IJBPAS, September, 2015, 4(9): 5915-5932

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

EFFECT OF MAGNESIUM ON GROWTH, FRUIT QUALITY AND SUGAR CONTENT IN CUCUMBER UNDER VARIOUS LIGHT INTENSITIES

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ABSTRACT

The effect of various Mg concentrations (0, 1, 2, 3 and 4 mM) in the nutrient solution on plant growth, fruit quality and sugars content in hydroponicallygrown cucumber (*Cucumis sativus*cv. Nagen 792) under optimum(100%)and low (50%) light intensities was evaluated.The results showed that the decreases in the dry matter, SPAD index and soluble protein and accumulation of soluble sugar and starch content in the leaves Mg deficiency (0 mM Mg)are suggestive of decreased growth, and the decrease induced by Mg deficiency was bigger under low light intensity than under optimum light intensity. Plant growth was improved at 3 mM Mg, but it was reduced when the Mg concentration increased (4 mM Mg). Concentration of Mg in the leaf and fruit increased drastically with increasing Mg in the nutrient solution. This became steadily more pronounced under low light intensity. Mg deficiency plants (0 mM Mg) developed visible symptoms- interveinal necrosis in middle leaves, especially optimum light intensity.Fruit quality traits such as fruit dry matter percentage and total soluble solid (TSS) and fruit Fv/Fm were increased at higher concentration of Mg (3 mM) in the solution, especially under optimum light intensity. But, fruit firmness was improved at lower concentration of Mg (1 mM) in the solution especially in optimum light intensity In conclusion, Mg requirement of cucumber plants likely increases with light intensity. Thus, higher concentration of Mg (3 mM) in the

nutrient solution was the most favorable for cucumber plant growth and fruit quality grown in hydroponics.

Keywords: Mg, Growth, Quality, Cucumber, Light intensity

INTRODUCTION

Mg is an essential element for plant growth and development and fruit quality. Apart from being a central atom of the chlorophyll molecule, Mg also acts as activator or regulator of many key enzymes in plant physiological processes [38, 50].Both Mg deficiency and oversupply have detrimental effects on plant photosynthesis [49], consequently resulting in abnormal or restricted growth of plants [50]). Mgplays a fundamental roles in phloem export of photosynthates so that a deficiency of Mg restricts the partitioning of dry matter between roots and shoots to result in excessive sugar, starch and amino acid accumulation in leaves (source tissues), chlorophyll breakdown, an over- reduction in the photosynthetic electron transport chain and the generation of highly reactive oxygen species (ROS) because of impairment in photosynthetic CO_2 fixation [9,25].

Mg had a greater effect on quality parameters, when Mg was supplies to low-Mg plants. However, there were no additional benefits when Mg was supplied to plants already grown under adequate Mg supply conditions [8]. Increasing Mg supply on Mg-deficiency plants caused to increase fruittotal soluble solid (TSS), dry matter and juice acidity, [21]. Excessive supply of Mg to fruit has negative effects on fruit firmness, texture and storability that are mainly determined by its antagonistic relationship with Ca[36].Despite the well-known fundamental roles of Mg in plant metabolism, there is very limited information on interactions between Mg and light intensity on fruit quality of cucumber.

The responses of plants to different Mg concentrations are not only affected by Mg availability in the root zone, but also depend on light intensity, temperature and species[10, 27]. The roles of Mg in plant metabolism particularly under stress conditions are well known [9]. The authors indicated that the Mg requirement is increased under high-light conditions. The higher requirement of Mg under high light might be reduced to the fact that under suboptimal Mg supply and high light processes are induced which finally lead to accumulation of reactive oxygen species (ROS) and thus plant damage. As plants are subjected to various light intensities at different seasons, this may alter the ability of plants to take up and translocate Mg. It seems that the adjustment of Mg concentration in the nutrient solution according to the light intensity should be crucial. The objective of this experiment was to determine the effects of Mg and light intensity on cucumber growth and qualitytraits in hydroponics.

