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Allometric Relationships of *Malva parviflora* Growing in Two Different Bioclimatic Regions

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A total of 660 individual plants of *Malva parviflora*, a medicinal plant in many countries, growing in two bioclimatic regions were randomly collected with the aim of examining the differences in the allometry of this herbaceous plant growing in two bioclimatic regions. Allometric relationships were found in plant height, stem width, leaf area, leaf length, leaf width, petiole length, and leaf dry weight whereas no relationship was found between plant height or petiole length with specific leaf area. Plants growing in the cool bioclimatic region showed that plant height increases more than the increase in stem width, leaf length, leaf width, and petiole length while plants growing in the warm bioclimatic region showed that plant height increase was lower than that of stem width, leaf length, leaf width, and petiole length. Plant height relationship with root length indicated that in the cool region the plant height increase was less than the increase in the root length while the opposite occurred in the warm region. These differences can be explained by the effects of the different environmental conditions present in the two bioclimatic regions such as water scarcity and availability on the growth of *M. parviflora*.

Keywords: allometry, bioclimatic regions, linear relationships, *Malva parviflora*, nonlinear relationships

Phenotypic plasticity can be defined as the environmental effects on morphology and architecture that include changes in size, structure and spatial positioning of plant organs (Huber et al., 1999). These changes result from environmentally induced changes in the allometry of a number of plant structures such as petiole length, internode length and meristem outgrowth (Bonser and Aarssen, 2001).

A number of studies have been carried out that examined the environmental effects on plant growth and allometry. Schenk and Jackson (2002) studied the effect of water-limited environments on the rooting depth, lateral root spreads and below-ground/ above-ground allometries of plants. They reported that root system sizes differed among growth forms and increased with above-ground size from annuals which represent the minimum to trees that represent the maximum. Henry and Thomas (2002) examined the effects of lateral shade and wind on the stem allometry while Huber and Stuefer (1997) studied the shade-induced changes in branching pattern. Both reported that shading can lead to modifications in plant stem height, growth form and architecture. Sack et al. (2003) studied the effects of combined shade and drought on the morphology of plants. They reported that contrary to what has been hypothesized that plants cannot tolerate combined shade and drought, the studied plant species showed tolerance to both shade and drought by reducing demand for resources. Kume and Ino (2000) investigated the effects of a heavy and light snowfall habitats on the shoot size and allometry of two evergreen broad – leaved shrubs. They showed that the size of new shoots and leaves was significantly different between the two varieties with different critical shoot sizes for flowering. Stamp et al. (2004) studied the effect of competition on plant allometry and defense. They found that there was a change towards less root mass for greater height as competition increased while competition did not affect leaf proteinase inhibitor activity or petiole glandular trichomes or total trichomes. Furthermore, Weiner and Fishman (1994) studied the effect of competition on allometry in *Kochia scoparia*. They showed that crowded and uncrowded *K. scoparia* individuals demonstrated pronounced effects of competition on plant allometry as well as distribution of different aspects of size. *Malva parviflora* is used in Jordan and in other countries as a medicinal plant. It is used as a demulcent for the treatment of coughs and ulcers in the bladder, and as a poultice on swellings, running sores, and boils (Saad et al., 1988). This study is a comparative study of plants from the same species *M. parviflora* growing at two different bioclimatic regions with the aim of determining if the abiotic factors at these sites can

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affect the allometric relationships and growth of this important medicinal plant.

MATERIALS AND METHODS

Study Sites and Species

M. parviflora L. is an annual, hairy herb with erect to prostrate stem. The leaves are petiolate, orbicular in outline, cordate to reniform at base, and crenate. Flowers range from 2-4 or more in axillary clusters, with a pink to purple color, sometimes white. Fruits are glabrous rarely hairy, and prominently wrinkled (Zohary, 1972). Based on rain distribution during the year, Jordan is considered to be of Mediterranean bioclimatic region since rainfall is mainly in winter and spring. The growing season of this plant is from January to May. *M. parviflora* grows in two different bioclimatic regions (biogeographical regions). The two studied bioclimatic regions; Mafraq which is of arid Mediterranean bioclimate of cool variety with mean annual rainfall of 164.0 mm. It is characterized by mean maximum temperature of 32.3°C in August as the hottest month and mean minimum temperature of 1.8°C in January as the coldest month. The second site, Zarqa is of arid Mediterranean bioclimate of warm variety, and mean annual rainfall of 148.0 mm. The mean maximum temperature is 33.2°C in August and the mean minimum temperature is 3°C in the coldest month (January). The two regions are characterized by warm summer, which is definitely warmer in arid zone than in cool zone (Al-Eisawi, 1996). Depending on bioclimatic and vegetation characteristic, vegetation in the Middle East is of four regions; Mediterranean, Irano-Turanan, Saharo-Arabian and Sudanian (Zohary, 1973). The two studied areas are considered to be of Irano-Turanain vegetation (steppe region) that is characterized by poor eroded soil and calcareous or loess type (transported by wind). The vegetation is a timber-less land (no trees) with mostly shrubs and bushes.

