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Effect of Altitudinal Gradients on the Content of Carbohydrate, Protein, Proline and Total Phenols of Some Desert Plants in Saint Katherine Mountain, South Sinai, Egypt

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Abstract: The present study was carried out to show the effect of altitudinal gradients on total soluble carbohydrate, water soluble protein, proline and total phenols of five plant species in Saint Katherine Mountain under natural conditions. All Analyses were carried out through five different altitudes viz., 1800 m a.s.l., 2000m a.s.l., 2200 m a.s.l., 2400 m a.s.l. & 2600 m a.s.l. for five species (*Nepeta septemcrenata*, *Seriphidium herba-album*, *Tanacetum sinaicum*, *Ballota undulate* & *Teucrium polium*). An obvious variation was recorded as regards the biochemical constituents of the plants among the different elevation ranks in all species. The maximum value of total soluble carbohydrate was recorded in *Teucrium polium* at elevation from 1800-2000, while the maximum value of water soluble protein was recorded in *Nepeta septemcrenata* at elevation from 1800-2000. At the same time, *Seriphidium herba-album* attained the maximum value of free proline at elevation from 2200-2400 and the maximum value of total phenols at elevation from 1800-2000.

Key words: Altitudinal gradient · Carbohydrate · Protein · Proline · Total phenols · Saint Katherine Mountain · Desert plant

INTRODUCTION

Perennial desert plants are under the impact of water stress throughout their lives except for short spells in the rainy season. These plants may tolerate, even for long periods, considerable water saturation deficits. Drought resistance and/or tolerance in desert plants are achieved by a complex of mechanisms. Recently, interest has been increased on biochemical aspects of water stress. The biochemical responses of plants to environmental stresses have been reviewed and discussed by Kozlowski [1], Levitt [2], Hsiao [3] and Kluge [4]. Among the biochemical processes involved is the accumulation of proline in stressed plants [5-12]. Altitudinal gradients determine not only temperature gradients but also the depth of the snow and the timing of snow melt which strongly influences plant phenology and the length of the growing season [13]. Both factors may affect patterns of plant growth, survival and reproduction [14]. Temperature may also affect the nitrogen concentration of vegetation and consequently its quality as food for herbivores. A negative relationship between nitrogen concentration and the temperature is a characteristic of some plants [15]. In mountainous environment, variation in altitude offers wide variety of environmental conditions. In general, with increase in elevation, stressors such as temperature, pressure, light intensity, rainfall, partial pressure of metabolic gases are known to influence plant metabolism [16, 17]. Like any other metabolic process, nitrogen metabolism is significantly influenced by variation in the altitude. Increased nitrogen content has been reported in plants with the increase in the altitude [18]. This implies that plants which are least influenced by altitudinal changes are much resistant to multiple stresses. Water stress in plants induced by either water deficiency or by excessive water supply greatly modifies the metabolism of carbohydrates [19]. Protein synthesis is also one of the most negatively affected anabolic processes [20] together with photosynthesis and phenolic compounds [21].

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The present investigation aims to study the effects of altitude on total soluble carbohydrate, water soluble protein, proline and total phenols in five plant species at Saint Katherine Mountain under natural conditions.

MATERIALS AND METHODS

Study Area: The research was conducted in Saint Katherine Mountain, the highest peak in Egypt (2641m a.s.l.). It lies in the center of the triangular mass of southern Sinai. It has three peaks of black volcanic rock that contrasts strongly with the surrounding rocks and contains two main deep gorges; Shaqq Musa and Wadi Garagneia. Katherine pluton forms a part of highly rugged mountains with acid plutonic and volcanic rocks belonging to the Precambrian basement complex of the southern part of Sinai Peninsula.

Collection of Plant Samples: Plant leaves were collected during May 2011 from five different altitudes viz., 1800 m a.s.l., 2000 m a.s.l., 2200 m a.s.l., 2400 m a.s.l. & 2600 m a.s.l. for five species (*Nepeta septemcrenata*, *Seriphidium herba-album*, *Tanacetum sinaicum*, *Ballota undulate* and *Teucrium polium*).