MATERIALS AND METHODS

Plant materials and growth conditions

The experiment was carried out at the Department of Horticultural Science, University of Tabriz, Iran. Cucumber (*Cucumis sativus* L. cv. Nagen 792) seeds were sown in cells plug trays filled with vermiculite, after emergence of two true leaves, seedlings were transplanted to a 14l growth bags (70, 20,10 cm) filled with a mixture of perlite and vermiculite (1:1 v/v). The nutrient solution was prepared based on full strength of Hoagland's solution [26]containing: 5.6 mM Ca $(NO_3)_2$, 4 mM KNO_3, 1 mM KH_2PO_4. The solution pH was maintained close to 6.5 by adding H_2SO_4. The electrical conductivity (EC) of the nutrient solution was within the range 2.2 - 2.4 dS m^{-1}.in order to keep the anionic-cationic balance and a similar electrical conductivity for the five solutions, mineral concentrations were adjusted leading to only slight variations. The greenhouse was under natural photoperiod condition during spring and summer and air temperature was set to 27 ± 2 ˚C and 18 ± 2 ˚C in the day and at night, respectively. The experiment was a split-plot design with light intensity as the main plot and various Mg concentrations as subplot with three replications in each treatment. Each plot contained three plants. The plants were treated with five Mg concentrations (0, 1, 2, 3 and 4 mM) as $MgSO_4.7H_2O$. Treatments were labelled Mg 0, Mg 1, Mg 2, Mg 3 and Mg 4. The plants were subjected to two light intensity treatments [optimum (100%) low (50%) light intensities] using green shade netting suspended above the box frame with the size of 1.5 m × 8 m × 4 m. the box frames were randomly placed in the greenhouse. Everyday light intensity at the canopy height under the shaded netting and in the glasshouse was monitored using a light-meter (Skye Instrument. Powys. UK). The average of light intensity under shaded netting and in the glasshouse (unshaded) over entire period of experimentation is shown in Fig.1.

Data collection and chemical analysis

At the end of the experiment, two plants from each treatment harvested and the internode diameter were recorded. The plant organs divided into leaf and stem, weighed and then all plant parts dried at 80 ˚C in an air-forced oven for 48 h for determination of leaf and stem dry matter. The percentage leaf and stem dry weight was then calculated as below: [(Dry weight/ Fresh weight) ×100]. Chlorophyll index value of fully expanded young leaves was determined using a portable SPAD-502 meter (Minolta, Tokyo, Japan) during the period of the plant's growth. Fruit quality was measured in a representative sample collected at the same position from plants in each treatment. The samples were taken from fruits with the same size. Each fruit was cut in to pieces and homogenized in a conventional blender in order to obtain the fruit juice. Thereafter, the fruit juice was filtered using a Whitman No. 4 filter paper and the filtrate was used to determine the pH, EC and TSS. The TSS content of the fruit was determined by using a digital refractometer (Atago Co., Tokyo, Japan). The juice pH and EC was measured by pH meter and EC meter, respectively. The measurement fruit firmness was determined using a penetrometer (Model: ST 977. Italy). A thin layer of the middle of fruit skin (0.5 mm) was removed by a sharp razor and fruit color or the extent of greening was measured using a chlorophyll-meter (SPAD-502, Konica, Minolta, Osaka, Japan). Titratable acidity was measured by titrating with 0.1 M NaOH to the neutralization point. Before chlorophyll fluorescence measurements, fruits were dark-adapted for 30 min using a dark towel. Measurements were taken in the middle and near the neck position positions of each fruit at the same location in the fruit surface and then averaged. The maximal quantum yield of PS II photochemistry (Fv/Fm) was measured using a plant efficiency analyzer, Handy PEA (Hansatech Instruments). Ten fruits per treatment per replicate were used for the determination of fruit dry weight. Each individual fruit from each treatment was placed in a sampling bag and dried in the oven at a temperature of 80°C for 48 h until a constant weight was obtained. The percentage dry weight was calculated as below: [(Dry weight/ Fresh weight) ×100].

