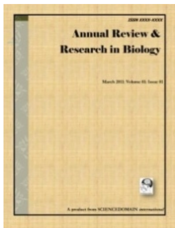

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Biological Response of Muskmelon (*Cucumis melo* L.) to Magnetic Field and Silver Nanoparticles

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Authors' contributions

This work was carried out in collaboration between all authors. Author HF designed the study, wrote the protocol, and wrote the manuscript. Author SJP performed the statistical analysis, and author KHR managed the analyses of the data. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Aims: This experiment was done to study the responses of muskmelon (*Cucumis melo* L.) to magnetic field and silver nanoparticles combinations in comparison with commercial fertilizers in field conditions.
Study Design: Experiment was conducted in a randomized complete block design with four replications.
Place of Study: The present study was done at the Razavi Research and Technology Institute in Mashhad, Iran.
Methodology: This experiment tested seven treatments based on a randomized complete block design in four replications. The treatments were as follows:
AgM: Silver nanoparticles + magnetic field;
HAgM: Humax commercial fertilizer + Silver nanoparticles + magnetic field;
Humax: Humax commercial fertilizer;
KAgM: Kemira commercial fertilizer + Silver nanoparticles + magnetic field;

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Kemira: Kemira commercial fertilizer;
Librel: Librel commercial fertilizer,
and Control.
Results: Results indicated that treatments of silver nanoparticles with magnetic field (AgM) had the highest fruit yield (16.420 ton ha^{-1}) followed by the Kemira fertilizer treatment (10.248 ton ha^{-1}). Significantly, silver nanoparticles with magnetic field treatment (AgM) showed by 150% more fruit yield in comparison to the control. The highest fruit yield in second harvest was achieved in silver nanoparticles + magnetic field + Kemira commercial fertilizer (KAgM) and the lowest was found in the control and Librel treatments. Using AgM, KAgM and Librel treatments caused early ripening of fruit in muskmelon. AgM treatment indicated larger fruit size than control. Using silver nanoparticles + magnetic field (AgM) significantly increased content of fruit soluble solid (13.1%) related to control (9.8%) in first harvest.
Conclusion: The treatment combining silver nanoparticles and magnetic field (AgM) most effectively improved early ripening of fruit, fruit and the quality of muskmelon fruit like soluble solid concentration compared to other treatments in firs harvest.

Keywords: Yield improvement; magnetic field; melon; silver nanoparticle.

1. INTRODUCTION

The manipulation of growth and increasing productivity of plants is the basis for most plant-related research. Economic studies have demonstrated the marked advances of early fruit production. As a result many techniques are used to accelerate and increase food crops productivity [1]. Using magnetic fields as a physical treatment to increase seed germination, emergence and crop performance is one of the safe and reasonable methods in crop production systems [2]. The mechanism of the effect of static magnetic field on physiological characteristics of plants is not clear, yet. Plant species responses to magnetic field are unpredictable. Their response depends on magnetic field intensity, the time of exposure to magnetic field, seed priming methods and species [3]. Some physical treatments often only change the course of some physiological processes in seeds and plants, which increase their vigor and contribute to enhanced development of a plant [4, 5]. It has been stated that the positive effect of magnetic treatment may be due to paramagnetic properties of some atoms in plant cells and pigments such as chloroplasts [6]. Magnetic properties of molecules determine their ability to attract and then change the energy of a magnetic field in other types of energy and to transfer this energy to other structures in plant cells, thus activating them [6]. Magnetic field may play an important role in cation uptake capacity and have a positive effect on immobile plant nutrient uptake, such as Ca and Mg, but negative electrical charges on plants inhibited the uptakes of anions such as P and S [7].

