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The role of magnesium salts in germination and growth of *Cucumis sativus* L.

Introduction

Fertilisation is an agro-technical treatment that affects both productivity and quality of crop plant. Its purpose is to improve and maintain soil fertility, as well as minimise environmental burden. In recent years, sulphur is one of the necessary macronutrient fertilisers, the deficiency of which is constantly growing (Scherer, 2001; Morris, 2007; Soleymani et al., 2010; Hussain et al., 2011).

Sulphur is commonly found in nature and it is an essential component in the physiological processes of living organisms. It is most often supplied to plants in the form of SO_4^{2-} and incorporated by biosynthesis into organic compounds. Among the sulphur organic compounds, cysteine, methionine, cystine dipeptide, glutathione, sulpholipids, biotin, and glucosinolates dominate. This element plays an important physiological role, protects the plant against diseases and pests. Sulphur cannot be replaced by other elements in oxidoreductive systems that control photosynthesis, chlorophyll synthesis and reduction of nitrates (V) to ammonia. Its deficiency weakens the vigour of plants, resistance to stress and reduces yields (Boreczek, 2000). It is necessary in the initial stages of plant growth, just as nitrogen and phosphorus are (Marska, Wróbel, 2000; Gaj, Klikocka, 2011).

Another important element for plants is carbonate ions. They have a significant impact on soil pH, which is one of the most important indicators of soil suitability for optimal cultivation and fertilisation (Hell, Rennenberg, 1998; Tao et al., 2019). The pH of soil plays an important role in the processes of mobilisation or immobilisation of trace elements in contaminated soils.

Cucumber (*Cucumis sativus* L.) belongs to Cucurbitaceae family. It is creeping vine, probably arises from the wild species *C. hardwickii* (Royle) Alef. (syn. *C. sativus* var. *hardwickii* (Royle) Gabaev), which grows in the Himalayas. In India it was cultivated around 3.000 years ago and was later widely spread. Currently, it is known in all climatic zones, and its berry fruit (lat. *bacca*) is widely used in the cuisine of many countries (Vaughan, Geissler, 2001). Raw fruits are rich in antioxidants, cucurbitacin, and also contain about 97% water and help cleanse the body of toxins (Pudelski, 1971; *Chief Inspector of Protection …*, 2014).

In many countries, the fertilisation does not give good production results, because the ingredients necessary for plants are found in soils in insufficient amounts. As a result, this leads to reduced plant productivity and reduced crop quality. Knowledge of the nutritional needs of plants allows the rational use of fertilisers in various technologies of their production (Wójcik, 2014). The implementation of new measures, treatments and technologies requires numerous and multi-faceted studies (Pruszyński, 2009). The aim of this study was to determine the effect of magnesium sulphate and carbonate on (1) germination capacity, (2) growth of plants and (3) fresh and dry mass parameters of cucumber (*C. sativus*).

Material and methods

Plant material and medium modification

Cucumis sativus seeds from POLAN company were used in the experiment. Kottke et al. (1987) medium and their modifications were used for the experiments: [1] – pH 5.4, [2] with the addition of $MgSO_4 \times 7H_2O$ – pH 4.8, [3] with the addition of $MgCO_3 \times 3H_2O$ – pH 6.5. The control was performed on distilled water [4].

Germination

The cleaned seeds, in a 1% solution of acetone and washed with running and distilled water, were put 25 pieces with tweezers on sterile Petri dishes with a triple layer of filter paper moistened with a suitable type of medium and distilled water (control). The Petri dishes with seed were placed in the dark, at room temperature. Every 24 hours the number of germinated seeds was checked. Germinated seeds were considered to be those with sprouts equal to at least 2 mm. After 7 days, germination capacity of cucumber seeds were measured by germination indexes according to Islam and Kato-Noguchi (2014): germination energy (GE), germination as a percentage of control (G%), speed emergence (SE), mean germination time (MGT) were measured.

Growth of plants

After 3 days, germinated seeds were rinsed with distilled water and planted into pots with sand (10 plants for each series). Plants were grown in a growth chamber (Angelantoni Industrie, Italy) in a 12 / 12h photoperiod, at 25°C / 20°C (day / night) and relative humidity RH% 70–90%.

