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*Zeolite has been successfully used in growing media for containerized production systems. In this study the effects of zeolite utilization with the mixture of different growing media (GM) on the seedling quality and nutrient contents of cucumber (*Cucumis sativus *L. cv. Mostar F1) were determined under the greenhouse conditions. For this purpose, natural zeolite, perlite, turf, and their different mixture forms were used as GM for growing of cucumber seedlings. Effects of these substances on the seed germination, plant height, stem diameter, seedling fresh weight, and macronutrient [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg)] and micronutrient [iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu)] contents were studied. As a result of this study, the effects of GM on the seedling quality parameters were found to be significant for seed germination, plant height, stem diameter and fresh weight, and nutrient contents of seedlings. The best results were generally obtained from turf + zeolite mixtures.*

Keywords Germination, mixture, perlite, seedling, turf, zeolite

Introduction

Greenhouse vegetable production is very important in the Mediterranean region of Turkey. There are approximately 30,000 ha of greenhouse space in Turkey, and horticultural (vegetable) production occupies nearly 96% of Mediterranean region. In addition, soilless cultivation is being practiced on a commercial basis only on 75 ha in Turkey (Gül, Eroğul, and Ongun 2005).

As the advanced seedling technology through use of plug tray for good cultivation of seeds was propagated along with the expansion and development of horticultural industry, the use of bed soils as growing medium (GM) has recently been increased (Lee et al. 2012). Cucumber is an important vegetable as a seedling extensively grown in Turkey as well as tomato, pepper, and eggplant. Vegetable production is conducted intensively in Akdeniz

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region, Turkey. Winter season is also possible for the growth. Therefore, Antalya is suitable for growth during any season of the year. Cucumber-growing area occupied 60,000 ha, in which the yield was recorded as 1.799.613 tons (Anonymous 2007). In vegetable production, having a qualified seed and also the seedling are important to achieve a good yield. Quality seedling will both increase fertility and provide quality crops (Sakinci 2007). The seedling growth period in plant production is a very important stage and this period has an effect on growing and development of plant, early harvest, total efficiency, and fruit numbers per plant. Seedling productions with traditional methods have caused plant stress (Markovic, Takac, and Ilin 1994).

There is a lot of variability in the origin, physical, and chemical characteristics of the substrates used by the horticultural industry. Moreover, new sources of natural and artificial by-products are being introduced as growing media from time to time. Description of substrates used in horticulture, as well as mode of soilless culture management, has been widely reviewed by various researchers (Kipp, Wever, and Krej 2000; Raviv et al. 2002; Nelson 2003; Jones 2005). There are three main types of soilless cultivation: buffering substrates (e.g., peaty substrates), inert substrates (e.g., rock wool), and no substrates (e.g., nutrient film techniques). In addition, substrates used have been differentiated depending on the countries; for example, rock wool is common in northwestern Europe, whereas perlite and locally mined pumice are used a lot in southern Europe (Van Os 2000).

Many materials can be used as GM, which have desirable properties, such as abundant nutrients, high water-retention capacity, adequate aeration, and easy transportation and availability, to ensure the optimum seedling growth. Among these, the use of GM such as turf, perlite, vermiculite, pumice, and coco peat for seedling production are important substrates. Zeolite is thought to be a promising media for this purpose; therefore, zeolite could be easily used in seedling production (Kılıc and Kılıc 2006). Clinoptilolite has been successfully used in GM for containerized horticultural and floricultural production (Trinchera et al. 2010).

Zeolites are a type of inclusion compounds. They are hydrated alumino-silicates and are characterized by three-dimensional networks of silicon tetraoxide (SiO_4) and aluminum tetraoxide (AlO_4) tetrahedral linked by the sharing of all oxygen atoms (Reháková et al. 2004). Zeolites are characterized to have a high ability to lose and gain water and to exchange cations without a major change of its structure (Mumpton 1999; Kithome et al. 1999). Because of their ion exchange, adsorption, hydration–dehydration, and catalysis properties, zeolites are widely used in agriculture and in numerous industries for the removal of pollutants from waste and drinking water (Mumpton 1999; Ming and Mumpton 1989).