Physico-Chemical Characteristics of Soil: At each elevation, soil samples from 20 cm depth were taken with a stainless steel auger. The samples were collected randomly from 3 sites were pooled together, stored in plastic bags, sealed and labeled. Soil samples were dried in an air-forced oven at 40°C. The dried samples were sieved out to remove stones and plant residues and were ground in a stainless steel mill and passed through a 2-mm sieve. The sieved soils were collected and stored until further analyses. Soil chemical analyses were carried out according to the methods described by Jackson [22].

Determination of Metabolites: The contents of soluble carbohydrates were determined using anthrone technique according to Umbriet *et al*. [23]. The contents of soluble proteins were estimated according to the method of Lowery *et al.* [24]. Proline content was measured according to the method of Bates *et al*. [25]. Total phenols were determined by Folin Ciocalteu reagent [26].

Statistical Analyses: All data were statistically analyzed using One-way ANOVA and Post hoc-LSD tests (the least significant difference) at 0.05, 0.01 and 0.001 levels of probability [27]. The values of the biochemical analysis are means of three replicates.

RESULTS

Variation in Soil Properties of among Different Elevation Ranks: The means of soil characteristics of the five elevation ranks supporting the sampled plants are presented in Table 1, 2 & 3. The means of soil parameters show that there is a highly significant variation in soil physical properties (Table 1), electrical conductivity (EC), total dissolved salts (TDS), water content, organic matter, calcium carbonate (Table 2), sodium, potassium, calcium, magnesium, chloride and sulphates and moderate significance in pH; and non-significant difference in bicarbonate.

Total Soluble Carbohydrates: The means of total soluble carbohydrates content shown in Table 4 clearly indicate that the maximum value was recorded in *Teucrium polium* at elevation from 1800-2000. At the species level, *Nepeta septemcrenata* recorded the maximum value (8.68 mg/ g dry wt) at elevation from 2000-2200 m and the minimum value (6.29 mg/ g dry wt) at elevation from 2400-2600 m. There are also highly significant differences among plants of the different elevation ranks ($F = 294.305$, $P = 0.000$); *Ballota undulata* exhibited the maximum value (7.28 mg/ g dry wt) at elevation from 2200-2400 m and minimum value (6.15 mg/ g dry wt) at elevation from 1600-1800 m and there were highly significant differences among plants from different elevation ranks ($F = 90.679$, $P = 0.000$). *Seriphidium herba-album* plants showed the maximum value (6.25 mg/ g dry wt) at elevation from 1800-2000 m and a minimum value (4.15 mg/ g dry wt) at elevation from 2400-2600 m and there were highly significant differences among plants from the different elevation ranks ($F = 494.576$, $P = 0.000$). *Tanacetum sinaicum* plants had the maximum value (6.86 mg/ g dry wt) at elevation from 1600-1800 m and minimum value (2.21 mg/ g dry wt) at elevation from 2400-2600 m and there were highly significant differences among plants from the different elevation ranks ($F = 2014.896$, $P = 0.000$). *Teucrium polium* attained the maximum value (10.24 mg/ g dry wt) at elevation from 1800-2000 m and minimum value (4.34 mg/ g dry wt) at elevation from 2400-2600 m and there were highly significant differences among plants from different elevation ranks ($F = 212.721$, $P = 0.000$). The results obtained showed significant variation in the total soluble carbohydrate contents at different altitudes. This trend different from one species to another. In this connection, *Nepeta septemcrenata* and *Ballota undulate* showed the maximum total soluble carbohydrate contents at relatively high altitude

Table 1: Results of one way analysis of variance (ANOVA) of physical properties of soil among different elevation ranks (ALT)