Biometric analysis

After 27 days, the length of underground and aboveground organs of cucumber plants was analysed. An inhibition percentage of growth (IP) index for root, hypocotyl, stalk, petioles was measured according to method used by Islam and Kato-Noguchi (2012).

Fresh, dry mass and turgor water content

Fresh mass of organ plants (root, hypocotyl, stalk, petiole, cotyledons, first leaves, second leaves) were measured on scale (Radwag WPS 120, Poland). Turgor water content (TWC) according to (Mullan, Pietragalla, 2012) was checked. Dry mass after 48 h of drying plant material in dryer (Wamed SUP 100, Poland) at temperature 105°C was measured.

Detailed analyses concerned the assessment of the effect of nutrients on germination, growth on the length, weight increase and water content of cucumber specimens: grown from seeds germinated in distilled water, and watered of the media during growth [I] and specimens grown from seeds germinated on media and also in the growth stage watered with media [II].

Statistical analysis

The germination experiment was carried out in two series by 25 seeds on Petri dishes for each Kottke medium modification and distilled water. In growth stage in two repetition,10 plants for each treatment of medium were measured. The results were analysed by the ANOVA / MANOVA parametric test using the post hoc Duncan test $p < 0.05$.

Results

Germination indexes

Germination energy (GE) for cucumber seeds watered with distilled water and Kottke medium reached similar values. The lowest germination capacity was found for seeds watered with the Kottke medium with the addition of magnesium carbonate (Fig. 1).

Analysis of *Cucumis sativus* seed germination based on germination index expressed as percentage of control showed that the most seeds germinated on Kottke medium, and the lowest on Petri dishes with $MgCO_3$ medium (Fig. 2).

The speed emergence (SE) of *C. sativus* seeds, in the first 3 days of germination, was from 80 to 90%. In the following days it was close to or equal to 100%. Compared to the control, for cucumber seeds watered Kottke medium, the highest values of this parameter were observed. For seeds treatment Kottke medium with carbon oxide, the lowest values of SE was revealed (Fig. 3).

Biometric analysis

The cucumber root growth was stimulated, regardless of the type of Kottke mediums and the time of their application (Tab. 1).

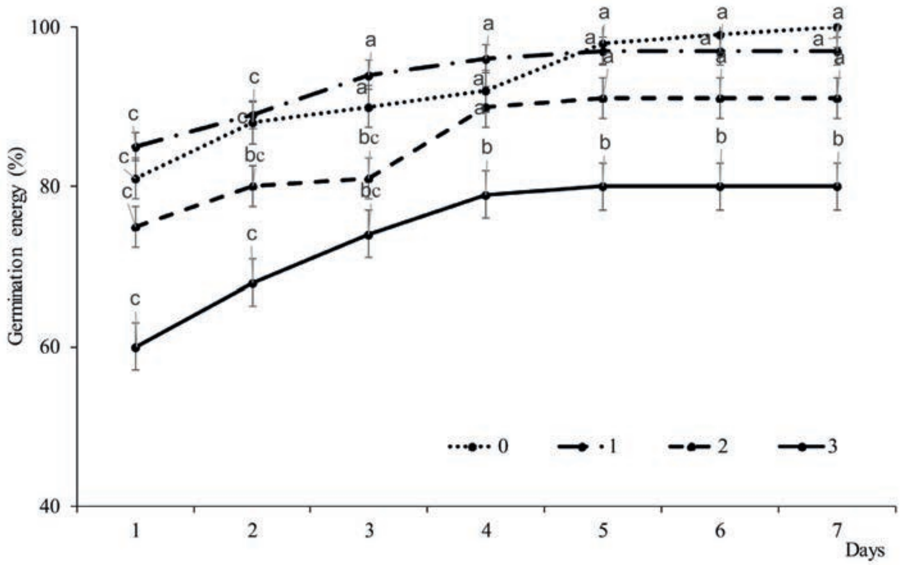

Fig. 1. Germination energy(GE) of *Cucumis sativus* L. seeds on: 0 – distilled water, 1 – Kottke medium, 2 – Kottke medium + $MgSO_4 \times 7H_2O$, 3 – Kottke medium + $MgCO_3 \times 3H_2O$; values marked letter (a, b, c) differ significantly according to Duncan test at $p < 0.05$

