IMPROVEMENT OF WATER USE EFFICIENCY THROUGH POTASSIUM APPLICATION IN *LEPIDIUM SATIVUM* LINN. A MEDICINAL PLANT WITH SPECIAL REFERENCE TO RATE OF PHOTOSYNTHESIS AND STOMATAL CONDUCTANCE

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Abstract

World-wide there is a massive challenge to produce almost 50% more food up to 2030, and double the productivity by 2050. This will probably have to be achieved with less water, mainly because of demands from growing urbanisation, industrialization and climate change. Drought has been the key environmental limitation to plant endurance and to crop production. Potassium is a vital macronutrient that plays a vital function in the regulation of plant growth and development. It alleviates the severe effects of a number of biotic and abiotic stress factors including drought. Productivity of plants that are reduced due to environmental stresses can possibly be improved through optimized potassium application. *Lepidium sativum* Linn., belonging to family Brassicaceae, is an important minor oil seed crop as well as a medicinal plant of repute in Indian traditional systems of medicine.

The nutrient management requires optimization of all the macronutrients including N, K and P along with other natural abiotic stresses such as drought and heavy metal stresses. The agronomic performance of *L. sativum* has not been documented earlier. Water stress adversely affected rate of Photosynthesis and stomatal conductance. It was observed that maximum rate of Photosynthesis and stomatal conductance was observed with the K– 80 dose (K 80 kg/ha). The K–80 dose was able to ameliorate the negative effect of water stress to the maximum and was closely followed by K-120 (K 120 kg/ha) dose in this ameliorative effect. Potassium fertilized plants showed better rate of Photosynthesis and stomatal conductance, in comparison to the plants under drought.

Thus, it is inferred from the study that K nutrition helps in mitigating drought stress and it is suggested that *Lepidium* can be successfully grown in areas having low water supply with addition of potassium.

Introduction

The biggest consumer of water is agriculture, which accounts for about 70% of all freshwater withdrawals worldwide. Moreover, with emerging global shortage of water, reducing the water consumption in crop production has become an essential strategy for sustainable agriculture. Agriculture need to use water more efficiently and sustainably. This requires a deeper understanding about the physiological mechanisms of crop plants response to soil water deficits (Turner, 1997). In order to cope with this problem, it is necessary to develop novel irrigation management systems and cultivate such plants that can withstand water stress. In addition, reduced levels of irrigation will decrease levels of water contamination and energy consumption, thus producing a significant positive impact on our environmental conservation efforts. Yield improvement under drought conditions may be brought about by formulating management strategies, like application of K fertilizers, which maximize the amount of water available to the crop (Turner and Begg, 1981; Loomis, 1983; Mahadhar et al., 1996).

The significance of balanced fertilizer utilization is extensively but, its real application over much of the agricultural regions in India continues to be ignored. The value of potassium in plant growth and development has been known for over 150 years and is well documented (Marschner, 1995). It is essential for the growth and development of all plants and animals. It is absorbed by plant roots as cation (K^+), a form in which it freely moves within the growing plant. But there is insufficiency in data regarding its role in improvement of quality and quantity attributes of a medicinal plant needs further examination. *Lepidium sativum* Linn., belonging to family Brassicaceae, is an important minor oil seed crop as well as a medicinal plant of repute in Indian traditional systems of medicine. Several studies have shown a marked influence of K application on the yields of cereals, pulses, oilseeds, vegetables, forages and other crops. Productivity of plants that are reduced due to environmental stresses can perhaps be enhanced through optimized potassium application. With this aim a selected genotype of *Lepidium,* was studied to identify the role of potassium in drought mitigation, so as to have an improved rate of photosynthesis and Stomatal conductance. As these in turn are the basic factors that affect the overall plant productivity.

Methodology

Healthy and authentic seeds of garden cress (*Lepidium sativum* Linn.) (Genotype IC-313636) used in the present study were obtained from National Bureau of Plant Genetic Resources (NBPGR) of the Indian Agricultural Research Institute (IARI), New Delhi.

This experiment was carried out to study the role of potassium (K) in mitigating the effect of water stress. Earthen pots of 12´´ lined with polythene bags were filled with well-aerated and equal amount of homogeneously ploughed soil and kept in the herbal garden at Jamia Hamdard for study. Soil was homogeneously mixed with variable doses of K while the doses of N and P were kept constant and water stress was maintained in pots with variable amount i.e. water 100%, 75%, 50% and 25%.The pots were covered completely with polyethylene bags whenever rain was imminent to maintain water levels for drought creation. The physiological parameters (Photosynthetic rate and Stomatal conductance) were measured in the intact leaves from various treatments. The sampling was done at pre-flowering, flowering and post-flowering stages. The summary of the treatments is given the following Table no. 1.