ALT (m)	Fine gravel	Coarse sand	Fine sand	Silt	Clay	Texture
1600-1800	18.5 ± 0.27	32.1±0.23	21.87±0.29	15.47±0.23	11.8±0.25	Loamy sand
1800-2000	11.5 ± 0.25	32.1±0.27	21.37±0.31	17.47±0.27	17.3±0.24	Loamy sand
2000-2200	13.1±0.26	29.5±0.26	22.87±0.28	15.47±0.25	18.8±0.25	Sandy clay loam
2200-2400	7.5±0.28	18.1±0.25	35.87±0.27	19.97±0.24	18.3±0.28	Sandy loam
2400-2600	10.5±0.26	24.1±0.26	24.87±0.29	20.47±0.23	19.8±0.31	Sandy clay loam
F_{ratio}	235.6	520.45	412.97	104.69	156.7	--
P_{value}	***	***	***	***	***	--

Each value is a mean of 3 replicates ± standard errors. *** = significant at P < 0.001

Table 2: Results of one way analysis of variance (ANOVA) of chemical properties of soil among different elevation ranks (ALT)

ALT (m)	pH	EC (µs/ cm)	T.D.S (ppm)	Water Content (%)	Organic matter (%)	$CaCO_3$ (%)
1600-1800	8.1±0.06	168.49±0.75	348.27±0.84	0.19±0.08	4.82±0.14	30.3±0.15
1800-2000	8.1±0.07	123.30±0.75	254.27±0.83	1.40±0.08	4.99±0.16	16.8±0.16
2000-2200	7.9±0.05	104.55±0.77	215.27±0.84	0.48±0.09	6.03±0.17	11.8±0.18
2200-2400	7.8±0.06	127.14±0.77	262.27±0.85	0.34±0.07	4.65±0.16	14.3±0.15
2400-2600	7.8±0.6	115.60±.78	238.27±0.89	0.53±0.08	4.30±0.14	16.3±0.17
F_{ratio}	6.900	1049.9	3667.07	30.58	22.78	2307.77
P_{value}	**	***	***	***	***	***

Each value is a mean of 3 replicates ± standard errors. ** = significant at P < 0. 01, *** = significant at P < 0.001

Table 3: Results of one way analysis of variance (ANOVA) of chemical properties of soil (Water Soluble Ions) among different elevation ranks (ALT)

ALT (m)	Na^+ (ppm)	K^+(ppm)	Ca^{++}(meq/L)	Mg^{++} (meq/L)	Cl^-(meq/L)	HCO_3^- (meq/L)	SO_4^{--} (meq/l)
1600-1800	23.87±0.16	77.42±0.38	26±0.27	6.38±0.18	12.60±0.02	13.47±0.65	69.96±0.22
1800-2000	16.02±0.15	37.36±0.44	25±0.26	2.38±0.15	17.50±0.02	13.97±0.87	58.96±0.29
2000-2200	15.52±0.14	25.34±0.35	20±0.28	1.38±0.16	15.40±0.02	12.97±0.77	49.96±0.24
2200-2400	18.86±0.12	40.71±0.65	25±0.26	2.38±0.22	10.50±0.02	12.47±0.61	52.46±0.23
2400-2600	17.60±0.13	22.39±0.38	17.5±0.29	2.38±0.23	16.10±0.04	12.47±0.55	59.96±0.23
F_{ratio}	326321.1	3541.87	206.67	132.82	37833.16	1.134	1159.63
P_{value}	***	***	***	***	***	NS	***

Each value is a mean of 3 replicates ± standard errors. NS = non-significant, *** = significant at P < 0.001

Table 4: Results of one way analysis of variance (ANOVA) of total soluble carbohydrate contents of plant species belonging to the five different altitudes (ALT) of Saint Katherine Mountain

