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RESEARCH ARTICLE

Impact of *Alternaria alternata* on the physiological and yield-related traits of *Vigna radiata*

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Abstract

This study examined the effects of the phytopathogenic micromycete *Alternaria alternata* on leaf pigments, total water content in leaves, exchange leaf water retention, transpiration rate in the flowering and podding period and yield-related traits in three replicates of mung bean (*Vigna radiata*) varieties. The chlorophyll a, chlorophyll b and carotenoid contents in leaves were comparatively assessed under infected (spray inoculation) and control conditions during the flowering and podding periods. The results indicated that *A. alternata* significantly reduced pigment content in most varieties. The Durdona and Andijon-1 varieties exhibited the greatest reduction in pigment content, while Barqaror and Baraka varieties showed the least sensitivity to *A. alternata*. Infection with *A. alternata* in mung bean varieties caused a decline in transpiration and water retention, likely due to stomatal closure and tissue damage. However, total water content generally increased, suggesting water accumulation in healthy tissues as a stress response. Regarding yield-related traits, the number of pods per plant, 1000-grain weight and total grain weight were reduced to varying degrees across all varieties under effect of *A. alternata* compared with the untreated control plants. A significant decline in yield was notably observed in the Durdona, Zilola and Marjon varieties. This study, for the first time, demonstrates the differences in physiological responses among mung bean varieties by jointly examining the effects of *A. alternata* on leaf pigment content, water exchange and yield across various cultivars. The findings obtained serve to protect mung bean and other leguminous plants from the influence of *A. alternata* in agriculture and increase their yield.

Keywords: fungal disease; mung bean; pigment; transpiration; yield-related traits

Introduction

Vigna radiata (mung bean) is a highly nutritious legume that provides various immunological benefits, due to its rich composition of bioactive compounds (1). Mung bean is one of the most widely cultivated legumes, covering an area of over 6 million hectares worldwide, accounting for 8.5 % of the world's total pulse area. The plant is highly susceptible to fluctuations in climate and environmental stress factors (2). Mung beans can harbor nitrogen-fixing bacteria, which reside in root nodules and this symbiotic association is beneficial for improving soil fertility (3). Mung bean is well-suited for sustainable agricultural systems because it is a pulse crop that offers multiple nutritional benefits. It is particularly valued for its high protein content, which ranges from 21 % to 33 % (4).

Alternaria alternata, a fungal pathogen, significantly impacts mung bean yield-related traits by reducing yield and seed quality. Studies have reported yield losses ranging from 20 % to complete crop failure due to this pathogen. Additionally, the infection can deteriorate seed quality and germination rates, further affecting economic returns (5,6). According to a previous study, *A. alternata* as a distinct species has been identified as a causal agent of leaf, stem and pod diseases in soybean and pea under natural field conditions (7). In Uzbekistan, a study conducted in 2020 reported that two *Alternaria* species - *A. alternata* and *A. tenuissima*, are responsible for diseases in leguminous crops such as soybean, chickpea, mung bean and common beans (8). These pathogens cause characteristic symptoms including dark brown necrosis, black lesions on stems and sunken black spots on pods. Plants affected by *Alternaria* develop a disease known as alternariosis, which is characterized by the formation of leaf surface lesions (9). The disease disrupts physiological functions, alters anatomical and morphological parameters, reduces productivity, causes necrosis of specific plant parts and may lead to the complete death of the plant (10). Alternariosis primarily affects the foliar surface, forming characteristic spots and leading to a reduction in the photosynthetically active leaf area (9).

Although studies have been conducted on the effects of *A. alternata* on various plants, its impact on the physiological and biochemical traits of mung bean plants has not been sufficiently investigated. In particular, limited information is available on variety-specific changes in leaf pigment content indicators and their influence on yield. The aim of this study is to examine the effects of *A. alternata* infection on the physiological, biochemical and yield-related characteristics of various mung bean varieties, specifically focusing on the water exchange process and pigment content of each variety.

Materials and Methods

Scientific research was conducted in 2024 in lysimeters and under laboratory conditions at the experimental field of the Regional Experimental Station of the Institute of Genetics and Plant Experimental Biology of the Academy of Sciences of the Republic of Uzbekistan, located in the Kibray district of the Tashkent region. Zilola, Marjon, Barqaror andijon-1, Baraka, Durdona, Ishonch, Turon and Zomin, were used as the objects to study. Micromycetes of the *A. alternata* species were used to create infectious condition. These micromycetes are stored in the unique scientific fund «Collection of phytopathogenic and other microorganisms» of the Institute of Genetics and Plant Experimental Biology of the Academy of Sciences of the Republic of Uzbekistan.

The present study determined the amount of chloroplast pigments, Excised Leaf Water Retention (ELWR), Transpiration Rate (TR) and Total Water Content (TWC) in mung bean leaves during the flowering and podding periods.

In laboratory conditions, the influence of the phytopathogen *A. alternata* on mung bean varieties was assessed through several physiological indicators during the flowering and podding period of plants. These indicators included:

Total Water Content (TWC)

The TWC of leaves was determined gravimetrically to assess plant water status (11). The experiment was performed using second and third leaves from the growth point. For each variant, three biological replicates were analyzed, with a fresh mass of at least 5 g per replicate. Clean, dry weighing boxes (with lids) were pre-dried in a drying oven at 100-105 °C, cooled in a desiccator and weighed to obtain a constant mass. Fresh leaf samples were placed loosely in the pre-weighed boxes, weighed and dried at 105 °C for 5 hr. Samples were then cooled in a desiccator and reweighed. Drying and weighing cycles were repeated until the mass remained constant (i.e. no further change between successive weighing's).