Of 40 natural zeolite species, clinoptilolite appears to be the most abundant zeolite in soils and sediments (Ming and Dixon 1987). It has a relatively high ion-exchange capacity with a preference for large cations such as ammonium (NH_4^+) and potassium (K^+) (Harland, Lane, and Price 1999). Zeolites are economic materials due to diminishing eluviations of elements and environmental contaminations (Gül, Eroğul, and Ongun 2005). Turkey has rich mineable deposits of zeolites with attractive physical and chemical properties for agriculture (Yücel 1987). Turkey holds approximately 50 billion tons of zeolite resources, which occur from clinoptilolite ore (Polat, Demir, and Onus 2005). Zeolites in Turkey have been used extensively as additive in fodder, underlay for animal, and GM for plant production and seedling as well as for adsorbing toxic waste and refining water for usage (Kılıc and Kılıc 2006). There are several studies on possibilities of using clinoptilolite as a substrate, and it is reported that clinoptilolite led to increases in yield (Baikova and Semekhina 1996; Loboda 1999).

Natural zeolite is often used in attempts to develop new substrates for plant growing and seedling production. Because it has strong sorption properties, high cation-exchange capacity (CEC), and macro- and micronutrient contents it is a reasonable alternative to Turf moss and other natural products used in the industrial production of substrates (Manolov et al. 2005). These beneficial properties of zeolite are important in terms of seed germination and root developments (Harland, Lane, and Price 1999). Zeolites are used in agriculture as soil amendments for (i) a source of phosphorus (P), potassium (K), and NH_4 nutrients in infertile soils and substrates (Allen, Ming, and Hossner 1995; Williams and Nelson 1997; Dwairi 1998); (ii) reducing nitrogen (N) losses and nitrate contamination (Ando et al. 1996), and (iii) improving water availability (Huang and Petrovic 1995; Yasuda et al. 1995).

Some researchers stated that zeolite could be used for scientific examination of plant physiology, to study plant growth and development and seedling bed preparation, and especially as growing media with perlite and sand in greenhouse production (Kurama et al. 1999). However, the same researchers reported that zeolite may also be used as a nitrogen (N) transporter; thus, N-utilization efficiency of plants could be enhanced and help save fertilizer. In addition, the use of clinoptilolite with adsorbed ammonium increases the amount of yield in biomass production (Dyer 1984).

The aim of this study was to determine the effects of zeolite with various types of media mixtures on seedling quality and nutritional contents of cucumber (C*ucumis sativus* L. cv. Mostar F1) plants.

Materials and methods

Materials

This experiment was conducted in the research greenhouse located at the Seed Research and Development Center of Akdeniz University in Antalya (southwestern Turkey). The greenhouse is 25 m × 6 m, and cucumber (*Cucumis sativus* L. cv. Mostar F1) was used as the plant material. The seeds were sown into the vials filled with various growing media, and the study ended after ∼35 days, when they grew to planting size (∼15 cm high). In this study, which was planned with four replicates, 45 seeds were sown into each growing medium. Seedling trays were regularly irrigated with tap water to maintain humidity suitable for plant growing.

In the present study, peat, perlite, natural zeolite containing clinoptilolite, and their mixtures were used as seedling growing media. The clinoptilolite used in the study were supplied from the mines in the mountain of Manisa–Gördes located in Aegean District of Turkey. Eight different growing media were used in the experiment (Table 1). Selected physical and chemical properties of substrates and water retention characteristics of growing media are given in Tables 2 and 3, respectively.

Methods

Field capacity and wilting point of growing media were determined by using pressure membrane apparatus as a percentage of water on a dry-weight basis retained by soil under 1/3 atm and 15 atm. In addition, available water amounts of media were obtained from subtraction between field capacity and wilting point (Demiralay 1993).