ALT (m)	*Nepeta septemcrenata*	*Ballota undulata*	*Seriphidium herba-album*	*Tanacetum sinaicum*	*Teucrium polium*
1600-1800	6.64 ± 0.09 a	6.15 ± 0.02 a	4.97 ± 0.04 a	6.86 ± 0.02 a	9.83 ± 0.06 a
1800-2000	8.18 ± 0.06 b	6.72 ± 0.04 b	6.25 ± 0.06 b	6.55 ± 0.08 b	10.24 ± 0.37 a
2000-2200	8.68 ± 0.06 c	6.80 ± 0.08 b	6.01 ± 0.04 b	4.38 ± 0,02 c	6.47 ± 0.04 b
2200-2400	7.14 ± 0.04 d	7.28 ± 0.04 c	4.56 ± 0.04 c	5.69 ± 0.02 d	6.93 ± 0.02 b
2400-2600	6.29 ± 0.4 a	6.20 ± 0.06 a	4.15 ± 0.04 d	2.21 ± 0.04 e	4.34 ± 0.04 c
F_{ratio}	294.305	90.679	494.576	2014.896	212.721
P_{value}	***	***	***	***	***

The plant samples were collected at altitudes ranging from 1,600 m a.s.l. to 2,600 m a.s.l. during summer season (May 2011). The mean values listed are expressed as mg/g dry weight of shoot. Each value is a mean of 3 replicates ± standard errors. Means in a column with similar letters are not significantly different according to LSD. *** = significant at P < 0.001.

Table 5: Results of one way analysis of variance (ANOVA) of water soluble protein contents of plant species belonging to the five different altitudes (ALT) of Saint Katherine Mountain

ALT (m)	*Nepeta septemcrenata*	*Ballota undulata*	*Seriphidium herba-album*	*Tanacetum sinaicum*	*Teucrium polium*
1600-1800	0.75 ±0.01 a	0.39 ± 0.01	0.07 ± 0.01 a	0.18 ± 0.01 a	0.06 ± 0.01 a
1800-2000	0.78 ± 0.04 a	0.19 ± 0.01	0.08 ± 0.01 a	0.04 ± 0.01 a	0.10 ± 0.01 b
2000-2200	0.28 ± 0.01 b	0.73 ± 0.03	0.16 ± 0.09 a	0.65 ± 0.06 b	0.05 ± 0.01 a
2200-2400	0.25 ± 0.01 b	0.05 ± 0.01	0.30 ± 0.01 b	0.13 ± 0.01 a	0.16 ± 0.01 c
2400-2600	0.19 ± 0.01 b	0.27 ± 0.01	0.17 ± 0.01 a	0.4 ± 0.01 c	0.04 ± 0.01 a
F_{ratio}	149.915	3.215	25.5	71.183	50.55
P_{value}	***	NS	*	***	***

(2000-2200 m, 2200-2400 m, respectively). On the other hand, the maximum carbohydrate content was attained at relatively lower altitudes (e.g. 1800-2000 m, 1600-1800 m in *Seriphidium herba-album*, *Teucrium polium and Tanacetum sinaicum*, respectively).

Water Soluble Protein: The means of water soluble protein contents are shown in Table 5. These results clearly indicated that the maximum value was recorded in *Nepeta septemcrenata* at elevation from 1800-2000 m. At the species level, *Nepeta septemcrenata* plants had the maximum value (0.78 mg/g dry wt) at elevation from 1800-2000 m and minimum value (0.19 mg/g dry wt) at elevation from 2400-2600 m and there were highly significant differences among plants from different altitudinal zones (F = 149.915, P = 0.000). *Ballota undulata* showed the maximum value (0.73 mg/g dry wt) at elevation from 2000-2200 m and minimum value (0.05 mg/g dry wt) at elevation from 2200-2400 m. There were no significant differences among plants from different elevation ranks (F = 3.215, P>0.05). *Seriphidium herba-album* plants had maximum value (0.30 mg/ g dry wt) at elevation from 2200-2400 m and minimum value (0.07 mg/g dry wt) at elevation from 1600-1800 m and there were significant differences among plants from different elevation ranks (F = 25.5, P<0.05). *Tanacetum sinaicum* plants had the maximum value (0.65 mg/g dry wt) at elevation from 2000-2200 m and minimum value (0.04 mg/g dry wt) at elevation from 1800-2000 m and there were highly significant differences among plants from different elevation ranks (F = 71.183, P = 0.000). *Teucrium polium* plants showed the maximum value (0.16 mg/g dry wt) at elevation from 2200-2400 m and minimum value (0.04 mg/g dry wt) at elevation from 2400-2600 m and there were highly significant differences among plants from different elevation ranks (F = 50.55, P = 0.000).