Soluble sugars were extracted using the method described by Sheligl(1986). About 0.5 g of dried leaf samples were extracted three times in 5ml of hot 80 % ethanol (80 ˚C)[51]. The supernatants from each extraction were combined and made to a convenient volume. 1 ml 5 % (w/v) phenol and 5ml concentrated H_2SO_4 were added to 2 ml the plant extract and mixed thoroughly. The reaction mixture was allowed to stand for 30 min before the absorbance was recorded at 485 using a spectrophotometer (Motic, CL-45240-00, Hong Kong, china). Total sugar content of the sample was calculated based on calibration curve from a glucose working standard.Starch content was extracted from the residual plant material from the soluble sugar extraction described above. This was done by incubating the dry pellet with 2 ml HCl (4.68M) in boiling water bath for 15 min. the soluble products were assayed by the same phenol-sulphuric method described above. Soluble protein content was determined in according to Bradford (1976) using bovine serum albumin as standard[5]. To measure the Mg, Leaves and fruits washed with distilled water were oven-dried at 80 ˚C for 48 h and weighed. The dry samples were ground to pass through a 0.5-mm screen. 1 g dry samples of leaves and fruits a were soaked in 10mL nitric acid (HNO_3) for 24 h then digested in digestion systems in a fume hood, heated to 110 ˚C for 3 h. The extracted solution was transferred to 100 mL volumetric flasks, and then diluted to 100mL with deionized water for Mg assays [35]. The Mg concentration in the leaf and fruit were measured at a wavelength 285.2 nm by atomic absorption spectrophotometry (Perkin-Elmer, Model 110, and USA).

Statistical Analysis

A statistical analysis was made using analysis of variance the SPSS 21 software and the means were separated by the Duncan test at a significance level of 0.05. The graphs were drawn using Excel software.

RESULTS AND DISCUSSION

Vegetative growth

The results showed that the highest leaf dry matter percentage was obtained in 3 and 4 mM Mg treatments. The leaf dry matter percent in concentration of 0 mM Mg was slightly higher than concentration of 1 mM Mg. Low light intensity largely decreased leaf dry matter percent compared to optimum light intensity (Table 1). This observation is in agreement with the finding of Lasa et al (2000) who showed that concentration of 0 mM Mg decreased 40 – 50% of shoot biomass compared with Mg sufficient plants in sunflower plants[32]. Low light intensity reduces the export of photosynthates from vegetative organs to the fruits. The reason for increase in leaf dry matter at 0 mM Mg may be due to impaired export of carbohydrates from source to sink sites and accumulation of soluble sugars in source leaves. Stem dry matter was not affected by various Mg concentrations, but optimum light intensity significantly increased stem dry matter than low light intensity (Table 1). In the present experiment, there was a significant difference in leaf SPAD value between low Mg concentrations and sufficient Mg concentrations (Table 1). Significant decrease in chlorophyll concentration in Mg deficiency leaves has been widely reported[23, 55]. A reason for higher chlorophyll content under adequate Mg supply could be an enhanced production of chlorophyll and chlorophyll associated proteins. It is well documented that chlorotic and necrotic symptoms appearance in Mg deficiency leaves is associated with chlorophyll destruction due to photo-oxidation and accumulation of soluble sugar and starch in source leaves [7]. In both light intensities, internode diameter was increased with increasing Mg concentration in the solution. However, internode diameter was higher under optimum light intensity compared to low light intensity (Table 1). Light quantity and quality are major determinants of internode growth. Reductions in both photosynthetically active radiation (PAR), and red: far-red ratio (R: FR) result in similar shade avoidance responses, such as increased internode elongation and thicker internode. In plant communities, the R: FR ratio seems to act as an early competition signal [20, 31].