As fertility parameters, germination percentage (%), plant height (cm), stem diameter (mm), and fresh weight per plant (g plant^{-1}) were measured in seedlings from the start of

Table 1
Growing media in experiment

Growing media (GM)	Composition
GM1	100% turf
GM2	80% turf + 20% zeolite
GM3	80% turf + 20% perlite
GM4	60% turf + 40% zeolite
GM5	60% turf + 40% perlite
GM6	50% turf + 25% zeolite + 25% perlite
GM7	100% zeolite
GM8	100% perlite

Table 2
Some physical and chemical properties of zeolite–clinoptilolite, turf, and perlite

Properties	Zeolite–clinoptilolite	Turf	Perlite
Bulk density (g cm^{-3})	1.32	0.09	0.39
CEC (cmol kg^{-1})	121	91.2	2.15
EC (dS m^{-1})	0.986	0.50	0.86
pH (1/10)	7.40	6.40	6.30
Total N (%)	0.07	0.22	–
Soluble P (mg kg^{-1})	1.67	121,6	0.59
Soluble K (mg kg^{-1})	289	351.3	19.49
Soluble Ca (mg kg^{-1})	676	706.5	82.50
Soluble Mg (mg kg^{-1})	248	219.4	5.78
Soluble Fe (mg kg^{-1})	0,01	0.775	0.695
Soluble Mn (mg kg^{-1})	0.09	0.125	0.105
Soluble Zn (mg kg^{-1})	0.035	0.155	0.11
Soluble Cu (mg kg^{-1})	0.01	0.030	0.015

Table 3
Water-retention characteristics of growing media

Growing media	Field capacity (%)	Wilting point (%)	Available water (%)
GM1	228.0	187.6	40.4
GM2	89.8	76.3	13.5
GM3	239.0	211.0	28.0
GM4	58.8	31.2	27.5
GM5	244.9	218.7	26.2
GM6	70.7	53.1	17.6
GM7	26.6	22.0	4.6
GM8	390.0	342.5	47.50

seedling until sufficient height for planting. Additionally, macronutrients [N, P, K^+, magnesium (Mg^{2+}), calcium (Ca^{2+})] and micronutrients [iron (Fe^{2+}), zinc (Zn^{2+}), manganese (Mn^{2+}), and copper (Cu^{2+})] were analyzed as well.

Plant samples were washed by distilled water and dried in a forced-air oven at 65 oC to reach constant weight. After drying, dry weight of seedlings was recorded. The seedlings were ground separately in a stainless mill to pass through a 20-mesh screen and kept in clean polyethylene bags for analysis. Dried seedling samples of 0.5 g each were digested with 10 ml nitric acid (HNO_3)/perchloric acid ($HClO_4$) (4:1) acid mixture on a hot plate. The samples were then heated until a clear solution was obtained. The same procedure was performed several times. The samples were filtered and diluted to 100 ml using distilled water. Total N was determined by a modified Kjeldahl method (Kacar 1972); the other elements in wet-digested extracts were determined by spectrophotometry for P (Kacar and Kovancı 1982) and atomic absorption spectrophotometry for K^+, Ca^{++}, Mg^{2+}, Fe^{2+}, Cu^{2+}, Zn^{2+}, and Mn^{2+} (Kacar 1972).

The experiment was carried out according to the randomized block design as four replicates. Data collected were subjected to analysis of variance (ANOVA) test using the MINITAP packet program, and the least significant difference test (LSD) at $P \leq 0.05$ was used for comparisons (Anonymous 1995).

Results and discussion

The results from in the experiment consisted of germination percentage (%), plant height (cm), stem diameter (mm), and fresh weight per plant (g $plant^{-1}$) are given in Figure 1.