The mass of water was calculated as the difference between fresh and dry mass. Water content was expressed both as a percentage of fresh mass and of dry mass, according to the following formulas:

$$\text{Water content (\% fresh mass)} = \frac{FW - DW}{FW} * 100$$

$$\text{Water content (\% dry mass)} = \frac{FW - DW}{DW} * 100$$

Where, FW=Fresh weight, DW=Dry weight

Excised Leaf Water Retention (ELWR)

The following protocol was used to evaluate ELWR (12). The youngest leaves were collected and weighed fresh weight, left for 2 hr, then wilted at 35° C and reweighed wilted weight after 2 hr. ELWR was calculated using the following formula:

$$ELWR = [1-(FW-WW2H)/FW] * 100$$

Where, FW= Fresh Weight, WW2H= Wilted weight after 2 hr

Transpiration Rate (TR)

TR was determined as follows (13), freshly excised leaves (400-500 mg) were used for transpiration measurements. Analytical balances were leveled and calibrated to zero prior to use. Each leaf was outlined on paper to determine its area (cm^2). The leaf was then placed on the balance and its mass was recorded at regular intervals (every 1-2 min) for 5-15 min after excision. During this period, water loss was not replenished, leading to gradual stomatal closure and a decrease in transpiration. The mean mass loss (g) per interval or over the entire observation period until transpiration ceased was calculated. TR was calculated using the following equation:

$$TR = \frac{A*60*1000}{B*S} *100$$

Where, A = decrease in leaf mass (g), B = time (min), S = leaf area (cm^2)

Pigment content

To determine pigment content, leaf samples (50 mg from three to four plants) were homogenized in 5 mL of 95 % ethanol. The homogenate was centrifuged and the absorbance of the supernatant was measured using a UV-Vis spectrophotometer at 664, 649 and 470 nm, corresponding to chlorophyll *a*, chlorophyll *b* and carotenoids, respectively (14). The pigment concentrations were calculated according to internationally recognized protocols using the following equations:

$$Chl\text{-}a = 13{,}36A_{664} - 5{,}19A^{649}$$

$$Chl\text{-}b = 27{,}43A_{664} - 8{,}12A^{649}$$

$$C_{x+c} = \frac{1000A_{470} - 2{,}13Chl\text{-}a - 97{,}63Chl\text{-}b}{209}$$

Yield-related traits

The number of pods per plant, total grain weight per plant and 1000-grain weight of mung bean varieties grown in field conditions (lysimeter) were determined using generally accepted methods (15).

The degree of susceptibility of mung bean varieties to phytopathogenic micromycetes, based on the studied traits, was assessed using a standard approach (16), by determining the Level of Adaptability (LA %).

$$LA\,\% = (\frac{X_1}{X_2} * 100) - 100\,\%$$

Where, X_1 represents the indicator of the trait under the influence of phytopathogenic micromycetes and X_2 represents the indicator of the trait under control conditions.

Statistical analysis

Data analysis was performed using *StatView 5.0* (SAS Institute Inc., Cary, NC, USA). Results are presented as mean ± Standard Deviation (SD). Differences among treatments were evaluated by one-way Analysis of Variance (ANOVA) and mean comparisons were carried out using Fisher's Protected Least Significant Difference (PLSD) test. Statistical significance was defined at $P < 0.05$ and $P < 0.01$.

Results and Discussion

Pigment content

Chlorophyll is an extremely important and critical biomolecule in photosynthesis, functioning in light absorption and light energy transformation (17). The amount of chlorophyll and carotenoids in infected plants decreased significantly under stress compared to those in the control (18). Previous research on soybeans showed that pathogenic diseases lead to a decrease in the amount of leaf pigments, which causes a slowdown in the photosynthesis process (19). Carotenoids act as potent antioxidants, safeguarding chloroplast structures and supporting chlorophyll stability under both normal and stress conditions (20). In addition to their antioxidant and photoprotective roles, carotenoids contribute to plant tolerance against environmental stresses by quenching reactive oxygen species and preventing photooxidative damage (21). According to a previous study *Alternaria* leaf spot reduced photosynthetic rate more and TR less than could be explained by the extent of infected leaf area alone (22).

In our experiment, the amount of leaf pigments in mung bean plants grown under laboratory conditions was studied during the flowering and podding periods. During the flowering period, the highest levels of chlorophyll a pigment were observed in the Marjon, Ishonch and Andijon-1 varieties (2.48 ± 0.08 mg/g, 2.44 ± 0.05 mg/g, 2.43 ± 0.14 mg/g, respectively), while the lowest levels were recorded in the Baraka and Durdona varieties (2.10 ± 0.43 mg/g, 1.99 ± 0.15 mg/g, respectively). In the infectious condition artificially inoculated with *A. alternata*, the highest levels of chlorophyll a pigment were observed in the Zomin, Barqaror and Zilola varieties (2.33 ± 0.05 mg/g, 2.17 ± 0.25 mg/g, 2.10 ± 0.01 mg/g, respectively), while the lowest levels were observed in the Andijon-1 and Durdona varieties (1.57 ± 0.22 mg/g, 1.45 ± 0.02 mg/g, respectively) (Table 1).