Soluble and insoluble sugars and soluble protein

The results showed that under both light intensities, concentration of 0 mM Mg in the solution had higher leaf soluble sugar and starch content compared to other treatments. However, leaf soluble sugar and starch content in optimum light intensity was higher than in low light intensity (Table 1). In almost all higher plants, the principle end products of leaf photosynthates are sucrose and starch. However, partitioning of sucrose and starch and their effect on dry matter distribution is influenced by several environmental factors, such as low temperature, drought and essential mineral nutrients [28, 56]. Mineral nutritional status of plants has a considerable impact on partitioning of carbohydrates and dry matter between shoots and roots [15, 34,38]. Under Mg deficiency, starch concentrations are high in source leaves[18] and low in sink organs such as cereal grains and fruits [2]. This may demonstrate impaired photosynthate transport from source leaves to sink organs. Hence, in Mg-deficient plants higher shoot/root ratios were found compared with Mg-sufficient plants[4, 10, 16]. The translocation of amino acids and sugars from sink to source might be inhibited under magnesium deficiency because of the effect of Mg on the H^+-ATPase [9]. The results clearly showed that by increasing Mg concentration in the solution, increased soluble protein content in the cucumber leaves (Table 3). Andrews et al (1999) reported that Mg deficiency induced an increase in the protein content of *Pisun sativum* and *Phaseolus vulgaris*[1]. The reduction of protein in Mg deficiency plants could be attributed to a decrease in protein synthesis due to the participation of Mg in the aggregation of ribosome subunits and its requirement for RNA polymerases [12]. Protein biosynthesis also is strongly reduced under Mg deficiency leading to increased concentrations of the precursor amino acids [19,40].

Leaf and fruit Mg concentration

The results indicated that with increased Mg concentration in the nutrient solution led to a significant increase in Mg content in leaves and fruits under both light intensity. But, Mg concentration in cucumber leaves and fruits under low light intensity was higher than in cucumber leaves under optimum light intensity (Fig. 2). Greater concentration of Mg was observed with increasing Mg levels in the nutrient solution. However, Mg concentration of leaf in shaded plant was higher than in unshaded plants. Visual symptoms of Mg deficiency appeared only in 0 mM Mg concentration and under both light intensities. However the symptoms severity became more pronounced under optimum light intensity. These symptoms observed after 35 days of treatment initiation and in middle leaves as necrotic lesion. Whereas, no visual symptoms of Mg deficiency were found in leaves of any other treatments in the range of 1 to 4 mM Mg concentrations, under both light intensity. The incidence of Mg deficiency was attenuated by the initial amount Mg present within the plant. Because the cucumber seedlings had been grown in one third of full nutrient solution (containing 0.3 mM Mg) for four weeks prior to treatment initiation, the initial accumulated Mg and its internal recycling in the seedling attenuated the visible signs of Mg deficiency. The Mg concentration sufficient for optimal growth varied with species. Kirkby and Mengel, (1979) reported that 0.35- 0.8% in the dry weight to be sufficient for cucumber[29]. However, the results obtained in this study agree well with the general threshold line for the occurrence of Mg deficiency determined by Kirkby and Mengel, (1979)[29]. The Mg- deficiency visible symptoms observed partially only on the full developed middle leaves [6, 7, 19, 43]. In cucumber, deficiency visible symptoms observed initially as interveinal chlorosis and finally, as interveinal necrosis on leaves. The occurrence of Mg- deficiency on the middle leaves could significantly affect the photoassimilate production and supply to other parts of plants. Both shading and Mg levels in the nutrient solution altered Mg concentration in the leaves. This is consistent with findings by Zhao and Oosterhuis (1998) and Sonneveld (1987) who indicated that high light intensity will decrease the ability of plants to absorb and translocate magnesium, since transpiration is reduced and the translocation of magnesium is driven by transpiration rates[57, 54].In general, the breakdown of chlorophyll under magnesium deficiency is associated with the accumulation of sugars and starch in the cells of deficient leaves [24, 9]. This causes an over-reduction of the photosynthetic electron transport chain, which leads to the formation of reactive oxygen species.