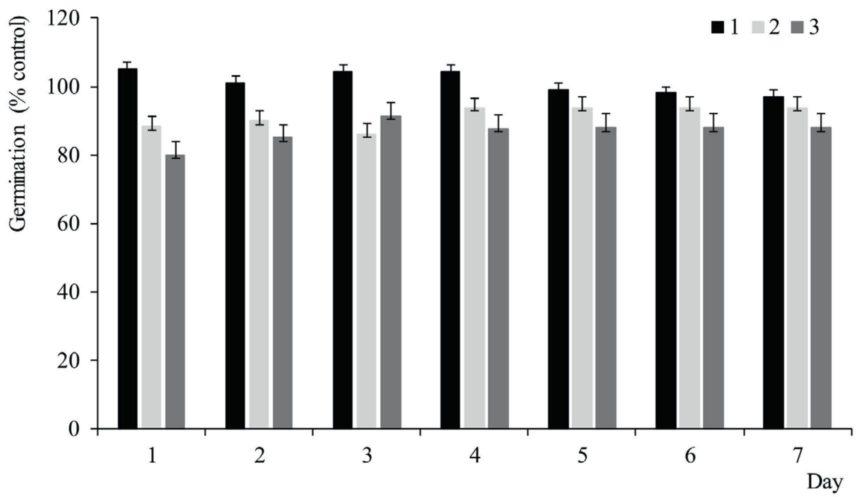

Fig. 2. Germination (% of control) of *Cucumis sativus* L. seeds watered with 1 – Kottke medium, 2 – Kottke medium + $MgSO_4 \times 7H_2O$, 3 – Kottke medium + $MgCO_3 \times 3H_2O$

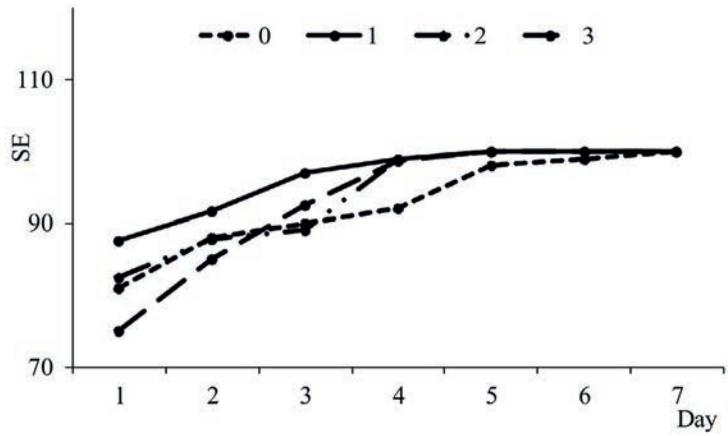

Fig. 3. Speed of emergence (SE) of *Cucumis sativus* L. seeds watered with 0 – distilled water, 1 – Kottke medium, 2 – Kottke medium + $MgSO_4 \times 7H_2O$, 3 – Kottke medium + $MgCO_3 \times 3H_2O$

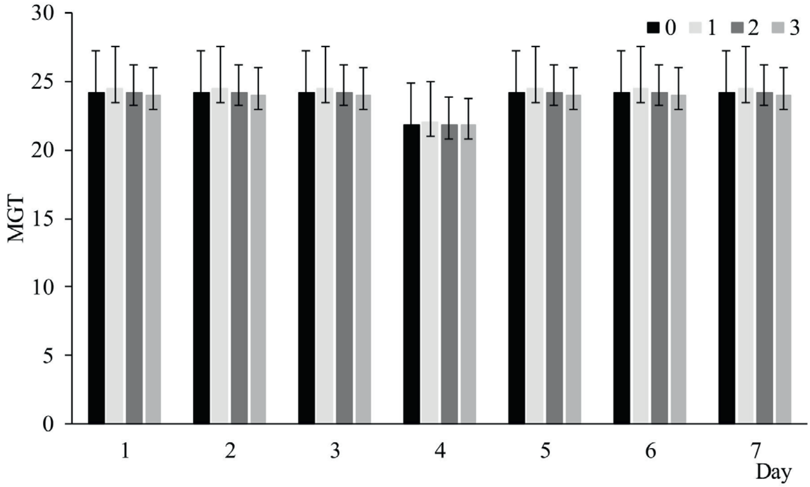

Fig. 4. Mean germination time (MGT) of *Cucumis sativus* L. seeds watered with 0 – distilled water, 1 – Kottke medium, 2 – Kottke medium + $MgSO_4 \times 7H_2O$, 3 – Kottke medium + $MgCO_3 \times 3H_2O$

MGT (mean germination time) reached very similar values regardless of the medium used. Compared to the control, the highest MGT values were found for seeds watered with Kottke medium, and the lowest for those treated with medium with $MgCO_3$ (Fig. 4).