During the flowering period, the highest amount of chlorophyll b pigment was recorded in the Ishonch, Marjon and Zomin varieties (1.15 ± 0.03 mg/g, 1.18 ± 0.06 mg/g, 1.12 ± 0.06 mg/g, respectively), while the lowest amount was observed in the Barqaror and Baraka varieties (0.99 ± 0.04 mg/g, 0.95 ± 0.18 mg/g, respectively). In plants infected with *A. alternata*, the amount of this pigment decreased significantly, with the lowest values observed in the Andijon-1 (0.66 ± 0.09 mg/g) and Durdona (0.79 ± 0.03 mg/g) varieties (Table 1).

During this vegetation period, the varieties Marjon (1.08 ± 0.05 mg/g), Ishonch (1.03 ± 0.02 mg/g) and Andijon-1 (1.03 ± 0.06 mg/g) showed the highest carotenoid content in the control group. In plants infected with *A. alternata*, the amount of this pigment decreased significantly. Notably, the lowest carotenoid content was observed in the Andijon-1 (0.63 ± 0.09 mg/g), Durdona (0.66 ± 0.01 mg/g) and Turon (0.70 ± 0.02 mg/g) varieties (Table 1).

Among mung bean varieties during the flowering period, the Baraka variety showed the least sensitivity to the phytopathogenic fungus *A. alternata* in terms of chlorophyll a content (-0.48 %), while the Andijon-1 variety exhibited the highest sensitivity (-35.39 %). Regarding chlorophyll b content, the lowest sensitivity was observed in the Zomin variety (-3.57 %) and the highest in the Andijon-1 variety (-40.54 %). In terms of carotenoid content in leaves, the Andijon-1 variety showed the highest sensitivity (-38.83 %), while the Baraka variety (-4.49 %) demonstrated the lowest.

During the podding period, the highest chlorophyll a pigment content was recorded in the Durdona (2.76 ± 0.01 mg/g), Zilola (2.60 ± 0.06 mg/g) and Ishonch (2.49 ± 0.24 mg/g) varieties. Under *A. alternata* infection conditions, the amount of this pigment decreased sharply, with particularly low levels observed in the Durdona (1.21 ± 0.01 mg/g), Zilola (1.50 ± 0.03 mg/g) and Baraka (1.43 ± 0.04 mg/g) varieties (Table 2).

The chlorophyll b pigment content during the podding period was high in the Durdona (1.26 ± 0.02 mg/g), Zilola (1.03 ± 0.02 mg/g) and Marjon (1.12 ± 0.18 mg/g) varieties. However, under the influence of *A. alternata*, the content of this indicator decreased significantly, with the lowest levels recorded in the Durdona (0.53 ± 0.00 mg/g), Baraka (0.61 ± 0.01 mg/g) and Andijon-1 (0.63 ± 0.00 mg/g) varieties (Table 2).

Our research results showed that the carotenoid pigment had varying effects on mung bean varieties infected with *A. alternata*. For instance, its content increased in the Durdona (1.13 ± 0.01 mg/g), Baraka (0.95 ± 0.05 mg/g) and Andijon-1 (0.87 ± 0.07 mg/g) varieties compared to the control, while it decreased in the Turon (0.79 ± 0.01 mg/g) variety and remained unchanged in the Barqaror variety (Table 2).

Table 1. Leaf pigment content in mung bean varieties during the flowering period (mg/g)

No	Varieties	Amount of chlorophyll *a* (mg/g)			Amount of chlorophyll *b* (mg/g)			Amount of carotenoid (mg/g)		
		Control	*A. alternata*	LA %	Control	*A. alternata*	LA %	Control	*A. alternata*	LA %
		M SD	M SD		M SD	M SD		M SD	M SD	
1	Ishonch	2.44 ± 0.05	2.04 ± 0.29	-16.39	1.15 ± 0.03	1.00 ± 0.12	-13.04	1.03 ± 0.02	0.81 ± 0.09	-21.36
2	Turon	2.32 ± 0.12	1.74 ± 0.04	-25	1.10 ± 0.04	0.81 ± 0.03	-26.36	0.98 ± 0.03	0.70 ± 0.02	-28.57
3	Marjon	2.48 ± 0.08	1.96 ± 0.02	-20.97	1.18 ± 0.06	0.95 ± 0.01	-19.49	1.08 ± 0.05	0.82 ± 0.00	-24.07
4	Zomin	2.38 ± 0.05	2.33 ± 0.05	-2.1	1.12 ± 0.06	1.08 ± 0.05	-3.57	1.01 ± 0.04	0.91 ± 0.02	-9.9
5	Barqaror	2.28 ± 0.01	2.17 ± 0.25	-4.82	0.99 ± 0.04	0.93 ± 0.13	-6.06	0.84 ± 0.01	0.92 ± 0.10	+9.52
6	Andijon-1	2.43 ± 0.14	1.57 ± 0.22	-35.39	1.11 ± 0.07	0.66 ± 0.09	-40.54	1.03 ± 0.06	0.63 ± 0.09	-38.83
7	Baraka	2.10 ± 0.43	2.09 ± 0.24	-0.48	0.95 ± 0.18	0.84 ± 0.05	-11.58	0.89 ± 0.17	0.85 ± 0.06	-4.49
8	Zilola	2.20 ± 0.23	2.10 ± 0.01	-4.54	1.00 ± 0.14	0.96 ± 0.01	-4.00	0.80 ± 0.10	0.85 ± 0.01	6.25
9	Durdona	1.99 ± 0.15	1.45 ± 0.02	-27.13	0.98 ± 0.06	0.79 ± 0.03	-19.38	0.81 ± 0.05	0.66 ± 0.01	-18.51