Fruit quality traits

Despite the well-known roles of Mg in plant metabolism, very limited information there have been concerning the significance of Mg for the quality of agriculture and horticulture produce, as compared to other major nutrients.A fruit quality trait like fruit firmness was significantly affected by treatments. So that the firmest fruit under optimum light intensity in 1 and 2 mM Mg and in low light intensity at 1 mM Mg were obtained. Underoptimum light intensity conditions,the fruits were firmer than under low light intensity conditions. This is consistent with findingby Marcelle, (1995) who showed that an optimal Mg concentration 'has to be relatively low' for good storage properties[38]. The reduced firmness in plant grown with low Mg content may be due to high concentration of fruit Ca. Fruit Firmness is an extremely important quality attribute of cucumber and consumer prefer a firm and crisp product. The Mg: Ca ratio mainly determines service and stability aspects as components of the total food quality, such as product firmness, texture and storability that are mainly determined by the role of Ca in stabilizing cell walls[21]. Since Mg is capable of replacing Ca from binding sites, imbalance Mg: Ca ratios in the tissue often negatively affect product quality. The fruit TSS increased with increasing Mg concentration up to 3mM Mg and then decreased with increasing Mg (4 mM). The fruit TSS under optimum light intensity was higher than under low light intensity. The increase of fruit juice TSS with increasing Mg concentration in the solution reported by Quaggio et al (1992) who indicated that juice pH, Soluble Solid and titratable acidity of fruit orange increased with increasing Mg[45]. Mg:K ratio appears to influence primarily quality properties through the role of both mobile cations in metabolite formation and translocation to fruits [46]. The highest marketable, high quality yield was observed when K and Mg were supplied in the highest amounts at a ratio of 5:1. This clearly points to the facts that only balanced crop nutrition can result in optimal quality [3].Fruit juice pH and EC were not affected by the treatments (Table 3).Fruit dry matter increased with increasing Mg concentration in the solution. Low light intensity decreased fruit dry matter (Table 2). Dry matter content is an important quality criterion.Marcelis (1993) showed a positive relationship between the dry matter distribution of the fruit and irradiance[37].Increases of dry matter percent can be due to the importance of Mg for photosynthesis and assimilate translocation. This finding was underlined by Feltran et al (2004) and Poberezny and Wszelaczynska (2001) who showed that increasing Mg supply consistently increased dry matter in potato[17, 44].Also, Hao and Papadopoulos(2004)indicated that at a given Ca supply increasing the Mg application enhanced the biomass allocation to the fruit, whereas the allocation to the leaves decreased, pointing to the decisive role of Mg in carbohydrate partitioning[22].The highest value in fruit Fv/Fm was obtained in 2 and 3 mM Mg treatments. Fruit Fv/Fm was higher under low light intensity than that under optimum light intensity (Table 2). Chlorophyll fluorescence is an indirect measurement of the physiological status of green tissues [48, 41], being used in both green leaves and several chlorophyll-containing fruits [52, 53, 13]. Concerning the evaluation of changes in fruit tissues, chlorophyll fluorescence measurement has the advantage of detecting cellular injury due to natural senescence or environmental stresses in advance to the development of visible symptoms [14, 52, 47].Fruit chlorophyll was significantly higher under optimum light intensity than under low light intensity (Table 2). Fruit color is one of the few practical criteria for assessing cucumber quality after harvest at present. A dark green cucumber is expected to have a longer shelf-life than a light green cucumber [33]. This result is agree with observation of Klieber et al (1993) who showed that high light intensity is necessary for high chlorophyll content in cucumber[30]. They also confirmed that high chlorophyll content was positively correlated with a high percentage of PPFD reaching the fruit surface.

CONCLOSION

It can be concluded that Mg requirement of cucumber plants likely increases with light intensity. The moderate concentration of Mg (2 mM) in the solution was the most desired for cucumber fruit quality. While, higher concentration of Mg (3 mM) in the solution was the most favorite for cucumber growth in hydroponics system.