The plant samples were collected at altitudes ranging from 1,600 m a.s.l. to 2,600 m a.s.l. during summer season (May 2011). The mean values listed are expressed as mg/ g dry weight of shoot. Each value is a mean of 3 replicates ± standard errors. Means in a Column with similar letters are not significantly different according to LSD. NS=non significance, *=significant at P<0.05, ***=significant at P<0.001.

Free Proline: The means of free proline contents presented in Table 6 clearly show that the maximum value was recorded in *Seriphidium herba-album* plants at elevation from 2200-2400 m. At the species level, *Nepeta septemcrenata* plants showed the maximum value (5.75 mg/g dry wt) at elevation from 2000-2200 m and minimum value (1.47 mg/g dry wt) at elevation from 1600-1800 m and there were highly significant differences among plants from different elevation ranks (F = 196.885, P = 0.000). *Ballota undulata* plants showed maximum value (3.46 mg/ g dry wt) at elevation from 2400-2600 m and minimum value (1.49 mg/ g dry wt) at elevation from 1600-1800 m and there were highly significant differences among plants from different elevation ranks (F = 68.313, P = 0.000). *Seriphidium herba-album* plants showed maximum value (10.68 mg/ g dry wt) at elevation from 2200-2400 m and minimum value (5.63 mg/g dry wt) at elevation from 2400-2600 m and there were highly significant differences among plants from different elevation ranks (263.565, P = 0.000). *Tanacetum sinaicum* plants had maximum value (6.44 mg/g dry wt) at elevation from 2200-2400 m and minimum value (2.33 mg/g dry wt) at elevation from 1600-1800 m and there were highly significant differences among plants from different elevation ranks (F = 175.055, P = 0.000). *Teucrium polium* plants showed maximum value (5.71 mg/g dry wt) at elevation from 2400-2600 m and minimum value (1.77 mg/g dry wt) at elevation from 2000-2200 m and there were highly significant differences among plants from different elevation ranks (F = 119.105, P = 0.000).

Total Phenols: The means of total phenols content are presented in Table 7 clearly indicate that the maximum value was recorded in *Seriphidium herba-album* plants at elevation from 1800-2000 m. At the species level, *Nepeta septemcrenata* plants recorded the maximum value (7.61 mg/ g dry wt) at elevation from 2200-2400 m and minimum value (2.34 mg/g dry wt) at elevation from 1600-1800 m. There are also highly significant differences among plants belonging to different elevation ranks (F = 322.863, P = 0.000). *Ballota undulata* plants exhibited the maximum value (5.64 mg/g dry wt) at elevation from 2200-2400 m and minimum value (2.54 mg/g dry wt) at elevation from 1600-1800 m. There were highly significant differences among plants from different elevation ranks (F = 56.392, P = 0.000). *Seriphidium herba-album* plants showed the maximum value (11.68 mg/ g dry wt) at elevation from 1800-2000 m and minimum value (2.52 mg/ g dry wt) at elevation from 2400-2600 m. There were highly significant difference among plants from different elevation ranks (F = 1011.069, P = 0.000). *Tanacetum sinaicum* plants showed the maximum value (6.57 mg/g dry wt) at elevation from 1800-2000 m and minimum value (4.43 mg/g dry wt) at elevation from 2400-2600 m. There were highly significant differences among plants

Table 6: Results of one way analysis of variance (ANOVA) of free proline content of plant species belonging to five different altitudes (ALT) of Saint Katherine Mountain