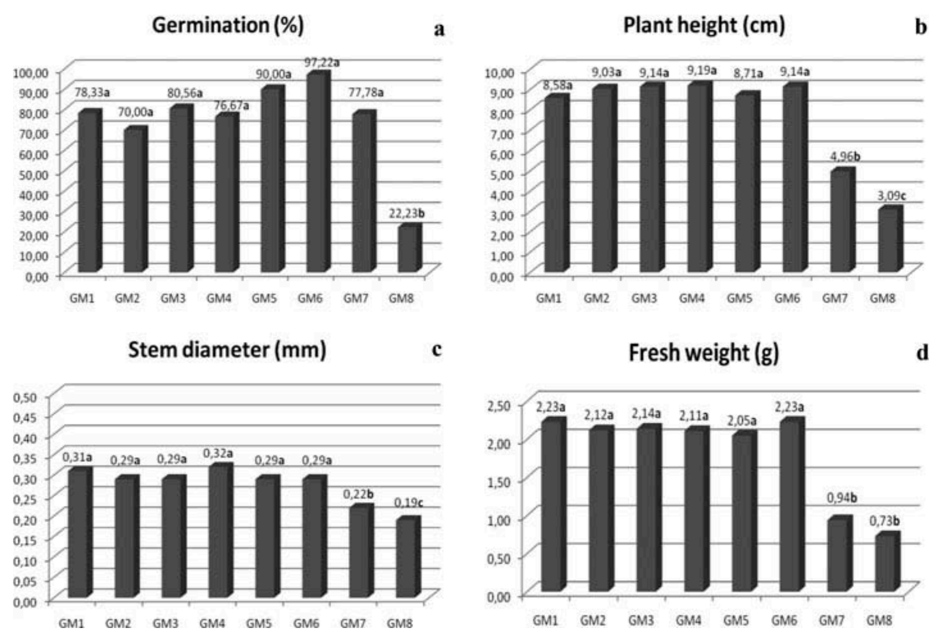

Figure 1. Effects of different media on germination percentage of seedling (a), seedling height (b), stem diameter (c), and fresh weight per plant in seedlings (d). Values of $n = 4$; the difference between values not shown with the same letter are significant at a $P < 0.05$ level.

With respect to germination percentage, all growing media (GM) had a statically significant effect ($P < 0.01$) on the germination percentage, and the first seven GM provided the greatest increase in the percentage of germination. There was no significant difference between these media. Minimum value of percentage of germination was obtained in GM8 (Figure 1). Turf and turf + zeolite combinations created positive impact on germination. It is thought that high water-holding and warming capacities of turf and turf combinations have effects on the germination percentage. Different substrates, turf and enriched zeolite, for pepper seedling production–compost were compared in another study, and the best results were obtained from the mixture of turf and zeolite (Markovic, Takac, and Ilin 1994).

Significant differences ($P < 0.001$) in the development of seedling (height, cm) that are the main parameters were obtained in different GM (Figure 1). The first six media created similar effects in the development of seedlings (Figure 1). The lowest seedling growth with values of 3.09 cm and 4.96 cm were obtained for GM8 and GM7, respectively. The natural zeolite, with the specific properties of high CEC and high contents of macro- and microelements, is one good alternative to the traditional potting media (Manolov et al. 2005). Hence, there was significant accelerated development (especially seedling height) on zeolite + organic matter substrates. An experiment compared different mixed zeolite groups (0, 5, 10, and 20%) for cucumber seedling quality and stated that the greatest development of cucumber plants was obtained with 10% and 20% group, which clearly grew faster from day 14, ending up at heights between 150 and 200 mm. The plants belonging to 0% and 5% groups grew more slowly and the final heights were on average less than 150 mm (Rydenheim 2007).

Considering the seedling stem diameter, GM had statistically significant effects ($P < 0.001$) on stem diameter of seedling. The first six media created similar effects (Figure 1). The lowest seedling stem diameters were obtained in GM8 and GM7, 0.19 mm and 0.22 mm, respectively. Some researchers have reported that significant accelerated development of seedling of cucumbers was observed on turf substrates enriched by chicken manure (Doğan 2003), and the best seedling development and seedling quality of cucumber were observed in turf enriched by humic acid (Apaydın 2002).