M=arithmetic mean; SD=Standard Deviation; LA %=Level of Adaptability

Table 2. Leaf pigment content in mung bean varieties during the budding period (mg/g)

No	Varieties	Amount of chlorophyll *a* (mg/g)			Amount of chlorophyll *b* (mg/g)			Amount of carotenoid (mg/g)		
		Control	*A. alternata*	LA %	Control	*A. alternata*	LA %	Control	*A. alternata*	LA %
		M SD	M SD		M SD	M SD		M SD	M SD	
1	Ishonch	2.49 ± 0.24	1.88 ± 0.28	-24.49	1.07 ± 0.13	0.77 ± 0.11	-28.04	0.80 ± 0.11	0.97 ± 0.07	21.25
2	Turon	2.30 ± 0.03	1.88 ± 0.04	-18.26	0.97 ± 0.01	0.85 ± 0.01	-12.37	0.90 ± 0.01	0.79 ± 0.01	-12.22
3	Marjon	2.48 ± 0.29	1.86 ± 0.04	-25	1.12 ± 0.18	0.82 ± 0.01	-26.78	0.79 ± 0.01	1.00 ± 0.12	26.58
4	Zomin	2.08 ± 0.05	1.68 ± 0.07	-19.23	0.90 ± 0.03	0.73 ± 0.02	-18.88	0.70 ± 0.03	0.83 ± 0.02	18.57
5	Barqaror	1.93 ± 0.08	1.91 ± 0.09	-1.03	0.79 ± 0.05	0.75 ± 0.04	-5.06	0.76 ± 0.03	0.76 ± 0.04	0
6	Andijon-1	2.27 ± 0.12	1.35 ± 0.05	-40.53	0.87 ± 0.06	0.63 ± 0.00	-27.58	0.54 ± 0.02	0.87 ± 0.07	61.11
7	Baraka	2.47 ± 0.13	1.43 ± 0.04	-42.10	0.98 ± 0.07	0.61 ± 0.01	-37.75	0.57 ± 0.01	0.95 ± 0.05	66.67
8	Zilola	2.60 ± 0.06	1.50 ± 0.03	-42.31	1.03 ± 0.02	0.68 ± 0.01	-33.98	0.61 ± 0.02	0.96 ± 0.02	57.37
9	Durdona	2.76 ± 0.01	1.21 ± 0.01	-56.16	1.26 ± 0.02	0.53 ± 0.00	-57.93	0.58 ± 0.09	1.13 ± 0.01	94.82

M=arithmetic mean; SD=Standard Deviation; LA %=Level of Adaptability

During the podding period, the experimental plants showed varying sensitivity in leaf pigments to the phytopathogenic fungus *A. alternata*, depending on the variety. The strongest sensitivity in chlorophyll a and b pigments was observed in the Durdona variety (-56.16 % and -57.93 % respectively), while the lowest sensitivity was observed in the Barqaror variety (-1.03 % and -5.06 %, respectively). By the podding stage, mung bean plant varieties exhibited different levels of sensitivity in carotenoid content. The strongest sensitivity was observed in the Turon variety (-12.22 %) and the lowest sensitivity in the Durdona variety (94.82 %). In the remaining samples, an increase in LA % of up to 95 % was observed. This is explained by the strong antioxidant function of carotenoids in response to stress.

Water exchange

In our research, we studied the TWC, ELWR and TR of leaves in mung bean varieties grown under control conditions and on an infectious condition (*A. alternata*).

According to the results, during the flowering period, the highest TWC was observed in Baraka and Marjon varieties (84.11 ± 2.05 % and 84.13 ± 0.70 %, respectively), while the lowest water content was found in Zilola and Zomin varieties (79.53 ± 0.33 % and 79.28 ± 0.38 %, respectively). In the infectious condition with *A. alternata*, the highest TWC indicators were recorded in Durdona and Marjon varieties (88.63 ± 0.84 % and 85.70 ± 0.90 %, respectively), while the lowest indicators were noted in Zomin (80.59 ± 0.57 %) and Turon (81.34 ± 1.54 %) varieties (Fig. 1).

During the flowering period, the ELWR of plant leaves in the infected condition varied depending on the variety compared to the control. In control plants, the highest water retention was observed in Andijon-1 and Durdona varieties (65.56 ± 6.55 % and 63.30 ± 14.33 %, respectively), while the lowest was found in Zomin and Ishonch varieties (31.26 ± 2.75 % and 32.89 ± 5.10 %, respectively). In the infected condition, Durdona (49.30 ± 7.50 %) and Marjon (47.43 ± 9.03 %) varieties showed the highest indicators of this trait, while Ishonch (20.94 ± 1.42 %) and Zomin (22.44 ± 6.94 %) varieties exhibited the lowest (Fig. 2).

