text{ m}^2/\text{ha}$ for leaf area and $620.9 \times 10^3 \text{ m}^2 \cdot \text{day}/\text{ha}$ for photosynthetic potential, while Sadaf achieved significantly higher values of $7.46 \times 10^3 \text{ m}^2/\text{ha}$ and $932.4 \times 10^3 \text{ m}^2 \cdot \text{day}/\text{ha}$, respectively. Both cultivars showed substantial increases—approximately 9- to 22-fold—during the transition from bud to flowering phase, reflecting intense metabolic activity during reproductive development. The specific density of leaf area (SDLA) differed between cultivars: Gunash increased linearly throughout growth, reaching $77.89 \text{ mg}/\text{cm}^2$ at maturity, whereas Sadaf exhibited a biphasic pattern with a maximum of $24.83 \text{ mg}/\text{cm}^2$ during technical fruit maturity, suggesting differential resource allocation strategies.

Both cultivars had similar total chlorophyll, chlorophyll a, chlorophyll b, and carotenoid accumulation patterns. Most pigments exhibited an initial peak followed by a three-wave oscillatory pattern, while carotenoids showed three synchronous peaks during bud formation. The chlorophyll a/b and total chlorophyll/carotenoid ratios—critical indicators of photoadaptation and stress response—varied significantly between cultivars, indicating differential adaptive mechanisms. Net photosynthetic productivity (NPP) dynamics also differed: Gunash displayed three distinct peaks while Sadaf showed two. Production efficiency coefficients (PEC) peaked during pollination/fruit formation and mass maturity. Late-stage differences were pronounced: Gunash exhibited sharp declines in CEP and PEC, while Sadaf showed increased CEP with stable PEC values, likely explaining the observed yield differences between cultivars.

Maximum biomass accumulation occurred at terminal growth for both cultivars, rapidly increasing during the transition to fruit formation. Biomass partitioning followed three distinct phases: the bud phase prioritized stems/shoots, leaves, and roots; the pollination/fruit formation phase redistributed biomass to stems/shoots, fruits, leaves, and flowers; and the terminal phase emphasized fruit development, followed by stems/shoots, leaves, roots, and flowers. This pattern underscores the critical roles of leaves as photosynthetic source organs and stems/shoots as transport organs in supporting fruit development, with allocation strategies reflecting evolved mechanisms for optimizing reproductive success and determining cultivar-specific yield potential.

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