Tab. 1. Length of *Cucumis sativus* L. organs watered with 0 – distilled water, 1 – Kottke medium, 2 – Kottke medium + $MgSO_4 \times 7H_2O$, 3 – Kottke medium + $MgCO_3 \times 3H_2O$ in germination and growth stages

Organ	0	Medium					
		0			1	2	3
		1	2	3			
root	13.3 b	15.0 a	14.6 a	16.0 a	15.0 a	15.0 a	16.0 a
hypocotyl	3.7 a	3.6 a	3.0 a	3.4 a	3.7 a	2.3 b	2.7 b
stalk	1.6 b	1.8 ab	1.9 a	1.9 a	1.9 a	2.0 a	2.1 a
petiole	0.6 b	1.3 a	1.2 a	1.2 a	1.4 a	1.2 a	1.0 a

values marked letter (a, b, c) in rows differ significantly according to Duncan test at $p < 0.05$

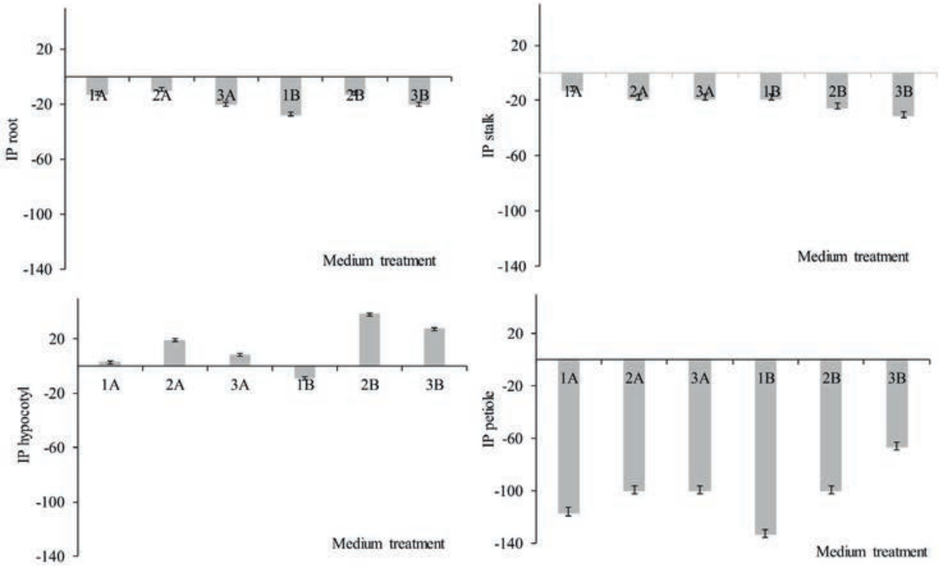

Fig. 5. Inhibition percentage (IP) as control % of roots, hypocotyls, stalk and petioles of *Cucumis sativus* L. plants growth (A) watered in germination stage 0 – distilled water and growth stage 1 – Kottke medium, 2 – Kottke medium + $MgSO_4 \times 7H_2O$, 3 – Kottke medium + $MgCO_3 \times 3H_2O$ and (B) watered in germination and growth stages 1 – Kottke medium, 2 – Kottke medium + $MgSO_4 \times 7H_2O$, 3 – Kottke medium + $MgCO_3 \times 3H_2O$; a minus (-) value on the Y axis indicates growth, and a plus (+) value indicates growth inhibition

The length of *C. sativus* hypocotyls was clearly inhibited by Kottke medium supplemented with magnesium sulphates and carbonates, which were used to water the plants during both germination and growth. For the stalk, the stimulating effect of each modification of the medium on cucumber growth was demonstrated. Compared to the control, the length of petioles during used the modification of the Kottke mediums was increased by half (Tab. 1).

