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The influence of NANO-GRO® organic stimulator on the yielding and fruit quality of field tomato (*Lycopersicon esculentum* Mill.)

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ABSTRACT

The effect of different methods of NANO-GRO® application on tomato plant growth and yield and its quality was determined. Four treatments were used: soaking seeds with NANO-GRO®, plants spraying, double application: soaking seeds + plants spraying and a control without NANO-GRO®. The cultivar Mieszko F_1 was used for the study. A significant influence of NANO-GRO® application method on tomato plant growth, yield and quality was observed. Pre-sowing application positively influenced plant height and the thickness of the stems. The highest total and marketable yield was observed in plants whose seeds were soaked with NANO-GRO® (respectively 87.02 and 53.13 t ha^{-1}) and in those with double application (respectively 73.48 and 45.67 t ha^{-1}). The lowest marketable yield was found in the plants from the control (37.01 t ha^{-1}). The highest lycopene content compared to the control was measured in fruits from plants sprayed with NANO-GRO®.

Key words: chemical composition, plant height, plant spraying, soaking seeds, stem thickness

INTRODUCTION

The profitability of tomato field production in Poland is most depended on the course of weather conditions, especially temperature and precipitation, during the growing period (Jędrszczyk et al. 2012, Skowera et al. 2014). Practically, therefore, the productivity of field tomato is threatened in any vegetation period. Achieving high yields of good quality depends on one's skills and capabilities to prevent the stresses caused by the course of weather, as well as the acceleration of a plant's metabolism and support of nutrient absorption.

Many plant species can defend themselves and at least in part surmount the influence of stress factors. However, often a defensive response comes too late, and losses are impossible to overcome. Therefore, it is relevant to support plants by the application of stimulators. In recent years, numerous studies have been carried out both on vegetables and fruit plants, as well as ornamental ones, where different kinds of preparations belonging to stimulators were examined (Mäkelä et al. 1998, Ashraf and Foolad 2007, Basak 2008, Skórska 2011, Gorczyca and Kasprowicz 2011, Matysiak et al. 2011, Nardi et al. 2016). Each of them had a specific composition. Most commonly extracts of sea weeds, aminoacids, humic acids, betaines or microelements, like manganese are used. Those compounds may have nourishing character, activate plant hormones, change quality and quantity of chemical composition or change plant morphology, stimulate root growth and

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enhance the antioxidant activity of the plant what ultimately result in obtaining higher yields and better quality (Finnie and Staden 1985, Adani et al. 1998, Mäkelä et al. 2000, Skórska 2008). Michalski (2010) sets the impact of stimulants on the plant as a mechanism of systemic acquired resistance (SAR). This reaction is associated with the accumulation of specific proteins, affecting the metabolism of the plant. This process must be changed so that the plant can become more resistant to stress.

At the moment there are a lot of preparations on the horticulture market which support plants, and research on new ones is in progress (Mäkelä et al. 1998, Matysiak and Adamczewski 2009, Kocira et al. 2013, Mila and Dobromilska 2013). NANO-GRO® is a stimulator with a unique composition, which has the form of an oligosaccharide granule (sucrose purified of 98% ethyl alcohol) soaked with sulfate elements: Fe, Co, Al, Mn, Mg, Ni, Ag at nanomolar concentrations. It was invented in U.S. in 2005 and was patented by OMRI. Influence of stimulator is based on inducing in the plant defense reaction due to stress caused by nanomolar concentrations of metal sulfates. When NANO-GRO® makes contact with the plants or seeds the interaction begins. The plant activates a defense mechanism without exposing it to real danger.

Studies on the NANO-GRO® effect for plant germination showed that seeds treated with a stimulator had a positive impact on the plant's emergence in the field (Jankowski et al. 2013). The total number of cucumber plants which have emerged in relation to the number of seeds sown for all dates was higher in the objects treated with a stimulator. According to Kirichenko et al. (2009) and Smirnova et al. (2009), the germination activity of two cultivars of winter wheat stimulated by NANO-GRO® was enhanced as compared to control. The authors also reported that NANO-GRO® stimulates the rooting of the green cuttings of the six species. A close rhizogenic effect of NANO-GRO® similar (or equal) to the activity of rooting hormone IBA (indole-3-butyric acid) was found. Janas (2012) found that presowing bioconditioning of garden rocket seeds with NANO-GRO® combined with foliar application of Tytanit increased plant resistance to diseases and adverse climatic condition and improved plant vigour. Hernández-Herrera et al. (2014) showed better germination (germination percentage, germination index and germination time) after seaweed extracts application on tomato seeds.