Potassium (K, kg ha^{-1})	**Water (W)**	**Remarks**
0	100%	K_0 W_{100} (irrigation100%)
0	75%	K_0 W_{75} (Irrigation 75%)
0	50%	K_0 W_{50} (Irrigation 50%)
0	25%	K_0 W_{25} (Irrigation 25%)
40	100%	K_{40} W_{100} (irrigation100%)
40	75%	K_{40} W_{75} (Irrigation 75%)
40	50%	K_{40} W_{50} (Irrigation 50%)
40	25%	K_{40} W_{25} (Irrigation 25%)
80	100%	K_{80} W_{100} (irrigation100%)
80	75%	K_{80} W_{75} (Irrigation 75%)
80	50%	K_{80} W_{50} (Irrigation 50%)
80	25%	K_{80} W_{25} (Irrigation 25%)
120	100%	K_{120} W_{100} (irrigation100%)
120	75%	K_{120} W_{75} (Irrigation 75%)
120	50%	K_{120} W_{50} (Irrigation 50%)
120	25%	K_{120} W_{25} (Irrigation 25%)

'W' represents irrigation level

The photosynthetic rate in leaves was recorded throughout the growth period by a portable Infra Red Gas Analyzer (IRGA, LI-COR 6200, Lincoln, USA) on the basis of the net exchange of CO_2 between leaf and atmosphere by enclosing the leaf in the leaf chamber, and monitoring the rate at which the CO_2 concentration changed over a short time interval (10-20s). The net photosynthesis was then calculated using this rate of exchange and other factors such as the amount of leaf area enclosed the volume of the enclosure and the temperature. It was expressed as µmol CO_2 m^{-2} s^{-1}. At every sampling the Stomatal conductance of leaves was measured with the help of a portable Infra Red Gas Analyzer (IRGA, LI-COR 6200, Lincoln, USA) and expressed as mmol m^{-2} s^{-1}.

Statistical Analysis

Each parameter was subjected to analysis of variance [ANOVA]. Least significant difference was used to test the significance of difference between treatments, following Gomez and Gomez (1984). Correlation coefficients for different parameters were worked out using MS Excel.

Results

Differences in rate of photosynthesis, as affected by different levels of potassium and water stress, were found to be significant at all the stages of growth studied viz. pre-flowering, flowering and post-flowering

On an average, it was found that potassium application increased the rate of photosynthesis under water stress conditions. The increasing level of water stress causes drop off in the rate of photosynthesis, which was moderately mitigated by the potassium application. The increasing level of water stress reduced the rate of photosynthesis by 7.95%, 11.19% and 10.70% under K_0 application but with K_{80} dose there was an improvement of about 13.48%, 5.30% and 16.27% at the three stages of growth respectively. The effect of K_{120} was also at par with that of K_{80} (Table 2).

The effect of potassium and its interaction with water stress was found non-significant at all the stages of growth. On an average, it was found that potassium application at the K_{80} x W_{100} level increased the stomatal conductance by 23.47%, 26.57% and 10.64% at pre-flowering, flowering and post-flowering stages of growth in comparison to control i.e. K_0 x W_{100}. Under the increasing levels of stress with low rate of applied potassium the stomatal resistance decreased but, under the higher rates of K80 it again enhanced. The K_{120} dose was found to be at par with K_{80} (Table 41). The lowest stomatal conductance was recorded at K_0 x W_{25} at the post-flowering stage (Table 3).

Table 2: Rate of photosynthesis (µmol CO_2 $m^{-1}s^{-1}$) in *Lepidium sativum* Linn. as affected by interaction of potassium with water stress at pre-flowering, flowering and post-flowering stages.