Recently, nanotechnology has many applications in agricultural research, such as in reproductive science and technology, the transfer of agricultural and food waste to energy and other helpful by-products through enzymatic nanobioprocessing, disease prevention and various other plant treatments using nanocides [8]. Nanoparticles have enhanced reactivity due to a greater proportion of surface atoms relative to the interior of a structure [9,10]. As such, insoluble substances can exhibit drastically enhanced solubility when particle size is less than 100 nm. In addition, materials with dimensions less than 5 nm exhibit unique magnetic/optical properties, electronic states, and catalytic reactivity that differ from equivalent bulk materials [11]. The average Ag content of soil is around 100 ng g^{-1}, ranging from 10 to 5,000 ng g^{-1}. Since Ag ions have a high affinity for sulphydryl, amino, and imino groups, it is believed that uptakes of these ions results in their binding to and/or mixing with membrane constituents and possibly active sites on some enzymes thereby altering membrane permeability [12]. In bean (*Phaseolus vulgaris*), corn (*Zea mays*), and tomato (*Lycopersicon esculentum*) plants, a low Ag^+ concentration (50 nanomolar) inhibited shoot uptake of the ions. In the roots, Ca uptake increased while P and S uptakes decreased [12]. Physiological activity of Ag^+ from nanoparticles is also a possibility. Ag^+, generally applied as silver thiosulfate, effectively inhibits ethylene-mediated processes, such as flower senescence and abscission [13,14]. As with other cations (e.g. K^+, Ca^{2+}), positive effects on plant stem hydraulic conductivity of Ag^+ are possible [15]. Ohkawa et al. [16] reported that silver-containing compounds extended the vase life of cut roses. Lu et al. [17] reported that a pulse treatment of 250 mg L^{-1} nanoparticles had a phytotoxic effect. However, pulse treatments for 1 h with 50 and 100 mg L^{-1} nanoparticle solutions extended vase life and suppressed reduction in fresh weight during the vase period. Amounts of water uptake and water loss by the cut flowers reduced under treatment with silver nanoparticles.

According to these findings, this experiment was done to study the responses of muskmelon (*Cucumis melo* L.) to magnetic field and silver nanoparticles combinations in comparison with commercial fertilizers in field conditions.

2. MATERIALS AND METHODS

2.1 Location Description

The present study was done at the Razavi Research and Technology Institute in Mashhad, Iran (latitude 36º, 15' N, longitude 56°, 28' E and altitude 985 m). The average annual rainfall was 252 mm and the long-term average minimum and maximum air temperatures were 6 and 22º C, respectively. A soil sample was taken from a depth of 0-30 cm before planting. Soil properties were determined using the following procedures; available nitrogen was analyzed using KCl extraction procedure, total nitrogen by Kjeldal method, phosphorus by the Olsen procedure, potassium by ammonium acetate extraction, soil texture by the hydrometric method [18], Fe, Mn, Zn and Cu by the DTPA-TEA procedure [19], organic carbon using the method suggested by Walky and Black [18], and $CaCo_3$ by neutralization with acid [20]. Physical and chemical properties of the soil were determined in the Soil and Plant Analysis Laboratory, Ferdowsi university of Mashhad, Iran (Table 1).

2.2 Treatments Explanation and Data Collection

This experiment tested seven treatments based on a randomized complete block design in four replications. The treatments were as follows:

AgM : Silver nanoparticles + magnetic field,
HAgM : Humax commercial fertilizer + Silver nanoparticles + magnetic field,
Humax : Humax commercial fertilizer,
KAgM : Kemira commercial fertilizer + Silver nanoparticles + magnetic field,
Kemira : Kemira commercial fertilizer,
Librel : Librel commercial fertilizer,
and Control.

Table 1. Physico-chemical properties of soil sample

Soil sample	$CaCO_3$ %	OC %	Zn	Fe	Mn	Cu	K	P	N (total)	N (available)	SP %	pH	EC dS m^{-1}	Texture
			mg kg^{-1}											
0-30 cm	10	0.75	1.1	6.1	13.3	0.75	200	5	882	10	31.5	7.7	1.10	Sandy clay loam

In each plot, a distance of 2.5 m was set between the rows and the final plant density was 1.3 plants m^{-2}. A cultivar of muskmelon named Ghasri was employed. A plot size of 7.5 m × 8 m was used. For all treatments nitrogen fertilizer (as urea) on the basis of 250, phosphorus fertilizer (as phosphate ammonium) 250 and potassium fertilizer (as potassium sulphate) 120 kg ha^{-1} were applied. Weeds were managed by hand weeding throughout the growing season.

Ingredients of Humax fertilizer consisted of 12% humic acid, 3% folvic acid and 3% K_2O. Components of Kemira and Librel fertilizers were 20% K_2O, 20% N, and 20% P_2O_5 and micronutrients (Fe, Zn, Mn, Cu, Mo, B and Mg). Humax and Kemira fertilizers were applied as fertigation and Librel fertilizer by foliar application according to factory recommendations. After seed emergence, magnetic field treatment was applied by employing magnet tapes with dimensions of 3×1 cm and strength of 10 mT, were located adjacent to or near each plant on the soil's surface up to harvest. At the same time, 40 g ha^{-1} of colloidal nanosilver was used in the irrigation water for the silver nanoparticle treatment. The average size of silver nanoparticles was around 20 nm, determined by Transition Electron Microscope (TEM) in the Central Laboratory of Ferdowsi University of Mashahd, Iran (Fig. 1). Harvests were applied three times during growth season of muskmelon. First harvest was conducted 90 days after seed sowing. Second and third harvest was done with 15 days intervals.