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Table 1: The effect of Mg and light intensity on cucumber vegetative growth

Light intensity	Mg (mM)	Leaf Dwt (%)	Stem Dwt (%)	Internode diagonal (cm)	Leaf SPAD index	Soluble sugar (mg g^{-1} DW)
Optimum Light	0	14.16	7.60	3.85	55.30^{ef}	35.82
	1	13.55	7.85	4.46	58.70^{c}	31.41
	2	14.44	7.80	4.54	59.50^{bc}	25.42
	3	16.63	8.02	4.79	61.30^{ab}	23.73
	4	15.36	7.75	4.11	62.63^{a}	24.39
Low Light	0	11.23	6.29	3.83	53.76^{f}	28.18
	1	11.20	6.66	4.05	54.33^{ef}	24.73
	2	11.74	7.00	4.22	55.06^{ef}	20.35
	3	13.17	6.94	4.00	56.23^{de}	19.48
	4	12.13	6.60	3.83	57.43^{cd}	18.74
Optimum Light		14.83	7.80	4.35	59.48	28.15
Low Light		11.89	6.70	3.98	55.36	22.29
Light intensity		0.001	0.001	0.001	0.001	0.001
Mg		0.01	ns	0.01	0.001	0.001
Light intensity×Mg		ns	ns	ns	0.05	ns

(ns) non significance; (0.05) significance at 0.05 probability level; (0.01) significance at 0.01 probability level; (0.001) significance at 0.001 probability level. Within each column, same letters indicate no significant difference between treatments (P < 0.01

Table 2: The effect of Mg and light intensity on cucumber fruit quality traits

Light intensity	Mg (mM)	Firmness (Kg)	Fruit dry matter (%)	Fruit Fv/Fm value	Fruit color (SPAD UNIT)
Optimum Light	0	3.66[bc]	3.92	0.737	53.83
	1	3.73[ab]	4.83	0.744	56.40
	2	4.20[a]	4.35	0.753	57.20
	3	3.30[bc]	4.90	0.760	56.96
	4	3.26[bc]	4.71	0.741	55.94
Low Light	0	3.10[bc]	4.21	0.749	51.10
	1	3.66[a]	4.31	0.751	53.96
	2	3.63[bc]	4.48	0.763	53.23
	3	3.23[bc]	4.46	0.764	53.03
	4	3.33[bc]	4.67	0.751	50.76
Optimum Light		3.63	4.85	0.747	56.07
Low Light		3.39	4.42	0.756	52.42
Light intensity		0.01	ns	0.01	0.01
Mg		0.001	0.001	0.01	ns
Light intensity×Mg		0.05	ns	ns	ns

(ns) non significance; (0.05) significance at 0.05 probability level; (0.01) significance at 0.01 probability level; (0.001) significance at 0.001 probability level. Within each column, same letters indicate no significant difference between treatments ($P < 0.01$)

Table 3: The effect of Mg and light intensity on cucumber fruit quality traits

Light intensity	Mg (mM)	Fruit juice pH	Fruit juice EC ($dS\ m^{-1}$)	Acidity (%)	Soluble protein ($mg\ g^{-1}$ FW)	Fruit Mg (mgg^{-1} DW)
Optimum Light	0	5.93	0.50	1.993	1.00	0.720
	1	5.86	0.56	2.213	1.22	1.253
	2	5.93	0.56	2.327	1.40	2.133
	3	5.74	0.56	2.417	1.57	2.727
	4	5.83	0.56	2.650	1.61	3.047
Low Light	0	5.72	0.46	1.703	0.83	0.880
	1	5.64	0.56	1.960	0.91	1.480
	2	5.69	0.56	2.027	1.24	2.687
	3	5.55	0.55	2.193	1.45	2.753
	4	5.63	0.56	2.387	1.43	3.213
Optimum Light		5.86	0.55	2.320	1.36	1.97
Low Light		5.65	0.54	2.054	1.17	2.16
Light intensity		0.05	ns	ns	0.01	0.01
Mg		ns	ns	ns	0.001	0.001
Light intensity×Mg		ns	ns	ns	ns	ns