The highest TR during the flowering period of mung bean vegetation in the control condition was observed in Marjon (809.83 ± 46.75 g/m^2·hr) and Durdona (820.26 ± 25.41 g/m^2·hr) varieties, while the lowest was seen in the Baraka (418.30 ± 20.37 g/m^2·h) variety. In the group of mung bean varieties artificially infected with the phytopathogenic micromycete, *A. alternata,* the highest TR was also noted in Marjon (796.95 ± 99.80 g/m^2·h) and Durdona (725.74 ± 60.11 g/m^2·h) varieties, while the lowest was recorded in the Ishonch variety (344.43 ± 26.69 g/m^2·hr) (Fig. 3).

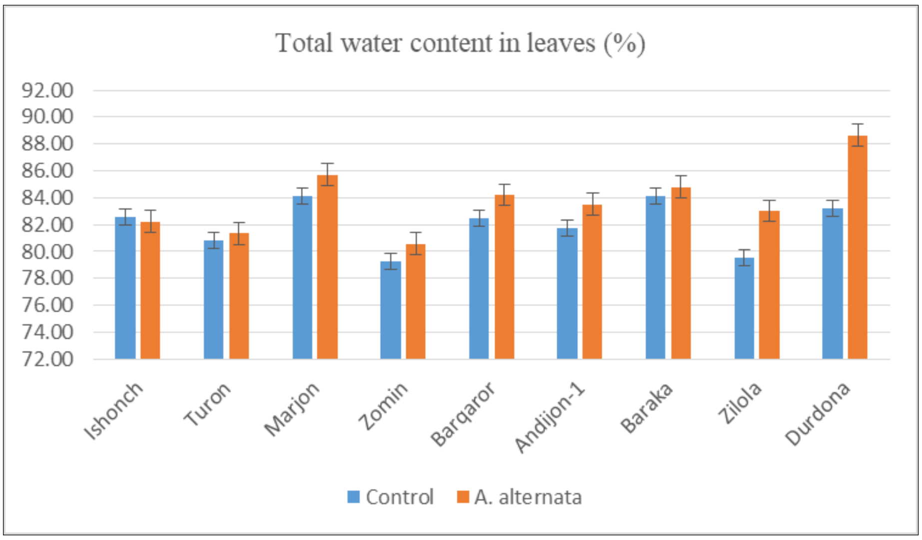

Fig. 1. Total water content in leaves of various mung bean varieties during the flowering period.

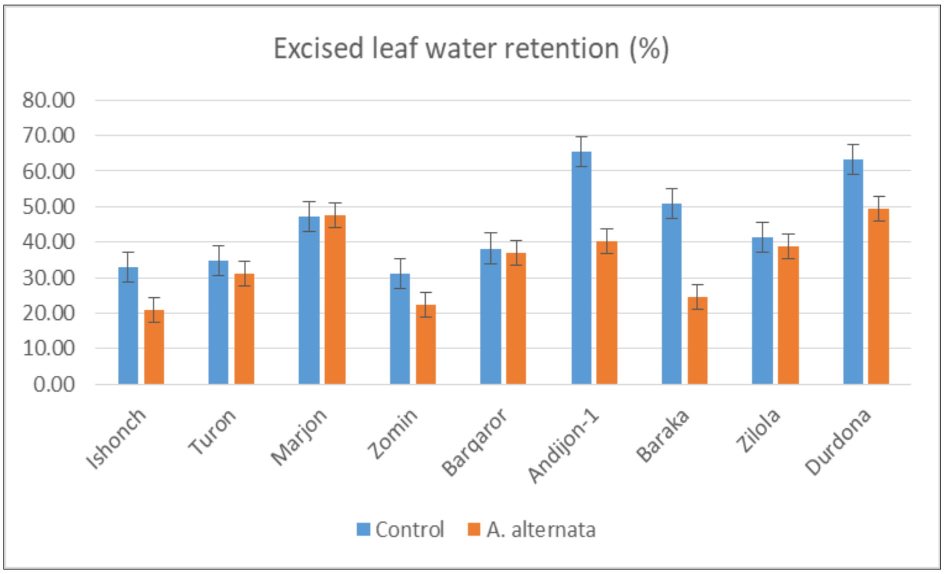

Fig. 2. Excised leaf water retention of leaves of various mung bean varieties during the flowering period.