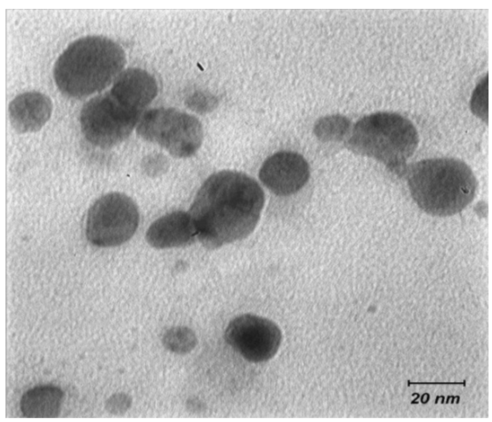

Fig. 1. Representation of silver nanoparticles size by Transition Electron Microscope (TEM)

2.3 Data Analysis

Recorded data analyzed by one way analysis of variance (ANOVA) based on a randomized complete block design. Data were analyzed using MSTAT-C software. Significant difference levels were calculated for all measured traits and the means were compared with the multiple ranges Duncan test (p-value= 0.05).

3. RESULTS AND DISCUSSOIN

3.1 Effects of Magnetic Field and Silver Nanoparticles on Fruit Yield and Size

As shown in Table 2, results in first fruit harvest of muskmelon indicated that treatments of silver nanoparticles with magnetic field (AgM) had the highest fruit yield (16.420 ton ha^{-1})

followed by the Kemira fertilizer treatment (10.248 ton ha^{-1}). Surprisingly, silver nanoparticles with magnetic field treatment (AgM) showed by 150% more fruit yield in comparison to the control (Table 2). In earlier work, we reported silver nanoparticles with magnetic field treatment and Kemira fertilizer increased fresh yields of maize by 35% and 17.5% in comparison to the control, respectively [21]. It has been reported that germination and early growth of maize seedlings improved when seeds were exposed to a continuously stationary magnetic field [22]. It was shown that a combination of nanosized SiO_2 and TiO_2 could increase nitrate reductase enzyme in soybean (*Glycine max*), improve its absorption ability of water and fertilizer, promote its antioxidant system, and in fact accelerate its germination and growth [23].

Table 2. Effects of magnetic field and silver nanoparticles on fruit yield of muskmelon in different harvests (harvest I was 90, Harvest II was 105 and Harvest III was 120 days after seed sowing)

Treatments	Fruit yield first harvest (ton h^{-1})	Fruit yield second harvest (ton h^{-1})	Fruit yield third harvest (ton h^{-1})	Total fruit yield (ton h^{-1})
AgM	16.420a	4.995c	4.093c	25.508a
HAgM	5.515e	4.710d	4.410c	14.635e
Humax	5.500e	5.448b	6.323a	17.270cd
KAgM	7.133c	6.565a	4.265c	17.963c
Kemira	5.325e	4.705d	4.528c	14.558e
Librel	10.248b	4.270e	5.160b	19.678b
Control	6.558d	4.410e	5.493b	16.460d

AgM: Silver nanoparticles + magnetic field; HAgM: Humax commercial fertilizer +Silver nanoparticles + magnetic field; Humax: Humax commercial fertilizer; KAgM: Kemira commercial fertilizer +Silver nanoparticles + magnetic field; Kemira: Kemira commercial fertilizer; Librel: Librel commercial fertilizer and Control.

This trend was not seen in case of second fruit harvest. The highest fruit yield in second harvest was achieved in silver nanoparticles + magnetic field + Kemira commercial fertilizer (KAgM) and the lowest was found in the control and Librel treatments (Table 2). This condition shows that application of AgM caused early fruit ripening. Application of Humax fertilizer indicated the greatest fruit yield in third harvest. This treatment had 18.4% more yield in comparing to control (Table 2). In general, one of the important features for muskmelon production in studied area (Khorasan province in Iran) is early fruit production. In such cases, earlier fruit production and transport to market increase competitive ability of farmers because of expensive price of fruit result in increase farmer's income. Overall, using AgM, KAgM and Librel treatments caused early ripening of fruit in muskmelon. Magnetic field may play an important role in cation uptake capacity and has a positive effect on immobile nutrient uptake by a plant, for example with Ca and Mg, but negative electrical charges on plants inhibited the uptake of anions such as P and S [7]. In previous study, authors indicated that incubation of fennel (*Foeniculum vulgare* Mill) seeds to 60 ppm nanosized TiO_2 highly improved germination percentage. Similar positive effects occurred in terms of shoot dry weight and germination rate [24].