Fresh weight per seedling was taken into account, and the effects of different GM on fresh weight of seedling were statically significant ($P < 0.001$). The first six media created similar effects (Figure 1). The lowest values of the fresh weight per seedling were obtained in GM8 and GM7. Cucumber seedling yield and quality in different mixture zeolite groups (0, 5, 10, and 20%) were studied, and the fresh weight of the cucumber plants were the greatest in 10% and 20% groups, approximately 9–10 g per plant (Rydenheim 2007). In addition, different substrate effects on development of cucumber plant were observed, and moderate and coarse perlite did not have significant effect on development and fertility of cucumber plant (Cantliffe et al. 2003). Some researchers compared different substrates for pepper and tomato seedling production: compost, different two turfs, prepared substrates, turf mix, and enriched zeolites (Zeoplant). The best results were obtained from the mixture peat and Zeoplant (2:1) (Markovic et al. 1994). The effects of natural zeolites and enriched zeolites with fertilizer amendment on cucumber (*Cucumis sativus*) seed germination, plant growth, and development were examined. Researchers have reported that germination was faster with ammonium sulfate, diamonium phosphate, and superphosphate (18% phosphorus pentoxide; P_2O_5) amendment than with enriched zeolites with these fertilizer amendments. Although fertilizers suddenly affect media at initial irrigation after the sowing, zeolites work slowly due to slowly released N from their colloidal sites (Kurama et al. 1999).

Twenty-five combinations of turf moss, vermiculite, composted sawdust, and crop residues compost were used as soil media for seedling production. Cucumber seedlings grown in sawdust media were either similar or superior to the control (turf moss + vermiculite, 1:1 v/v) for each of the plant growth parameters: plant height, number of leaves, chlorophyll content, and fruit yield as well as number of fruits per plant. The greatest plant growth and, subsequently, the greatest yield were obtained by mixing control (turf/vermiculite 1:1) + sawdust + compost 2:2:1 (v/v/v) (Sawan, Eissa, and Abou-Hadid 1999).

The effects of soil, sand, perlite, pumice stone, turf, and sawdust on quality and yield of cucumber were examined. Cucumber yield increased 33.0, 31.7, and 17.6% but decreased 7.2 and 27.9% with perlite, pumice stone, turf, sand, and sawdust, respectively, compared to the control. Perlite and pumice stone may be better substrates in terms of flower number, yield, and fruit number (Demirer, Müftüoğlu, and Öztokat 1998). Lee et al. (2012) have stated that the growth lengths and fresh and dry weights of red pepper were significantly greater in the treatments of illite, phylitte, zeolite, and bentonite than in the control.

Nutrient content of seedlings is given in Table 4. Statistically significant differences ($P < 0.001$) between GM were determined with respect to N, P, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Zn^{2+}, Mn^{2+}, and Cu^{2+} contents of the seedlings. High N contents of seedlings were obtained in GM1, GM6, and GM7, and P and K were obtained in GM1 (Table 4). The zeolite is very effective in increasing the N in plant tissues. Clinoptilolite especially has a pronounced selectivity for cations, such as ammonium. Natural clinoptilolite is more selective to $NH_4{}^+$ than Na^+, Mg^{2+}, and Ca^{2+} (Ames 1967). Clinoptilolite has been used as fertilizer, being a source of N slow-release compounds, if previously treated with ammonium ions (Ahmed, Aminuddin, and Husni 2006). While the greatest value for Ca^{2+} content of cucumber seedlings was obtained in GM6, Mg^{2+} content was greatest in GM8 (Table 4). Clinoptilolite is a rich-zeolite type with Mg^{2+} and K^+ contents (Ayan 2001). Using zeolite accelerates availability of nutrients in spinach production (Burriesci et al. 1984).