Treatments		Phenological stages		
		Pre-flowering	Flowering	Post-flowering
K_0	W_{100}	20.92 ± 0.040	22.94 ± 0.031	18.22 ± 0.031
	W_{75}	20.32 ± 0.031 (-2.84%)	22.58 ± 0.040 (-1.54%)	17.93 ± 0.047 (-1.59%)
	W_{50}	19.72 ± 0.035 (-5.71%)	21.60 ± 0.036 (-5.83%)	17.50 ± 0.050 (-3.95%)
	W_{25}	19.25 ± 0.031 (-7.95%)	20.37 ± 0.040 (-11.19%)	16.27 ± 0.045 (-10.70%)
K_{40}	W_{100}	22.09 ± 0.035 (+5.63%)	24.37 ± 0.042 (+6.26%)	19.61 ± 0.047 (+7.67%)
	W_{75}	21.59 ± 0.035 (+3.24%)	24.07 ± 0.053 (+4.94%)	19.12 ± 0.040 (+4.94%)
	W_{50}	21.88 ± 0.031 (+4.62%)	22.90 ± 0.074 (-0.17%)	18.20 ± 0.031 (-0.07%)
	W_{25}	20.17 ± 0.040 (-3.57%)	22.69 ± 0.035 (-1.09%)	17.92 ± 0.051 (-1.61%)
K_{80}	W_{100}	25.89 ± 0.030 (+23.78%)	26.34 ± 0.046 (+14.84%)	22.41 ± 0.065 (+23.04%)
	W_{75}	24.99 ± 0.070 (+19.47%)	25.94 ± 0.050 (+13.09%)	22.07 ± 0.060 (+21.13%)
	W_{50}	24.30 ± 0.031 (+16.16%)	24.75 ± 0.031 (+7.92%)	21.83 ± 0.055 (+19.85%)
	W_{25}	23.74 ± 0.045 (+13.48%)	24.15 ± 0.040 (+5.30%)	21.18 ± 0.056 (+16.27%)
K_{120}	W_{100}	25.38 ± 0.035 (+21.35%)	25.09 ± 0.025 (+9.40%)	22.08 ± 0.056 (+21.21%)
	W_{75}	24.07 ± 0.057 (+15.09%)	24.84 ± 0.035 (+8.31%)	21.69 ± 0.045 (+19.09%)
	W_{50}	23.83 ± 0.047 (+13.91%)	23.61 ± 0.045 (+2.95%)	21.18 ± 0.047 (+16.25%)
	W_{25}	23.16 ± 0.036 (+10.73%)	23.10 ± 0.040 (+0.70%)	20.84 ± 0.045 (+14.38%)

The values are the mean of 3 replications ± standard deviation (S.D.). Parentheses include percent variation over control. K = Potassium (0, 40, 80 and 120 kg ha^{-1}); W = Water (100, 75, 50 and 25%).

CD at 5%

	Pre - flowering	Flowering	Post - flowering
K	0.033	0.036	0.041
W	0.033	0.036	0.041
K X W	0.065	0.073	0.082

Table 3: Stomatal conductance (mmol m^{-2} s^{-1}) in *Lepidium sativum* Linn. as affected by interaction of potassium with water stress at pre-flowering, flowering and post-flowering stages.

Treatments		Phenological stages		
		Pre-flowering	Flowering	Post-flowering
K_0	W_{100}	0.65 ± 0.015	0.69 ± 0.020	0.63 ± 0.015
	W_{75}	0.61 ± 0.015 (-7.14%)	0.65 ± 0.015 (-6.28%)	0.61 ± 0.020 (-2.66%)
	W_{50}	0.57 ± 0.021 (-12.24%)	0.62 ± 0.015 (-9.66%)	0.55 ± 0.015 (-11.70%)
	W_{25}	0.54 ± 0.025 (-16.84%)	0.59 ± 0.015 (-14.98%)	0.52 ± 0.015 (-17.55%)
K_{40}	W_{100}	0.73 ± 0.015 (+11.22%)	0.74 ± 0.025 (+7.73%)	0.58 ± 0.015 (-7.98%)
	W_{75}	0.70 ± 0.021 (-6.63%)	0.67 ± 0.010 (-2.90%)	0.53 ± 0.015 (-14.89%)
	W_{50}	0.64 ± 0.015 (+1.53%)	0.63 ± 0.025 (-8.21%)	0.49 ± 0.015 (-21.28%)
	W_{25}	0.63 ± 0.015 (-4.08%)	0.62 ± 0.020 (-10.14%)	0.47 ± 0.015 (-25.53%)
K_{80}	W_{100}	0.81 ± 0.015 (+23.47%)	0.87 ± 0.021 (+26.57%)	0.69 ± 0.015 (+10.64%)
	W_{75}	0.76 ± 0.015 (+15.82%)	0.81 ± 0.015 (+16.91%)	0.65 ± 0.015 (+3.19%)
	W_{50}	0.70 ± 0.015 (+7.65%)	0.74 ± 0.025 (+7.73%)	0.62 ± 0.015 (-1.60%)
	W_{25}	0.68 ± 0.015 (+4.59%)	0.72 ± 0.010 (+4.35%)	0.59 ± 0.020 (-5.85%)
K_{120}	W_{100}	0.78 ± 0.015 (+18.88%)	0.84 ± 0.025 (+22.22%)	0.66 ± 0.020 (+5.32%)
	W_{75}	0.74 ± 0.015 (+12.76%)	0.77 ± 0.015 (+12.08%)	0.63 ± 0.015 (0.00%)
	W_{50}	0.69 ± 0.021 (+5.10%)	0.73 ± 0.010 (+5.80%)	0.59 ± 0.015 (-5.32%)
	W_{25}	0.66 ± 0.010 (+1.02%)	0.70 ± 0.015 (+0.97%)	0.56 ± 0.010 (-10.64%)

The values are the mean of 3 replications ± standard deviation (S.D.). Parentheses include percent variation over control. K = Potassium (0, 40, 80 and 120 kg ha^{-1}); W = Water (100, 75, 50 and 25%).