ALT (m)	*Nepeta septemcrenata*	*Ballota undulata*	*Seriphidium herba-album*	*Tanacetum sinaicum*	*Teucrium polium*
1600-1800	1.47 ± 0.06 a	1.49 ± 0.07 a	7.30 ± 0.12 a	2.33 ± 0.12 a	2.65 ± 0.06 a
1800-2000	1.78 ± 0.012 a	3.44 ± 0.03 b	6.49 ± 0.12 a	3.58 ± 0.17 b	3.41 ± 0.24 b
2000-2200	5.75 ± 0.12 b	1.56 ± 0.20 a	9.71 ± 0.09 b	6.40 ± 0.12 dc	1.77 ± 0.10 c
2200-2400	3.37 ± 0.15 c	2.44 ± 0.09 c	10.68 ± 0.15 c	6.44 ± 0.06 c	2.41 ± 0.15 a
2400-2600	3.32 ± 0.15 c	3.46 ± 0.12 b	5.63 ± 0.17 d	5.54 ± 0.19 d	5.71 ± 0.06 d
F_{ratio}	196.885	68.313	263.565	175.055	119.105
P_{value}	***	***	***	***	***

The plant samples were collected at altitudes ranging from 1,600 m a.s.l. to 2,600 m a.s.l. during summer season (May 2011). The mean values listed are expressed as mg/g dry weight of shoot. Each value is a mean of 3 replicates ± standard errors. Means in a Column with similar letters are not significantly different according to LSD. ***= significant at P<0.001

Table 7: Results of one way analysis of variance (ANOVA) of total phenols content of plant species belonging to five different altitudes (ALT) of Saint Katherine Mountain

ALT (m)	*Nepeta septemcrenata*	*Ballota undulata*	*Seriphidium herba-album*	*Tanacetum sinaicum*	*Teucrium polium*
1600-1800	2.34 ± 0.12 a	2.54 ± 0.12 a	10.39 ± 0.09 a	5.60 ± 0.23 ab	4.24 ± 0.10 a
1800-2000	2.73 ± 0.07 a	2.74 ± 0.15 b	11.68 ± 0.06 b	6.57 ± 0.20 a	4.60 ± 0.07 ca
2000-2200	2.65 ± 0.09 a	3.66 ± 0.18 a	3.73 ± 0.16 c	5.36 ± 0.12 db	3.59 ± 0.09 b
2200-2400	7.61 ± 0.18 b	5.64 ± 0.20 c	10.69 ± 0.12 a	5.52 ± 0.09 a	4.66 ± 0.09 c
2400-2600	2.56 ± 0.15 a	4.66 ± 0.20 b	2.52 ± 0.23 d	4.43 ± 0.15 dc	4.41 ± 0.20 ca
F_{ratio}	322.863	56.392	1011.069	20.924	13.017
P_{value}	***	***	***	***	**

The plant samples were collected at altitudes ranging from 1,600 m a.s.l. to 2,600 m a.s.l. during summer season (May 2011). The mean values listed are expressed as mg/ g dry weight of shoot. Each value is a mean of 3 replicates ± standard errors. Means in a Column with similar letters are not significantly different according to LSD. ** = significant at P < 0.01, *** = significant at P < 0.001.

from different elevation ranks (F = 20.924, P = 0.000). *Teucrium polium* had the maximum value (4.66 mg/g dry wt) at elevation from 2200-2400 m and minimum value (3.59 mg/ g dry wt) at elevation from 2000-2200 m. There were moderately significant differences among plants from different elevation ranks (F = 13.017, P < 0.01).