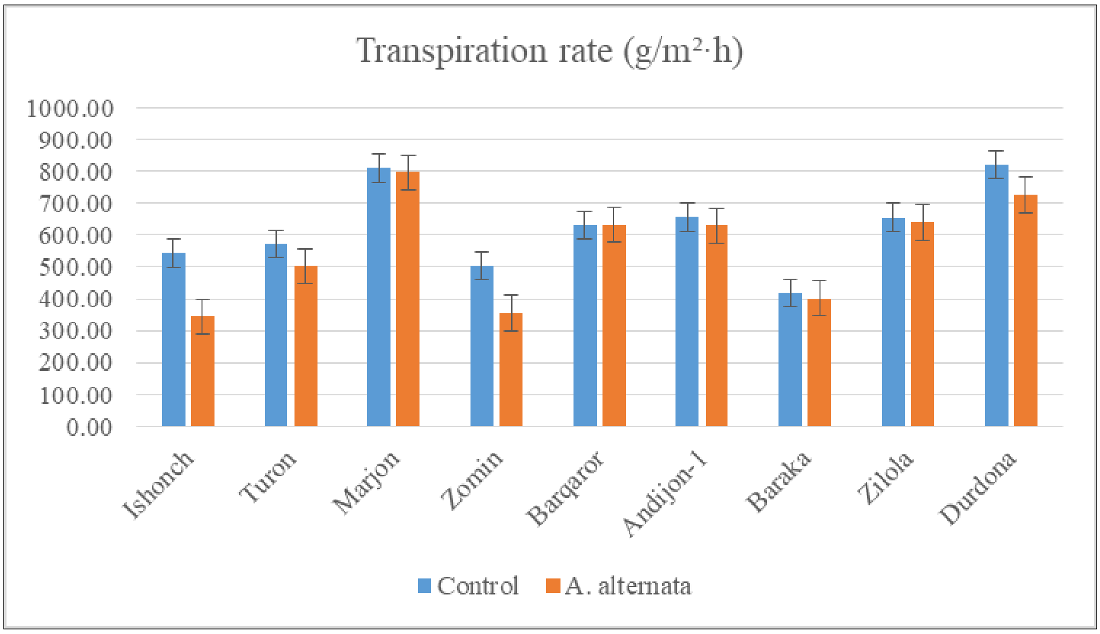

Fig. 3. Transpiration rate in various mung bean varieties during the flowering period.

By the podding period, it was found that in all studied mung bean varieties, the TWC in plant leaves significantly increased on the infectious condition compared to the control. Among untreated control plants, the highest indicator TWC in leaves was observed in the Durdona (84.73 ± 0.84 %) and Marjon (81.96 ± 0.23 %) varieties, while the lowest was observed in the Andijon-1 (78.59 ± 0.30 %) and Zilola (78.36 ± 0.35 %) varieties. Under condition of artificial infection with *A. alternata*, the highest indicator of this trait was recorded in the Andijon-1 (56.96 ± 0.63 %) and Baraka (88.44 ± 0.60 %) varieties (Fig. 4).

In the control variant without phytopathogenic micromycetes, the highest indicator of ELWR in plant leaves was observed in the Baraka (68.72 ± 0.51 %) and Zilola (58.17 ± 4.17 %) varieties, while the lowest was observed in the Marjon (35.68 ± 4.70 %) and Zomin (30.87 ± 1.09 %) varieties. The water retention capacity of plant leaves on the infectious condition artificially infected with *A. alternata* was high in the Andijon-1 (56.96 ± 5.60 %) and Barqaror (48.00 ± 4.35 %) varieties, while in the Turon (24.04 ± 1.56 %) and Durdona (18.09 ± 0.96 %) varieties, this trait showed low values (Fig. 5).

During the podding period, the highest TR was observed in Andijon-1 (895.53 ± 10.82 g/m^2·hr) and Barqaror (883.35 ± 16.85 g/m^2·hr) varieties grown in the untreated control condition, while the lowest TR was observed in Zomin (518.03 ± 18.32 g/m^2·h) and Zilola (534.29 ± 19.47 g/m^2·hr) varieties. Under the influence of the phytopathogenic micromycete *A. alternata*, the highest TR was recorded in Andijon-1 (885.08 ± 36.39 g/m^2·hr) and Barqaror (776.18 ± 23.45 g/m^2·hr) varieties (Fig. 6).

During the flowering period of mung bean varieties, it was found that under the influence of the phytopathogenic micromycete *A. alternata*, the TWC in leaves increased in most varieties (from 0.63-6.56 %) compared to the control. However, experiments from a previous study reported a decrease in TWC in chickpea plants (23). It was observed that the water retention capacity (from 3.06-51.8 %) and TR (from 1.59-36.6 %) of plant leaves decreased under the influence of *A. alternata* compared to the control. In a previous study, a decrease in TR under the influence of *A. alternata* was also observed compared to untreated control plants (24). By the podding period, the TWC in the leaves of plants on the infected condition significantly increased from 0.74 % to 11.12 % compared to plants

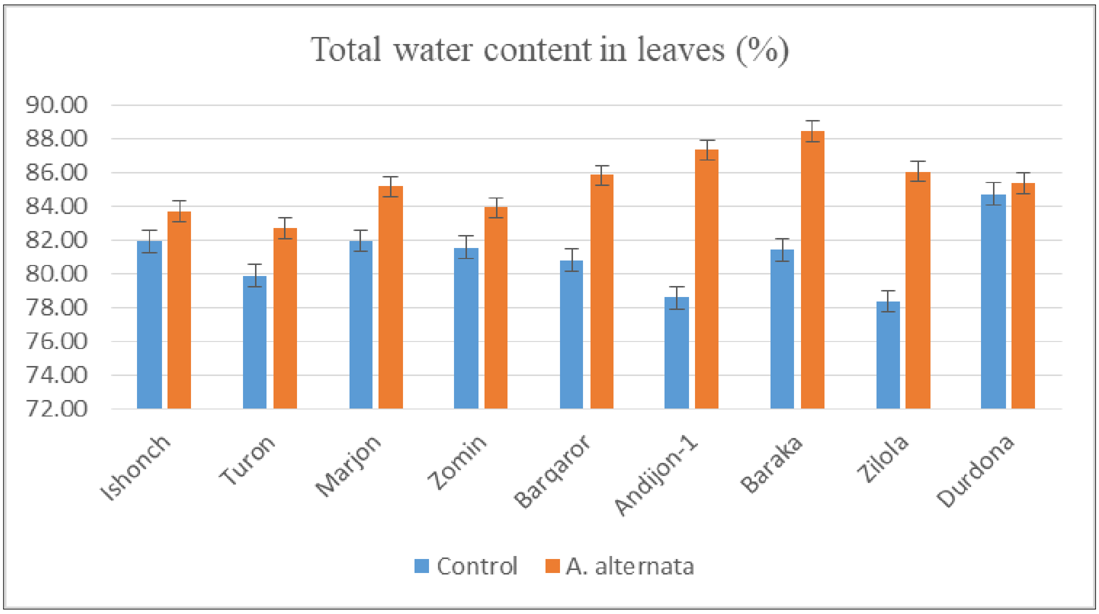

Fig. 4. Total water content in the leaves of various mung bean varieties during the podding period.