(ns) non significance; (0.05) significance at 0.05 probability level; (0.01) significance at 0.01 probability level; (0.001) significance at 0.001 probability level. Within each column, same letters indicate no significant difference between treatments ($P < 0.01$)

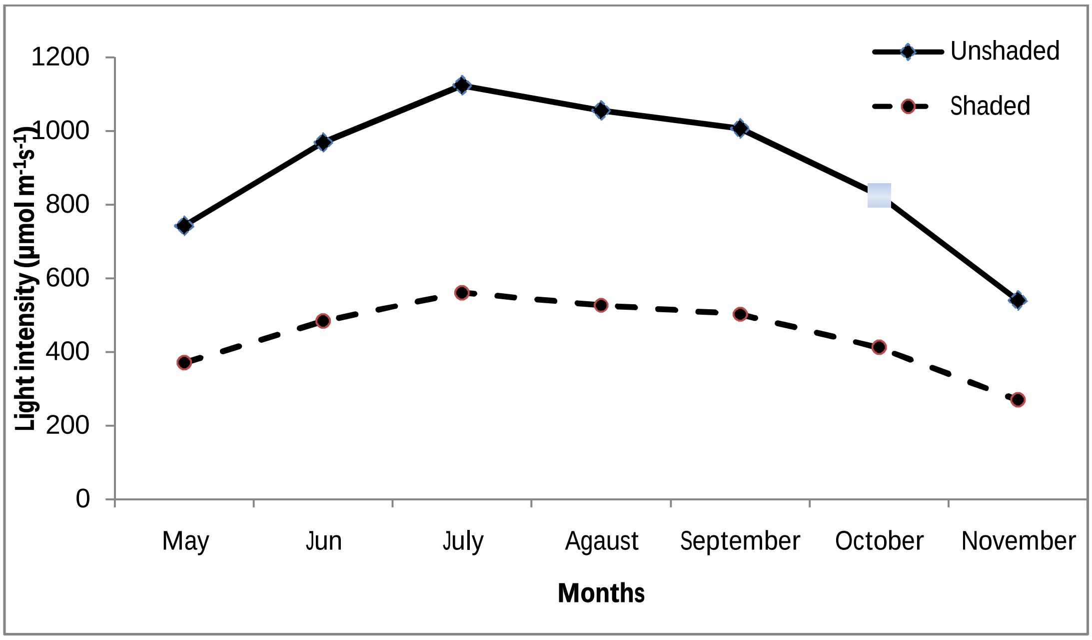

Fig. 1: Light intensity at the optimum (100%) and low (50%) light intensity during the entire of period of experimentation

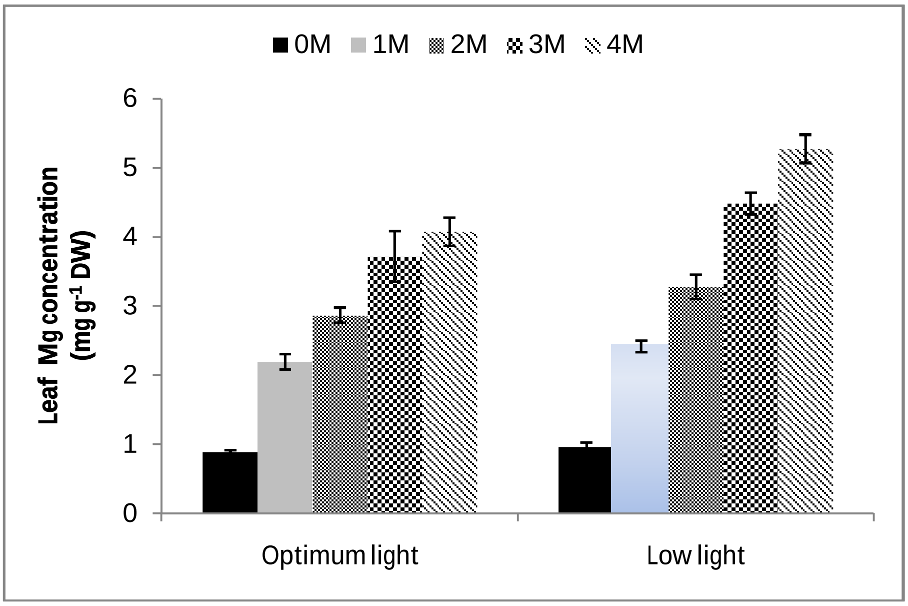

Fig. 2: The effect of Mg and light intensity on the leaf Mg concentration in cucumber plants (error bars on the columns represent standard error)