DISCUSSION

Elevation strongly influences landscape topography, geology, rainfall amount and consequently soil moisture and texture, ground-water depth, hydrology, evaporation, soil type and vegetation itself [28]. From the outcome of the obtained results, it is worth to mention that most, if not approximately all the investigated metabolic constituents were greatly affected in response to the difference in elevation ranks and habitats. A great diversity was recorded as regards the metabolic constituents of the plants among the different elevation ranks with the five species under investigation. Similar results were observed by several other investigators. In this regard, plants growing in semi-arid environments have various physiological and morphological characteristics to acclimate to stressful environments, such as drought and strong light conditions [29, 30]. When plants experience environmental stresses, such as drought, salinity and temperature, they activate various metabolic and defense systems to survive [31]. The different species under study showed different values of total soluble carbohydrate, water soluble proteins, proline and total phenol contents under the same environmental condition. Meanwhile the same species exhibited different values of these metabolites under different elevation ranks. In general, total soluble carbohydrate, water soluble proteins, proline and total phenols were increased with the increase of elevation until 2200 to 2300 m a.s.l. and then were slightly decreased. It could be noted that the curve showing changes in total soluble carbohydrate, water soluble proteins, proline and total phenol showed similar trends in the different species. The highest proline and total phenols contents were attained in *Seriphidium herba-album* and *Tanacetum sinaicum* because these two species showed weak vegetative growth.

As elevation increases, the climate becomes cooler, due to the lower air pressure. The characteristic flora in the mountains tends to strongly depend on elevation, because of the change in climate. Elevation strongly influences the biochemical processes in plants. To the best of our knowledge, there is no study available, so far, that have investigated the effect of altitudinal gradients on total soluble carbohydrate, water soluble proteins, proline and total phenols on desert plants in mountain ecosystem in Egypt. Actually, the increase in elevation is associated with water stress [32]. Water stress induces certain biochemical processes, which may be considered of ecological importance under water deficit conditions. Water stress in plants was induced by either water deficiency or by excessive water supply that greatly modifies the metabolism of carbohydrates [19]. Water stress affects nitrogen fractions and protein metabolism in numerable ways. Thus, when a plant is subjected to any biotic or abiotic stress factor, the first observed response is a decrease in its normal metabolic activities, with a consequent reduction of growth. In this 'alarm phase', protein synthesis is one of the most negatively affected anabolic processes [20] together with photosynthesis, transport of metabolites and uptake and translocation of ions [3, 33, 34].

The accumulation of leaf soluble proteins may represent a reserve of nitrogen to be used during recovery once stress has ceased [25, 36]. Under an eco-physiological point of view, most of the stress proteins have a role either in (1) helping the plants survive, or (2) minimizing the effectiveness of the stress agent [37]. Among the characteristic responses to water stress is the accumulation of proline. Greater amounts of proline in wilted leaves, compared to non-wilted leaves, have been reported in leaves of Bermuda grass [6], *Citrus* [38], Wheat [39], Ladino clover [40] and other plants [8]. This suggests that the phenomenon is a general one. Water stress can stimulate the accumulation of phenolic compounds [21]. These responses have been correlated with an increase of tolerance against stress [41] as an adaptive role of phenolics. Batanouny and Ebeid [42] reported that proline was accumulated under water stress conditions in desert plants. Singh *et al.* [11, 43] reported that proline accumulation in water stressed plants is readily reversed if the stress situation is eliminated by rewatering the plants. Stewart [9] also stated that the accumulation of non-protein proline caused by wilting is stopped when leaves are rehydrated. Among the several protection mechanisms against low temperatures adaptability at high altitudes, increased sugar content acting as osmoregulant has been reported by Korner [32]. Sucrose and other sugars play a central role as signaling molecules that modulate the physiology, metabolism and development of plants [44, 45, 46]. A combination of both stress associated proteins and sucrose are reported to confer stress protection [47].

Thus, it might be concluded that proline and phenols have more intimate association with survival adaptability of plants at high altitudes. This might be interpreted on the bases of subjection of higher altitudes to more stressful conditions. At lower altitudes, on the other hand, carbohydrate and protein content are rather controlling factors to plant growth rates. Their availabilities are generally consistent with water stress, as determined by species plasticity.

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