CD at 5%

	Pre - flowering	Flowering	Post - flowering
K	0.015	0.014	0.013
W	0.015	0.014	0.013
K X W	NS	NS	NS

Discussion

Under drought stress, water deficit develops in plant tissues, thus leading to a significant inhibition of photosynthesis. The ability to maintain the photosynthetic machinery functionally under water stress, therefore, is of major importance for drought tolerance. Plants react to water deficit with a rapid closure of stomata to avoid further water loss via transpiration (Cornic, 2000). As a consequence, CO_2 diffusion into the leaf is restricted (Chaves, 1991). The decrease in net photosynthetic rate under drought stress observed in many studies is often explained by lowered internal CO_2 concentration, which results in a limitation of photosynthesis at the acceptor site of ribulose-1, 5-bisphosphate carboxylase/oxygenase (Rubisco) (Cornic et al., 1992) or by the direct inhibition of photosynthetic enzymes like Rubisco (Haupt-Herting and Fock, 2000) or ATP synthase (Nogués and Baker, 2000). However, many other studies show that the decreased photosynthetic rate under water stress can be attributed to the perturbations of the biochemical processes (Lauer and Boyer, 1992). There are several reports, which mark the photosynthetic stomatal limitations as a primary event, followed by respective changes of the photosynthetic reaction (Chaves, 1991). Today, there is a consensus that a decrease of the photosynthesis rate under water stress can be attributed to both stomatal and non-stomatal limitations (Shangguan et al., 1999).

In the study undertaken, supplementation of K ameliorated the photosynthetic rate in plants grown under drought stress. The significant, increase in photosynthetic rate with K supplementation might be due to K-utilization. That K application resulted in significantly improved rates of photosynthesis under water stress support the findings of Manivel et al. (1995) who reported a sustained high rate of photosynthesis in tea plants treated with potassium. The results were similar in different target crops under study. They also confirm to those of Sharma et al. (1993) who reported increased photosynthetic rate by K levels under water stress conditions. Lower sensitivity to drought stress in terms of biomass production and yield might be a result of higher potassium concentration in stroma and a corresponding higher rate of photosynthesis (Marschner, 1995).

The most probable response to various stresses affecting water status of plants is stomatal closure to minimize water loss. The loss of water from crop plants is controlled mainly by the stomata on leaves, sensitive to various environmental factors like drought stresses (Yordanov et al., 2003). Stomatal closure to minimize water loss is a common response of plants exposed to various stresses affecting plant water status. It has been identified as an early event in plant response to drought and cadmium-induced water deficiency leading to limitations to carbon uptake by leaves (Chaves, 1991; Cornic and Massacci, 1996). Stomata operate to enhance the rate of photosynthesis on one hand, and avoiding dehydration damage on the other (Arshi et al., 2002; Qureshi, 2005). The process of stomatal opening and closing is necessary for uptake of CO_2. Stomatal conductance shows strong relationship between opening of stomata, environmental parameters and the process of photosynthesis which is re-altered by a variety of stress factors; whereas stomatal conductance is also a function of the leaf-age and its morphological adaptation to its micro-environment during the period of growth (Baldocchi, 1991). The process of opening and closing of guard cells is mainly determined by the turgor pressure (TP) of guard cells and the pressure difference between the guard cells and the adjacent epidermal cells. The uptake of water increases the turgor pressure in guard cells when the osmotic pressure (OP) increases.

Accumulations of various ions viz. K^+, Cl^- in the guard cells are thought to cause the above processes. Besides, the production of abscisic acid (ABA) under drought conditions and conditions leading to senescence, control the movement of the stomata (Loske and Raschke, 1988). Alteration of mineral nutrition (N, K, P, Ca etc.), caused by stress effects may also contribute to the reductions in stomatal conductance which, in turn, lead to suppression of major physiological processes and metabolic activities.

Conclusion

Under drought stress the lower rate of photosynthesis and stomatal conductance were successfully alleviated with K supplementation. Application of K altered rate of photosynthesis and stomatal conductance in the leaves of *Lepidium sativum*. The dose of 80 Kg K ha^{-1} given was most effective, and can be proposed for better production of *L. sativum* in field conditions facing drought or having less availability of water. Moreover, as inferred from the study K nutrition helps in mitigating drought stress thus it is suggested that *Lepidium* can be successfully grown in areas having low water supply with addition of K.

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