Sampling and Analysis

A sample of 660 healthy plant individuals (whole plant with its complete root system) was randomly collected from an area of 0.5 km^2 from the two sites during the growing season from January to May. Collected samples were immediately placed in plastic bags and sprinkled with water and returned to the laboratory within two hours. The root of plants was submerged in water for 16-20 h. One leaf (youngest fully expanded) was harvested from each plant by cutting the petiole at point where it is completely separated from the main axis. Petioles were excised from leaf blade, and length of each was recorded. The photosynthetic surface area of leaf was measured using leaf area meter (Area Meter AM 200; ADC Bioscientific, England). The measured leaves and petioles were dried at 70°C to constant weight, and the weight of each was determined. For each individual plant, the plant height (PH), stem width (SW)), petiole length (PL), leaf area (LA), leaf length (LL), leaf width (LW), root length (RL), leaf dry weight (LDW), petiole dry weight (PDW), and specific leaf area (SLA in cm^2g^{-1}) were measured (Nagashima and Terashima, 1995; Verwijst and Wen, 1996; Cao and Ohkubo, 1998; Chang et al., 2004). Allometric analysis was carried out using nonlinear and linear regression analysis. In such analyses, the variables of interest as listed above are analyzed using the nonlinear equation $y = ax^k$ and the linear equation $y = a + bx$. Thus the nonlinear relationship is allometric if the allometric coefficient (k) $\neq$ 1 and (a) represents the mean value of the ratio of y/x. For the linear relationship, (a) and (b) represent the y-intercept and slope of the straight line, respectively. The calculations were carried out using STATISTICA software for windows (StatSoft, USA).

RESULTS

The results of the nonlinear and linear regression analysis for plants from both sites are listed in Table 1 and 2. Table 1 shows the parameters of both nonlinear and linear equations for the allometric relationships between plant height with stem width, leaf area, leaf length, leaf width, petiole length, leaf dry weight, root length and specific leaf area; and petiole length with specific leaf area for plants growing in Mafraq site. Table 2 shows these values for plants from the Zarqa site.

The results show strong nonlinear and linear relationships between PH-SW, PH-LA, PH-LL, PH-LW, PH-PL, and PH-LDW as determined by the values of the correlation coefficients (r). A weak nonlinear and linear relation is noticed between PH-RL and no relationship between PH-SLA and PL-SLA in the plants growing in the Mafraq site. On the other hand, there is a weak relationship in both nonlinear and linear between PH-SW and somewhat between PH-LL in the plants growing in the Zarqa site and a strong relationship between PH-RL. The relationships between

Table 1. Parameters of nonlinear and linear equations for plants from Mafraq site (n=322).

Relationship	Nonlinear			Linear		
	a	r	k	a	b	r
PH-SW	13.197	1.228	0.736	-5.626	20.274	0.713
PH-LA	0.328	0.878	0.900	12.359	0.119	0.918
PH-LL	0.272	1.687	0.776	-15.949	3.396	0.710
PH-LW	0.261	1.708	0.907	-31.343	4.210	0.827
PH-PL	0.052	1.928	0.874	-24.414	2.406	0.744
PH-LDW	4.705	0.863	0.811	13.562	2.310	0.838
PH-RL	1.266	0.705	0.281	15.681	0.179	0.308
PH-SLA	36.657	0.021	0.010	40.626	-0.065	0.030
PL-SLA	23.514	0.038	0.041	27.003	-0.025	0.038

Abbreviations used: plant height (PH), stem width (SW), leaf area (LA), leaf length (LL), leaf width (LW), petiole length (PL), Leaf dry mass (LDW), specific leaf area (SLA), root length (RL), correlation coefficient (r).