As shown in Table 2 and Fig. 2, AgM treatment enhanced total fruit yield in comparison to control. Use of silver nanoparticles + magnetic field (AgM) increased total fruit yield by 55% related to control group. It was also revealed that suspended TiO_2 contents in soil suspensions were positively correlated with the dissolved organic carbon and clay contents of the soil, but were negatively correlated with ionic strength pH, and zeta potential [25].

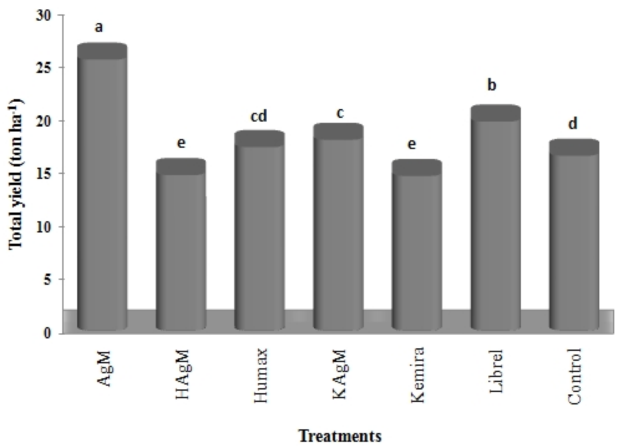

Fig. 2. The mean of fruit yield for muskmelon treated with magnetic field, silver nanoparticles and fertilizers

One of the major factors for marketable fruit in muskmelon is fruit size. Whatever the plants produce heavier and larger fruits the marketable yield is superior for consumers. Therefore our results indicated that in first harvest Librel fertilizer produced heavier fruit than other treatments (Table 3). However, in second harvest AgM treatment indicated larger fruit than control. In the third harvest Kemira and Librel fertilizers showed the highest weight and size of fruit related to other treatments (Table 3). Vashisth and Nagarajan [26] stated that magnetic field increased seedling dry weight of 1-month-old chickpea plants. De Souza et al. [27] reported that electromagnetic treatments led to a significant increase in leaf area, leaf dry weight, mean fruit weight, fruit yield per plant, and fruit yield of tomato per area.

Table 3. Effects of magnetic field and silver nanoparticles on average fruit weight of muskmelon in different harvests (harvest I was 90, Harvest II was 105 and Harvest III was 120 days after seed sowing)

Treatments	Fruit weight at first harvest (kg)	Fruit weight at second harvest (kg)	Fruit weight at third harvest (kg)	Fruit weight average (kg)
AgM	3.140c	2.688a	2.013f	2.613b
HAgM	3.123cd	2.513c	2.390b	2.675a
Humax	2.800e	2.558bc	2.225d	2.528c
KAgM	2.820e	2.605b	2.293c	2.570bc
Kemira	3.045d	2.520c	2.538a	2.703a
Librel	3.658a	1.870e	2.550a	2.693a
Control	3.233b	2.338d	2.128e	2.565bc

AgM: Silver nanoparticles + magnetic field; HAgM: Humax commercial fertilizer +Silver nanoparticles + magnetic field; Humax: Humax commercial fertilizer; KAgM: Kemira commercial fertilizer +Silver nanoparticles + magnetic field; Kemira: Kemira commercial fertilizer; Librel: Librel commercial fertilizer; and Control.