Analysis of the IP root index showed the stimulating effect of all the media used on the growth of this organ. The highest IP root values of cucumber for plants watered with mediums, both during germination and growth stages were found. In the case of the IP hypocotyl index, the growth of this organ, in virtually all cases, was inhibited. Only, for hypocotyls of plants watered with Kottke medium during the germination and growth stages inhibiting stimulation of growth was found. For IP stalk index, the lowest values for plants grown from seeds watered with Kottke medium were found. The highest growth of cucumber stalks for plants watered with medium modifications during the germination and growth stages was noted. IP petiole index values were stimulated in each sample tested. Mediums caused 100% or even higher increase in *C. sativus* petioles (Fig. 5).

Compared to the control, the fresh mass of cucumber root was higher in each of the samples studied. For plants watered with Kottke medium both in the germina-

Tab. 2. Fresh and dry mass and turgor water content of *Cucumis sativus* L. organs watered with 0 – distilled water, 1 – Kottke medium, 2 – Kottke medium + $MgSO_4 \times 7H_2O$, 3 – Kottke medium + $MgCO_3 \times 3H_2O$

Organ	Medium						
	0	0			1	2	3
		1	2	3			
Fresh mass [g]							
root	0.505 c	1.039 a	0.938 a	1.063 a	1.104 a	0.854 ab	0.852 ab
hypocotyl	0.117 ab	0.168 a	0.138 a	0.171 a	0.181 a	0.110 ab	0.090 c
stalk	0.032 b	0.063 a	0.067 a	0.067 a	0.069 a	0.072 a	0.068 a
petiole	0.018 c	0.034 a	0.029 a	0.026 a	0.029 a	0.032 a	0.025 ab
cotyledons	0.274 b	0.352 a	0.316 a	0.0319 a	0.333 a	0.344 a	0.311 a
1-st leaves	0.111 c	0.239 a	0.191 ab	0.178 ab	0.183 ab	0.201 a	0.179 ab
2-nd leaves	0.042 c	0.191 a	0.166 ab	0.181 a	0.177 a	0.203 a	0.156 ab
Dry mass [g]							
root	0.052 c	0.064 ab	0.077 ab	0.072 ab	0.092 a	0.081 ab	0.092 a
hypocotyl	0.007 b	0.010 a	0.009 a	0.010 a	0.010 a	0.006 b	0.006 b
stalk	0.003 b	0.005 a	0.006 a	0.005 a	0.004 a	0.004 a	0.005 a
petiole	0.001 a	0.002 a	0.002 a	0.002 a	0.002 a	0.002 a	0.002 a
cotyledons	0.024 b	0.030 a	0.027 a	0.038 a	0.035 a	0.019 c	0.021 b
1-st leaves	0.016 b	0.028 a	0.030 a	0.032 a	0.032 a	0.018 b	0.021 ab
2-nd leaves	0.005 c	0.019 a	0.015 a	0.020 a	0.014 ab	0.020 a	0.016 ab
Turgor water content [%]							
root	89.70	93.84	91.79	93.23	91.67	90.52	89.20
hypocotyl	94.02	94.05	93.48	94.15	94.48	94.55	93.33
stalk	90.63	92.06	91.04	92.54	94.20	94.44	92.65
petiole	94.44	94.12	93.10	92.31	93.10	93.75	92.00
cotyledons	91.24	91.48	91.46	88.09	89.49	94.48	93.25
1-st leaves	85.59	88.28	84.29	82.02	82.51	91.04	88.27
2-nd leaves	88.10	90.05	90.96	88.95	92.09	90.15	89.74

values marked letter (a, b, c) in rows differ significantly according to Duncan test at $p < 0.05$

tion and growth stage and only during growth, the highest increase in the value of this parameter was demonstrated. Also, the medium with the addition of $MgCO_3$ increased the fresh mass of root, by half, in plants watered during growth stage. In other modifications, it was also showed a positive effect of the mediums on the growth of fresh mass of root. In the case of fresh mass of hypocotyls, a positive effect of medium was demonstrated, only Kottke medium with $MgCO_3$ caused a statistically significant decrease in the value of this parameter. The fresh mass values of stalk and petioles increased by half, in each of the measured samples, compared to the control. For the fresh mass of cotyledons, the positive effect of the medium used was also demonstrated. In all modification of Kottke medium, a significant increase in fresh mass of first and second leaves was observed (Tab. 2).