Table 2. Parameters of nonlinear and linear equations for plants from Zarqa site (n=338).

Relationship	Linear			Nonlinear		
	r	b	a	r	k	a
PH-SW	119.222	0.305	0.280	109.315	16.791	0.197
PH-LA	5.277	0.510	0.790	70.239	0.095	0.726
PH-LL	23.845	0.452	0.571	66.550	1.281	0.532
PH-LW	6.105	0.924	0.768	2.377	4.546	0.766
PH-PL	8.378	0.676	0.676	37.219	1.504	0.672
PH-LDW	52.861	0.359	0.707	105.588	1.614	0.557
PH-RL	0.681	1.067	0.653	-19.728	1.083	0.656
PH-SLA	150.064	-0.0168	0.014	150.033	-0.202	0.0623
PL-SLA	32.601	0.203	0.195	60.985	0.183	0.127

Abbreviations used: plant height (PH), stem width (SW), leaf area (LA), leaf length (LL), leaf width (LW), petiole length (PL), leaf dry mass (LDW), specific leaf area (SLA), root length (RL), correlation coefficient (r).

the other variables are the same between plants growing in both sites. The values of (k) in the relationships between all variables indicate an allometric relationship ($k \neq 1$) except between PH-RL in the plants growing in the Zarqa site which appears to be isometric. These allometric relationships between plant height with stem width, leaf length, leaf width and petiole length for plants from both sites are shown in Figure 1 and 2. Relationships between plant height with SLA, and petiole length with SLA for plants from both sites are shown in Figure 3 and 4, and the relationship between plant height with petiole dry weight and leaf dry weight for plants from both sites are shown in Figure 5 and 6.

Furthermore, when comparing the values of the allometric coefficient (k) in the nonlinear equation, which represent the slope of the straight line after converting the equation $y = a*X^k$ to linear form to become $\log y = \log a + k \log x$, there are noticeable differences between the plants growing in both sites. These values for the plants growing in Mafraq site are in most relationships at least twice those of the Zarqa site. Rewriting the allometric equations shows that:

$PH = 13.197 * SW^{1.228}$ (Mafraq site)
$PH = 119.222 * SW^{0.305}$ (Zarqa site)

Furthermore,

$PH = 1.266 * RL^{0.705}$ (Mafraq site)
$PH = 0.681 * RL^{1.067}$ (Zarqa site)

The same pattern of relationships is also present between plant height and leaf length and width when the values of the two sites are compared. This means that the increase in plant height was more than the increase in stem width for plants growing in the Mafraq site while the opposite is true for plants grow-

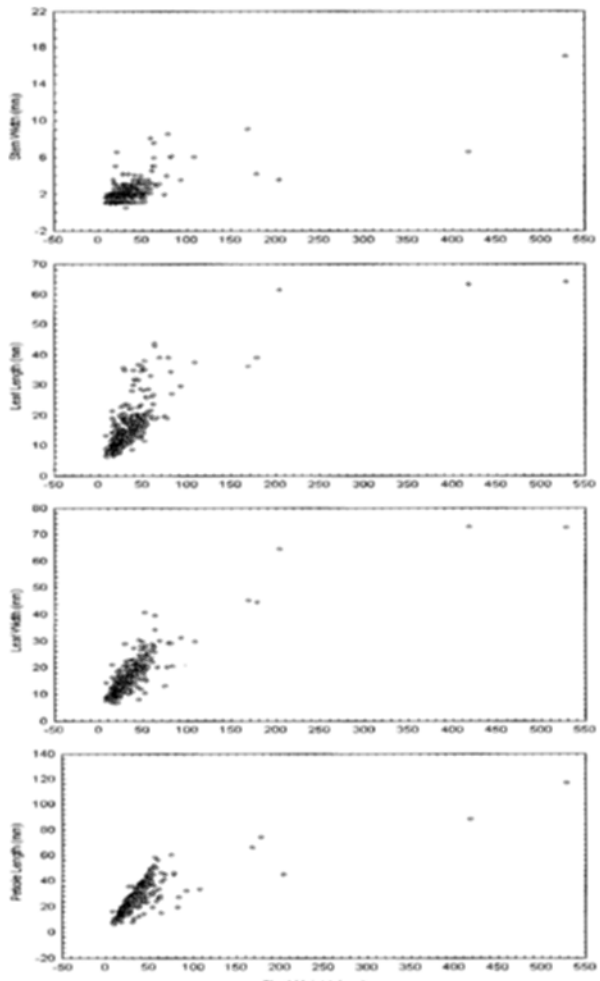

Figure 1. Relationships between plant height with stem width, leaf length, leaf width and petiole length for plants from Mafraq site.