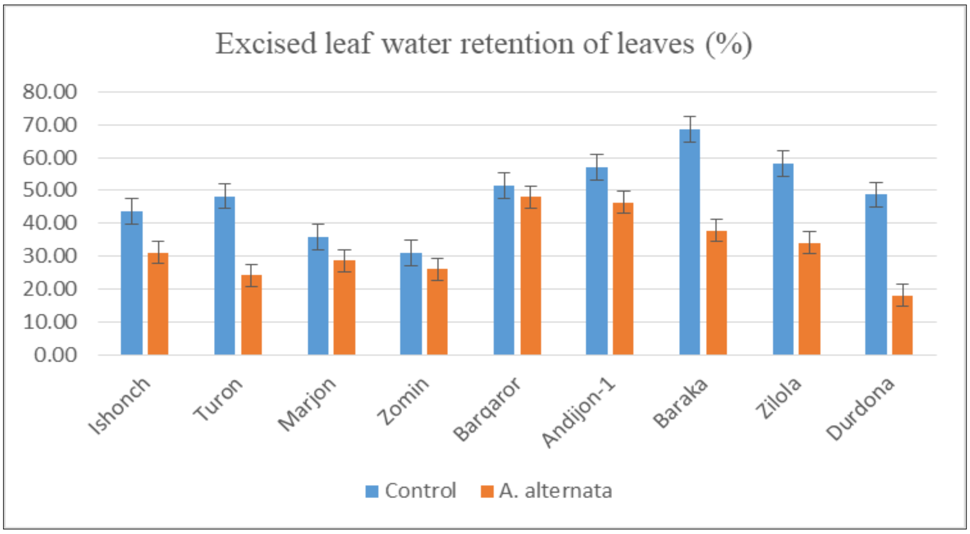

Fig. 5. Excised leaf water retention of leaves in various mung bean varieties during the podding period.

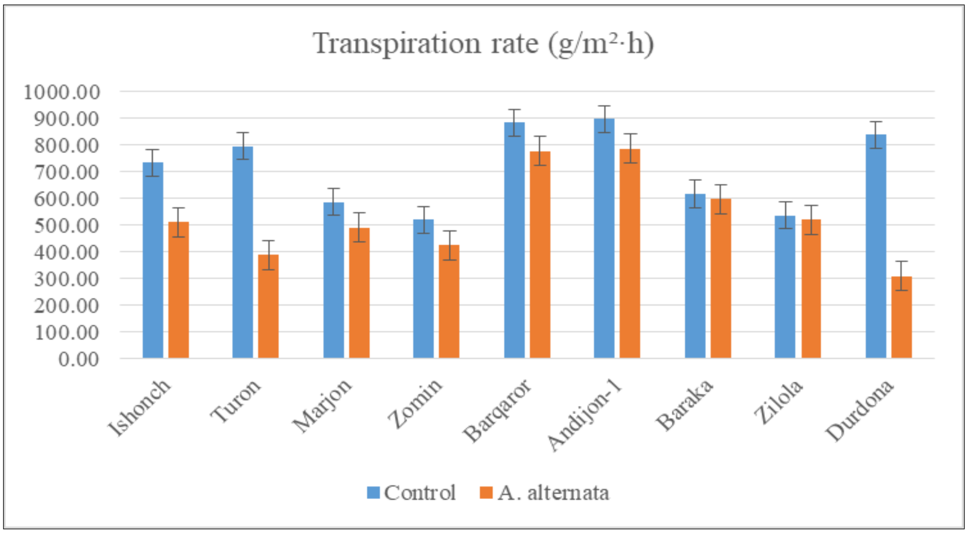

Fig. 6. Transpiration rate in various mung bean varieties during the podding period.

grown on the control condition. The ELWR of the leaves decreased from 6.72-62.84 %, while the TR decreased from 2.80-63.16 %. These results indicate that *A. alternata* infection significantly alters physiological processes associated with water exchange. An increase in the TWC in leaves is caused by the activation of protective mechanisms, while a decrease in water ELWR and TR is caused by stomatal closure, tissue damage and disruption of the cell membrane structure. These differences indicate varying degrees of resistance among varieties.

Yield-related traits

During the research, important yield-related traits of mung bean varieties grown under field (lysimeter) conditions in control and artificially created infectious condition with *A. alternata* were studied, including number of pods per plant, 1000-seed weight (g) and total grain weight. It was found that in all studied mung bean varieties, the indicators of yield-related traits decreased to varying degrees in the infectious condition compared to the control.

Among untreated control plants, the highest number of pods per plant was observed in the Durdona variety (54.75 ± 5.30 pods per plant), while the lowest number of pods was found in the Ishonch (26 ± 0.51 pods per plant) and Marjon (26 ± 1.29 pods per plant) varieties. Under the influence of the phytopathogenic micromycete *A. alternata*, the Andijon-1 variety (28.33 ± 0.92 pods per plant) had the highest number of pods, while the Marjon variety (11.2 ± 1.77 pods per plant) had the lowest number of pods (Table 3).