Considering the micronutrient content of seedlings, the greatest contents of Fe^{2+} and Zn^{2+} of cucumber seedlings were obtained in GM7, and the greatest content of Mn^{2+} was obtained in GM4 (Table 4). It is estimated that the high micronutrient uptake of seedlings in this experiment may be explained by the fact that zeolite has a high CEC: Zeolites have a very high CEC value and stability compared to other materials used (Ayan 2007). Growing media (GM5) has been providing the greatest increase of Cu^{2+} content of seedlings in the experiment. Aydeniz and Danışman (1989) have stated that the greatest Cu contents of tomato plant were associated with perlite and fertilizer use together.

Conclusions

When the collected results were evaluated, all growing media (GM) except GM7 (100% zeolite) and GM8 (100% perlite) had similar influences on the germination percentage, height, stem diameter, and fresh weight of cucumber seedlings. Generally, zeolite, turf, and perlite mixture effects on seedling improvement and quality have been successful. While peat + perlite are preferred in practice for the cultivation of seedlings, zeolite might have a chance to be used successfully in seedling production. Plant tissue analyses revealed that the use of turf led to greater N, P, and K contents in comparison to other media. Use of zeolite showed effective results in nutrient supply and quality parameters of seedlings. These results support the previous reports (Harland, Lane, and Price 1999) that show zeolite acts as a reservoir, holding elements in its structure for slow release to the

Table 4
Average nutrient contents (%) of seedlings in different growing media[a]

Growing media	N	P	K	Ca	Mg	Fe	Zn	Mn	Cu
GM1	2.99**a**[b]	0.700**a**	5.42**a**	4.23**d**	0.173**bc**	180.00**d**	117.40**g**	65.20**c**	13.60**e**
GM2	2.52**c**	0.661**b**	3.60**d**	3.95**e**	0.186**b**	162.00**e**	144.00**c**	74.40**b**	21.40**d**
GM3	2.84**b**	0.612**c**	3.65**d**	4.46**c**	0.153**c**	148.00**g**	143.60**c**	45.40**e**	25.80**c**
GM4	2.74**b**	0.537**f**	4.01**c**	3.65**f**	0.186**b**	186.00**c**	141.20**d**	79.00**a**	03.00**g**
GM5	2.52**c**	0.564**e**	3.38**f**	4.86**b**	0.163**bc**	150.00**f**	122.40**f**	15.40**f**	44.20**a**
GM6	2.99**a**	0.592**d**	3.49**e**	5.17**a**	0.163**bc**	144.00**h**	135.40**e**	09.00**g**	21.40**d**
GM7	3.05**a**	0.311**g**	4.26**b**	2.56**g**	0.166**bc**	236.00**a**	184.20**a**	50.00**d**	38.20**b**
GM8	1.00**d**	0.308**h**	0.57**g**	3.99**e**	0.326**a**	230.00**b**	158.00**b**	14.80**f**	08.20**f**
LSD 5%	0.1435	0.007789	0.05669	0.04447	0.02579	1.374	1.854	1.307	1.127
Significance	***	***	***	***	***	***	***	***	***

[a]Values of $n = 4$.
[b]The difference between values not shown with the same letter are significant at a $P < 0.05$ level.
$^{***}P < 0.001$.

substrate solution or directly to plant roots. Trinchera et al. (2010) reported that secondary roots and the proliferation of root hairs in maize increase with both micronized and granular clinoptilolite substrates where zeolite particles adhere to the root surface, and this result is related to the enhanced solubilization of organic matter and nutrient availability. Thus, it is remarkable that while zeolite + turf combination was effective in increasing N content of seedling. Phosphorus (P) and K contents of seedlings were affected by turf in the experiment.

From this point of view, natural zeolite can be used for optimization of the root environment in soilless culture by promoting efficient nutrient uptake. Further studies are needed to assess the interaction between zeolite and different soilless substrates.

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