The values of dry mass of roots and all aboveground organs of cucumber plants were significantly higher under the influence of applied modifications of Kottke media, compared to the value of control masses. Turgor water content parameter, in the studied *C. sativus* plant organs, was similar and close to the control values. Generally, Kottke's medium and its modifications increased the water content of the cucumber's organs (Tab. 2).

Discussion

Crop plants need different mineral substances for proper growth and development. From an agricultural point of view, the most important role is played by available forms of elements, which are determined by many factors (Domska et al., 1998; Kaniuczak, 1999). Currently, the natural soil richness in nutrients does not fully meet their nutritional needs. One of the main reasons for the reduction of soil organic mass is the intensification of agricultural production, including the introduction of simplified crop rotation with a predominance of cereal monocultures. Unquestionable factors for increasing agricultural production are balanced organic and mineral fertilisation, correct crop rotation, plow tillage and pro-ecological activities, which, when used properly, have a positive effect on plant growth and development (Tujak, 2006; Jadczyszyn et al., 2010; Jaskulski et al., 2012).

Magnesium is one of the many substances that condition the proper course of life processes of living organisms. Conducted experiment showed that the presence of magnesium carbonates and sulphates slightly inhibited the germination indexes of cucumber seeds compared to the control. The values of the determined germination indexes showed that the most inhibitory effect on germination capacity had Kottke medium with $MgCO_3 \times 3H_2O$ (Fig. 1–4). The reaction to the acid reaction of the soil is not the same. It depends on the plant species, its variety and other soil properties. The formation of soil pH values is mainly related to their mineralogical composition, changes and content of organic mass, as well as climatic conditions. Acid cations have a toxic effect on crops, which is revealed in a reduction in the growth and size of the root system.

At the same time, in the soil intensive processes of retarding absorbable phosphorus compounds and reducing the content of basic cations occur. Magnesium uptake by plants occurs in the form of Mg^{2+} ions. To a large extent it depends on the pH of soils, as well as the competitive action of H^+, K^+, NH_4^+ and Ca^{2+} cations. Their high mobility can contribute to the displacement of magnesium from the soil sorption complex, and thus disrupt the proper functioning of plants (Kabata-Pendias, 1999).

Biometric root analysis showed the stimulating effect of the nutrients regardless of the time of watering. Compared to the control, the increase in hypocotyl length was inhibited in the presence of magnesium ions and sulphates (Fig. 5, Tab. 1). The highest growth of stems was observed in plants watered with nutrients supplemented with magnesium salts throughout the experiment. The petiole growth in length was stimulated by all modifications of Kottke media.

Fresh mass values, regardless of the type of medium and the time of its use, were higher in relation to the mass values from the control sample (Tab. 2). Only the fresh mass of hypocotyls watered throughout the experiment with magnesium salts was lower compared to the control. An increase in the dry mass value was demonstrated for all cucumber organs analysed. The percentage of water content was the lowest for the roots and first leaves compared to the control.

The positive effect of magnesium sulphate is most likely due to the presence of sulphur. This chemical element maintains normal physiological parameters that directly affect plant growth and development (Dobermann et al., 1998; Thomas et al., 2003; Hitsuda et al., 2005). The compounds of this element play key roles in many cellular processes (Dubuis et al., 2005). Sulphur is involved in the formation of proteins, carbohydrates, fats, in photosynthesis and in the synthesis of chlorophyll and lignin (Hell, Rennenberg, 1998). The positive effect of magnesium carbonate on plants can be due to the optimal pH of the soil, in which magnesium was easily absorbed. Slightly acidic soils have the best magnesium content. The content of available forms of magnesium decreases on very acidic and alkaline soils (Tao et al., 2019).

Stress conditions induce various biochemical processes in plant cells, as a result of which the metabolic and transport processes change (Konieczna et al., 2018a–b). They lead to a loss of cellular homeostasis, and even to the death of plants (Szatanik-Kloc et al., 2007; Pająk, Durak, 2018). As part of broadly understood ‘sustainable agriculture’ one should strive to comply with the principles of good practice, which includes, among others, limiting the use of synthetic pesticides and the production of healthy and good quality food.