3.2 Effects of Silver Nanoparticles and Magnetic Field on Accumulation of Soluble Solid in Fruit

The content of soluble solid is another important concern in fruit quality of muskmelon. We concluded that using silver nanoparticles + magnetic field (AgM) significantly increased content of fruit soluble solid (13.1%) related to control (9.8%) in first harvest. This treatment enhanced fruit quality by 33.7% compared to control result in improve marketable yield (Table 4). This trend was found in second harvest as AgM and Humax fertilizers produced the highest content of soluble solid in fruits (10.4 and 10.3% respectively). It seems that these treatments induce appropriate condition such as release soluble carbohydrates in fruit and nutrients uptake from soil and consequently improve fruit quality. At the end of growing season, the greatest content of soluble solid in fruit was found in KAgM treatment that was 35.8% more than control group. Finally, average of fruit soluble solids content was achieved in AgM treatment. It increased soluble solids content by 20.3% related to control (Fig. 3). Other researchers have reported increasing of plant quality by magnetic field and nanoparticles. Berahmand et al. [21] stated that employment of silver nanoparticles and magnetic field (AgM) led to better accessibility and uptake of soil nutrients for plants improving the growth and development of fodder maize and enrichment of that fodder. In an experiment by Racuciu et al. [28] a stimulatory effect on plants was demonstrated on maize seeds exposed to a low static magnetic field (50 mT) at their early growth stages; effects were enhancement of fresh weight, level of assimilatory pigments as well as the chlorophyll ratio, average level of nucleic acids, and an increased seedling length. Karimi et al. [29] reported that magnetic field treatment enhances drought stress tolerance of common fig (*Ficus carica* L.) explants by increasing water absorption, increasing WUE, and inducing proline accumulation in the leaves.

Table 4. Effects of magnetic field and silver nanoparticles on soluble solids concentration of muskmelon fruit in different harvests (harvest I was 90, Harvest II was 105 and Harvest III was 120 days after seed sowing)

	Fruit soluble solids at first harvest (%)	Fruit soluble solids at second harvest (%)	Fruit soluble solids at third harvest (%)	Average of fruit soluble solids (%)
AgM	13.10a	10.40a	9.60b	11.04a
HAgM	10.15c	9.13d	9.40b	9.56c
Humax	9.10e	10.30a	8.10c	9.17d
KAgM	10.13c	9.10d	10.73a	9.98b
Kemira	11.03b	9.45c	9.50b	9.99b
Librel	10.05c	9.65bc	8.10c	9.27d
Control	9.80d	9.85b	7.90c	9.18d

AgM: Silver nanoparticles + magnetic field; HAgM: Humax commercial fertilizer +Silver nanoparticles + magnetic field ; Humax: Humax commercial fertilizer; KAgM: Kemira commercial fertilizer +Silver nanoparticles + magnetic field; Kemira: Kemira commercial fertilizer; Librel: Librel commercial fertilizer, and Control

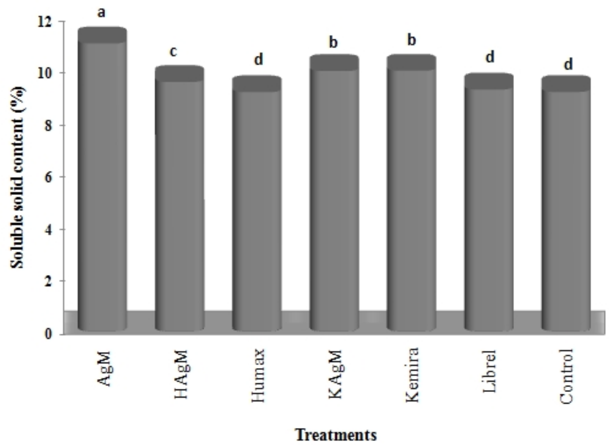

Fig. 3. The mean concentration of soluble solid in muskmelon fruit treated with magnetic field, silver nanoparticles and fertilizers

4. CONCLUSIONS

This experiment evaluated responses of yield and fruit quality of muskmelon to silver nanoparticles, magnetic field and some fertilizers in field condition. In general, application of a combination of silver nanoparticles and magnetic field led to improve quantitative and qualitative yields of muskmelon. In first fruit harvest, treatments of silver nanoparticles with magnetic field (AgM) indicated the highest fruit yield (16.420 ton ha^{-1}) followed by Kemira fertilizer treatment (10.248 ton ha^{-1}). Significantly, silver nanoparticles with magnetic field treatment (AgM) showed by 150% more fruit yield in comparison to the control. The treatment combining silver nanoparticles and magnetic field (AgM) most effectively improved the quality of muskmelon fruit like soluble solid concentration compared to other treatments in first harvest. It is recommended that further studies are conducted on the influence of magnetic field or silver nanoparticles alone on muskmelon. Supplementary research is recommended on reasons for encouraged plant growth from this mode of action by silver nanoparticles in combination with a magnetic field in the field condition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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