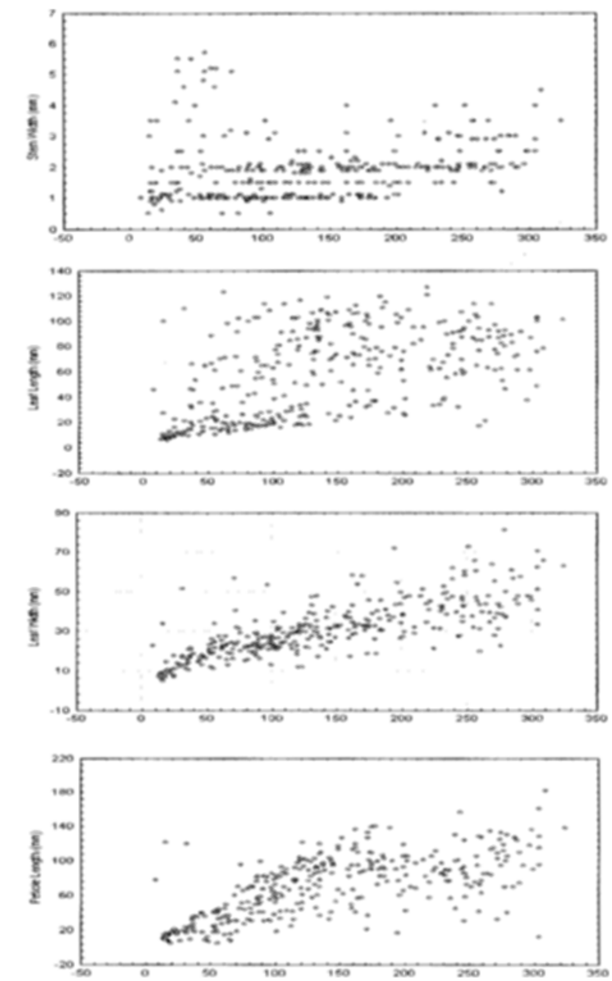

Figure 2. Relationships between plant height with stem width, leaf length, leaf width and petiole length for plants from Zarqa site.

ing in the Zarqa site. This is true also for the relationships between plant height and leaf length, leaf width and petiole length. The relationship was the opposite when comparing plant height with root length. The increment of the plant height was lower than that for root length for the plants growing in Mafraq site whereas for the plants growing in the Zarqa site the increment for the plant height was higher than that for root length.

DISCUSSION

The results showed that there are differences in the allometric relationships of the *M. parviflora* growing in the Mafraq site from the one growing in the Zarqa site. The differences were in relationships between plant height and each of the variables of stem width, leaf length, leaf width, petiole length or root length. The Mafraq site that is classified as the cool bioclimatic variety showed that the increase in plant height was higher than that of leaf length, leaf width, petiole length, and stem width. On the other hand, the Zarqa site that is classified as a warm bioclimatic variety showed that the increase in plant height was lower than that of leaf length, leaf width, petiole length, and stem width. An opposite allometric relationship occurred when comparing the plant height with root length. Although there have been relatively few studies that examined these relationships between plants growing in different bioclimatic regions, there are studies that show the effects of environmental factors on the allometric relationships of plants. Chang et al. (2004) reported differences between two herbs one