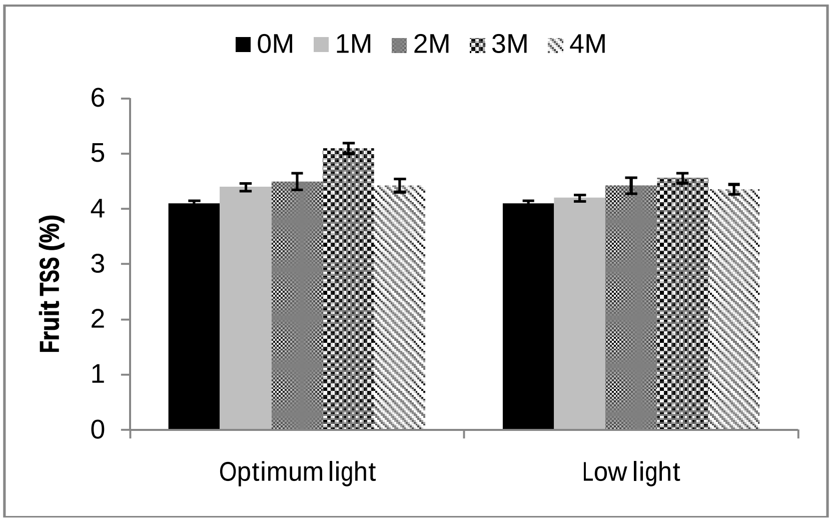

Fig. 3: The effect of Mg and light intensity on fruit TSS in cucumber plants (error bars on the columns represent standard error)

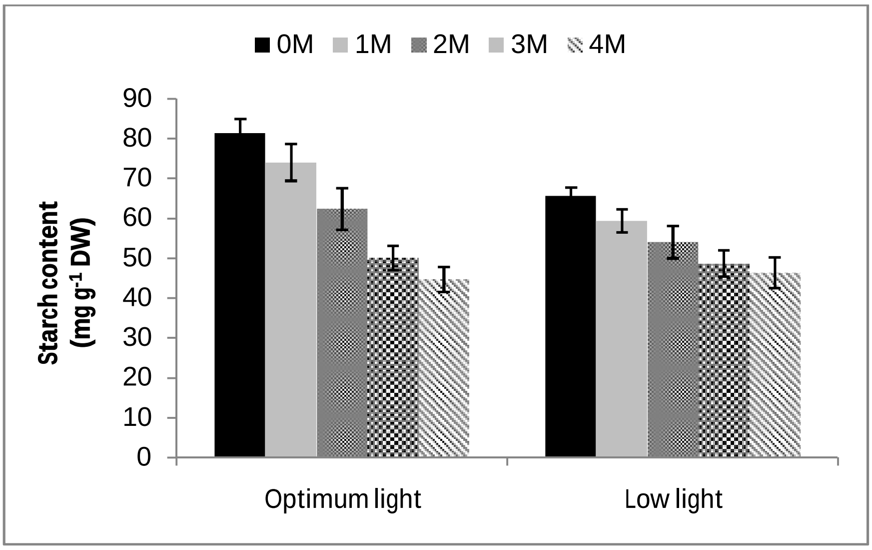

Fig. 4: The effect of Mg and light intensity on starch content in cucumber plants (error bars on the columns represent standard error)

A B

Fig. 5: Visual symptoms of Mg sufficient leaves (A) and Mg deficiency leave (B)