Thousand grain weight is an important yield contributing parameter which positively affects final yield of mung bean (25). The highest thousand grain weight in the control condition was found in the Andijon-1 variety (7.31 ± 0.32 g), while the lowest was in the Baraka variety (2.93 ± 0.33 g). When studying the thousand grain weight in the infectious condition, the highest indicator was observed in the Andijon-1 variety (7.06 ± 0.38 g) and the lowest in the Baraka variety (2.62 ± 0.23 g) (Table 3).

When studying the total grain weight per plant in the control group, the highest value was observed in the Durdona variety (31.66 ± 3.66 g) and the lowest value in the Marjon variety (8.26 ± 1.02 g). Under conditions of artificial infection with *A. alternata*, the total grain weight per plant was highest in the Andijon-1 variety (10.24 ± 0.91 g) and lowest in the Baraka variety (3.34 ± 0.01 g) (Table 3).

Regarding the number of pods per plant, the strongest susceptibility to *A. alternata* was observed in the Durdona variety (72.60 %), while the lowest susceptibility was found in the Ishonch variety (11.54 %). For the 1000-grain weight trait under *A. alternata* influence, the highest susceptibility was observed in the Marjon variety (16.84 %) and the lowest susceptibility was also in the Turon variety (1.21 %). In terms of total grain weight, the strongest susceptibility was found in the Durdona variety (79.23 %) and the lowest susceptibility was observed in the Barqaror variety (4.21 %). Based on the three yield-related traits studied, the most resistant variety was found to be the Barqaror variety, while the least resistant variety was determined to be the Durdona variety.

Table 3. Yield-related traits of *Vigna radiata* under impact of *A. alternata*

No	Varieties	Number of pods per plant			-seed weight (g)			Total grain weight (g)		
		Control	*A. alternata*	LA %	Control	*A. alternata*	LA %	Control	*A. alternata*	LA %
		M ± SD	M SD		M SD	M SD		M SD	M SD	
1	Ishonch	26 ± 0.51	23 ± 2.64	-11.54	5.47 ± 0.11	5.37 ± 0.21	-1.88	12.74 ± 0.46	6.37 ± 0.53	-49.96
2	Turon	29 ± 2.06	16.6 ± 0.66	-42.76	6.58 ± 0.07	5.98 ± 0.17	-1.21	11.75 ± 1.19	7.97 ± 0.74	-32.13
3	Marjon	26 ± 1.29	11.2 ± 1.77	-56.92	6.65 ± 0.36	5.53 ± 1.11	-16.84	8.26 ± 1.02	4.36 ± 0.66	-47.18
4	Zomin	33.6 ± 1.43	18 ± 1.73	-46.43	7.00 ± 0.51	6.65 ± 0.38	-5.01	19.31 ± 1.25	8.7 ± 0.41	-54.95
5	Barqaror	32.33 ± 0.25	25.75 ± 5.54	-20.35	5.24 ± 0.21	4.74 ± 0.31	-9.55	8.59 ± 0.7	8.23 ± 0.81	-4.21
6	Andijon-1	39.67 ± 0.66	28.33 ± 0.92	-28.58	7.31 ± 0.32	7.06 ± 0.38	-3.41	25.69 ± 1.03	10.24 ± 0.91	-60.12
7	Baraka	50.5 ± 4.84	27 ± 0.0	-46.53	2.93 ± 0.33	2.62 ± 0.23	-10.52	12.40 ± 1.32	3.34 ± 0.01	-73.04
8	Zilola	38.25 ± 4.59	13 ± 1.0	-66.01	4.99 ± 0.14	4.84 ± 0.22	-3.18	9.99 ± 2.18	4.71 ± 0.76	-52.87
9	Durdona	54.75 ± 5.30	15 ± 1.53	-72.60	5.96 ± 3.57	5.25 ± 0.60	-11.97	31.66 ± 3.66	6.57 ± 0.56	-79.23

M=arithmetic mean; SD=Standard Deviation; LA %=Level of Adaptability

Conclusion

According to the research results, the phytopathogenic micromycete *A. alternata* reduces the amount of chlorophyll a and chlorophyll b in mung bean leaves, decreases the leaves' water retention capacity and lowers the intensity of transpiration. Simultaneously, an increase in carotenoid content was observed in some varieties, which is attributed to the activation of the plant's defense mechanisms in response to stress. Under infection conditions, a significant decrease in yield-related traits was observed: the number of pods per plant, the weight of thousand seeds and the total seed weight decreased. These changes confirm that *A. alternata* has a significant negative impact on the physiological processes and yield of mung beans. Furthermore, differences in the susceptibility of various varieties were identified, demonstrating that their response mechanisms play a crucial role in assessing the degree of resistance. This study, for the first time, revealed physiological differences between varieties by studying pigments, water exchange and yield changes together. The obtained results serve as a scientific and practical basis for protecting mung beans and other leguminous crops from the influence of *A. alternata*, selecting resistant varieties and maintaining a stable yield.

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Authors' contributions

TDN conducted laboratory experiment. MHX participated in the design of the study. NIQ performed the statistical analysis. RST participated in determining yield-related traits. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors have no conflicts of interest to declare.

Ethical issues: None

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