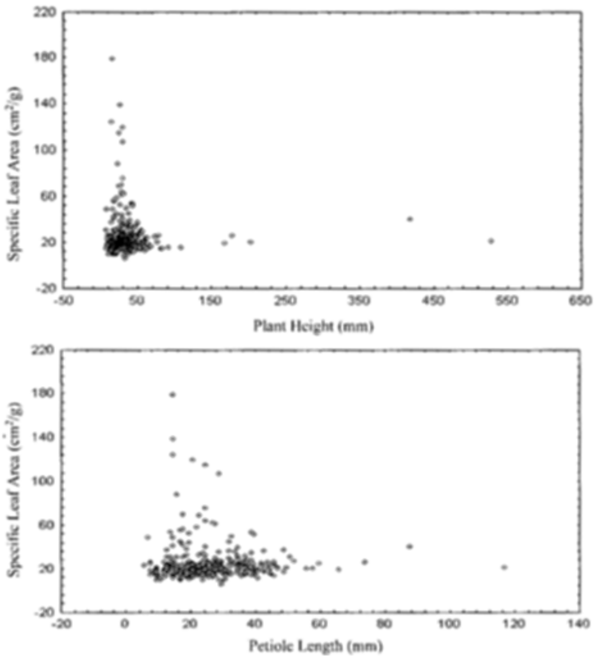

Figure 3. Relationship between plant height and petiole length with specific leaf area for plants from Mafraq site.

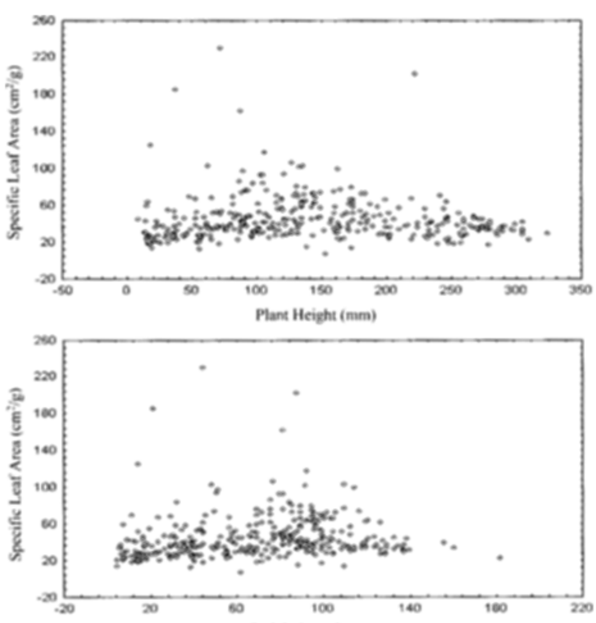

Figure 4. Relationship between plant height with specific leaf area and petiole length with specific leaf area for plants from Zarqa site.

growing in the middle to northern subtrobical evergreen forest zones of China where it needs to capture light more effectively and another growing in a moist and sunny environment near the banks of creeks and rivers. Shipley and Meziane (2002) reported that both

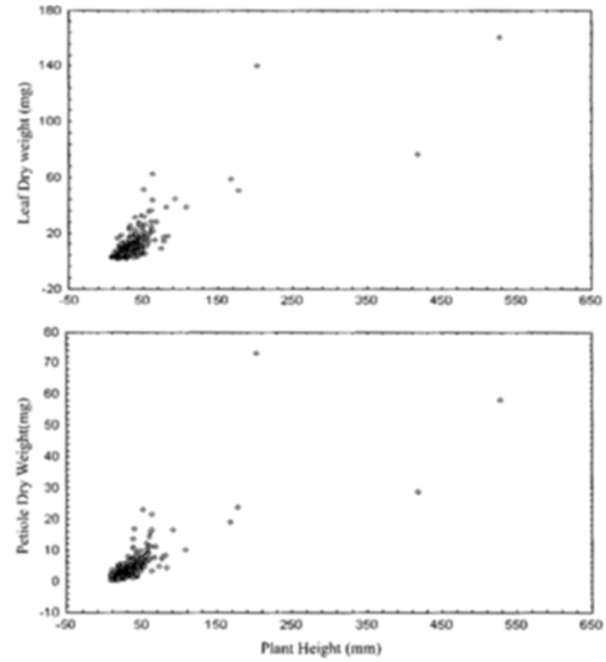

Figure 5. Relationship between plant height with leaf dry weight and petiole dry weight for plants from Mafraq site.