Conclusion

(1) Germination indexes of cucumber seeds watered with Kottke medium and its modification reached similar values, compared to the control group (distilled water). For seeds watered with the Kottke medium with the addition of magnesium carbonate the lowest germination capacity was observed.
(2) Kottke mediums and its modifications had positive effect on growth of cucumber plants, regardless the stages which they were used. Only Kottke medium modifications used in both stages had negative effect on the growth of cucumber hypocotyls.
(3) The values of fresh and dry mass and water content increased in plants watered with Kottke mediums and its modifications, compared to the control.

Conflict of interest

The authors declare no conflict of interest related to this article.

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Abstract

The aim of the study was to determine the effect of magnesium sulphate and carbonate on the germination and growth of cucumber seeds (*Cucumis sativus* L.). For the experiment was used (1) Kottke et al. (1987) medium (pH 5.4) and its modification: (2) Kottke medium with the addition of $MgSO_4 \times 7H_2O$ (pH 4.8), (3) Kottke medium with the addition of $MgCO_3 \times 3H_2O$ (pH 6.5) and (4) distilled water (control). Characterisation of the germination capacity of cucumber seeds, under the influence of Kottke medium and its modification, were measured by germination indexes. An attempt was also made to assess the effect of mediums on growth on the length of plants, fresh and dry mass and water content. Germination indexes showed that the presence of magnesium carbonates and sulphates slightly inhibited seed germination, compared to the control. Biometric analysis of *C. sativus* roots showed a stimulating effect of mediums regardless of the time of watering the plants. Compared to the control, the length of hypocotyl was inhibited in the presence of the magnesium and sulphates ions. The highest growth of cucumber stalks in plants watered with mediums supplemented with magnesium salts for all time of experiment was observed. The petiole growth in length was stimulated by all modifications of Kottke medium. Fresh mass values, regardless of the type of medium and the time of its use, were higher in relation to the mass values from the control sample. Only the fresh mass of hypocotyl from plants watered throughout the experiment with magnesium salts was lower compared to the control. For all tested *C. sativus* organs an increase in the dry mass value was demonstrated. The percentage of water content was the lowest for roots and first leaves compared to the control.

Key words: fertilisation, germination, mass, organs' length

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Rola soli magnezu w kiełkowaniu i wzroście *Cucumis sativus* L.

Streszczenie

Celem pracy było określenie wpływu siarczanu i węglanu magnezu na kiełkowanie oraz wzrost ogórka gruntowego (*Cucumis sativus* L.). Do doświadczeń użyto (1) pożywki Kottke et al. (1987) (pH 5,4) i jej modyfikacji: (2) pożywka Kottke z dodatkiem $MgSO_4 \times 7H_2O$ (pH 4,8), (3) pożywka Kottke z dodatkiem $MgCO_3 \times 3H_2O$ (pH 6,5) oraz (4) wodę destylowaną (kontrola). Charakterystykę zdolności kiełkowania nasion ogórka, pod wpływem pożywki Kottke i jej modyfikacji, zmierzono za pomocą wskaźników kiełkowania. Podjęto również próbę oceny wpływu pożywek na wzrost na długość, przyrost mas i zawartość wody. Wskaźniki kiełkowania wykazały, że obecność węglanów i siarczanów magnezu nieznacznie hamowała kiełkowanie nasion, w stosunku do kontroli. Analiza biometryczna korzeni roślin wykazała stymulujący wpływ pożywek niezależnie od czasu podlewania roślin. W porównaniu do kontroli, przyrost na długość hipokotyli był hamowany w obecności zastosowanych jonów magnezu i siarczanów. Największy przyrost łodyg ogórka zaobserwowano u roślin podlewanych pożywkami z dodatkiem soli magnezu przez cały okres eksperymentu. Wzrost na długość ogonków liściowych był stymulowany przez wszystkie modyfikacje pożywek Kottke. Wartości świeżej masy niezależnie od rodzaju pożywki i czasu jej stosowania, były wyższe w stosunku do wartości mas z próby kontrolnej. Jedynie świeża masa hipokotyli roślin podlewanych przez cały okres eksperymentu solami magnezu była mniejsza, w porównaniu z kontrolą. Wzrost wartości suchej masy wykazano dla wszystkich badanych organów roślin. Procentowa zawartość wody była najniższa dla korzeni i pierwszych liści, w porównaniu z kontrolą.

Słowa kluczowe: nawożenie, kiełkowanie, masa, długość organów

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