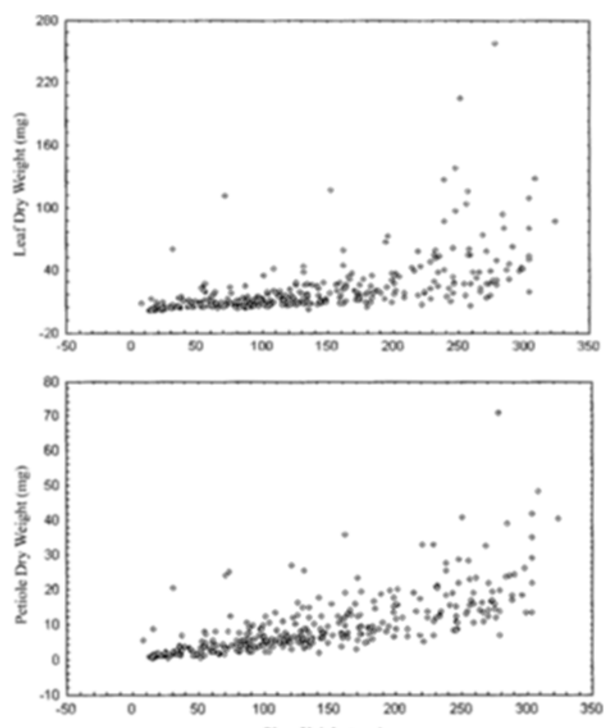

Figure 6. Relationship between plant height with leaf dry weight and petiole dry weight for plants from Zarqa site.

irradiance and nutrient supply affect the slope and intercept of the root: shoot allometry, where decreased nutrient supply increased allocation to roots and decreased irradiance increased allocation to leaves. Brouat and McKey (2001) studied leaf-stem allometry in myrmecophytes compared to plant with solid stems. They indicated that leaf-stem relationship over ontogeny was allometric in contrast to the isometry of the solid stemmed plants because mechanical stability requires a minimum ratio of thickness of the solid ring to external radius of the cylinder, therefore, cross-sectional area of the ring of the wood must vary with that of the cavity. Studies on woody plants also show differences in allometry due to environmental factors. Cao and Ohkubo (1998) reported that root/shoot ratio deceased rapidly with increasing plant height for saplings shorter than about 1.5 m and that less shade-tolerant species tended to have smaller root/shoot ratios for saplings taller than 1.5 m. Their findings also indicated that root depth was not related to shade tolerance. Cornelissen (1999) reported that interspecific variation in leaf size of adult plants corresponded allometrically with interspecific variation in the weight of the seed bearing inflorescence. This relationship was interpreted in terms of ecological strategy.

It is interesting to note that in our study *M. parviflora* allocated more growth to the root in the warm bioclimatic zone than that growing in cool bioclimatic zone where more allocation was directed toward the shoot. It seems that the need to find water in a warm habitat exceeds the need to increase the height. This need can be lessened somewhat in a cool bioclimatic variety. Schenk and Jackson (2002) studied the rooting depths, lateral root spreads and below-ground/above ground allometries of plants in water-limited ecosystems. Their results indicated that relative to above-ground plant sizes, the relative rooting depth tended to increase with aridity is in agreement with our results.

Furthermore, the lack of relationships both nonlinear and linear between plant height and specific leaf area for plants growing in both sites indicate that it is water scarcity that affects allometric relationships more than irradiance. This is also indicated by the similar allometric coefficient (k) in the nonlinear equation where both coefficients for plant height with leaf area and leaf dry weight for plants growing in the two sites where both coefficients are less than one. The slopes of the linear equation are also similar for the plants growing in both sites. The lack of both nonlinear and linear relationships between petiole length and specific leaf area for the plants growing in both sites further support this explanation. A possible explanation for the alterations of the expression of the structural blue-print or the timing of ontogenetic changes by the effects of environmental conditions is stated by Huber et al. (1999). They indicated that the environmental effects on morphology and architecture can result in major changes. These include changes in size, structure and spatial positioning of plant organs including changes in internode and petiole length, in meristem utilization, timing of meristem outgrowth and the fate of the meristems.

In summary, the studied plant species showed allometric relationships between plant height with stem width, leaf area, leaf length, leaf width, petiole length and leaf dry weight for plants growing in both sites. The plants growing in the cool variety bioclimate (Mafraq site) showed a higher increase in plant height compared to stem width, leaf length, leaf width, and petiole length whereas the plants growing in the warm variety bioclimate (Zarqa site) showed the opposite. The pattern is reversed when comparing the plant height with root length for plants growing in these sites. No relationship either nonlinear or linear was found between plant height and petiole length with specific leaf area. These allometric relationships can be explained by the effects of the variations in the abiotic factors between the two bioclimatic regions on the growth of *M. parviflora*.

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