There are few reports in the literature on the effect of NANO-GRO® on the growth and development of vegetables grown in the field. The aim of this study was to demonstrate the effect of the NANO-GRO® stimulator and the method of its application on the plant growth and yield of field tomato.

MATERIAL AND METHODS

The experiments were carried out in 2011-2012 in the Vegetable Experimental Station of the Agricultural University in Mydlniki near Krakow. The area of the experiment was 86.4 m^2 (180 plants). The investigation was done on the dwarf variety of field tomato (*Lycopersicon esculentum* Mill.) 'Mieszko' F$_1$ (PlantiCo Zielonki), which is suitable for processing tomato crop production. Tomato field cultivation is more exposed to stress conditions associated with changes in the environment. The experiment was laid out in the random block method with three replications on brown soil (pH 7.5, C organic content 5.6%), 15 plants per replication. Basic soil fertilization was adjusted to the results of soil analysis; available forms of mineral constituents were supplemented to the level of (mg dm^{-3}) 120 N; 80 P; 250 K; 80 Mg. Four treatment combinations were used in the experiment: NANO-GRO® seeds soaking (30 sec. soaking in a NANO-GRO® solution at a dose of one granule per 1 dm^3 of water), plant spraying (application of NANO-GRO® in a solution of 1 granule per 10 dm^3 of water, sprayed on plants on 31.05.2011 and 28.05.2012), double application: seeds soaking + plants spraying and control without NANO-GRO®, were seeds and plants were treated with pure water.

Tomato seedlings were planted on May 16 in both years, at a spacing of 80 × 60 cm. During the growing season typical treatments such as weeding and chemical disease protection were carried out according to current recommendations. Measurements of the plants were performed twice: in the full flowering phase and at the end of the vegetation. They included plant height, stem thickness at the base and top.

After the fruits were harvested the total and marketable yield was determined. The quality of marketable fruits was analysed according to the following parameters: dry matter (%) at 65°C (PN-90/A-75101/03), acidity (%) using the titration method (PN-90/A-75101/), L-ascorbic acid (mg%) – (PN-71/A/75101), soluble sugars (% f.w) using the anthrone method (Yemm and Wills 1954), lycopene and β-carotene (mg 100 g^{-1} f.w.) using the spectrophotometric method (Nagata and Yamashita 1992) and macroelements: calcium, potassium and magnesium (mg 100 g^{-1} f.w.) using the flame method, with an atomic absorption spectrometer (Varian Spectr-AA). Phosphorus (mg 100 g^{-1} f.w.) was determined using the colorimetric method.

All of the data were subjected to an analysis of variance using the NIR Fisher test, at $p = 0.05$ using Statistica 10.

RESULTS

In 2011, there was no effect of NANO-GRO® on plant height either in the middle of flowering or at the end of the growing season (Tab. 1). In 2012, the NANO-GRO® application method had a significant impact on plant development. Tomatoes obtained from seeds treated with the stimulator were significantly higher than those where plants were only sprayed. In the middle of flowering there was an increase was of 8.3%, and 8.7% at the end of the vegetation. Taking the average for the years of investigation, spraying plants with NANO-GRO® was found to inhibit plant growth, whereas soaking the seed stimulated it.

The use of the NANO-GRO® stimulator positively influenced the thickness of the stem at the base of the plant (Tab. 2). The measurement taken in the middle of flowering showed that in 2011, the plants sprayed with NANO-GRO® had 1.98 mm thicker stems than plants from control, whereas plants from the double application (on seeds and plants) were 2.53 mm thicker. In 2012, the plants from the soaked seeds had 1.85 mm thicker stems, and those from the double application 2.00 mm thicker at the base than the control plants.

Table 1. The influence of NANO-GRO® stimulator on tomato plant height

Objects		Plant height (cm)					
		middle of flowering			end of vegetation		
		2011	2012	Mean	2011	2012	Mean
Control		58.90 a*	59.33 ab	59.11 a	79.71 a	79.13 ab	79.42 ab
NANO-GRO®	seed soaking	63.00 a	62.33 b	62.67 b	82.34 a	83.60 b	82.97 c
	plant spraying	61.31 a	57.13 a	59.22 a	81.12 a	76.33 a	78.73 a
	double application	61.90 a	61.13 b	61.52 b	82.00 a	81.06 ab	81.53 bc

*Means followed by the same letters within columns are not significantly different at $p = 0.05$

Table 2. The influence of NANO-GRO® stimulator on tomato stem thickness at the base

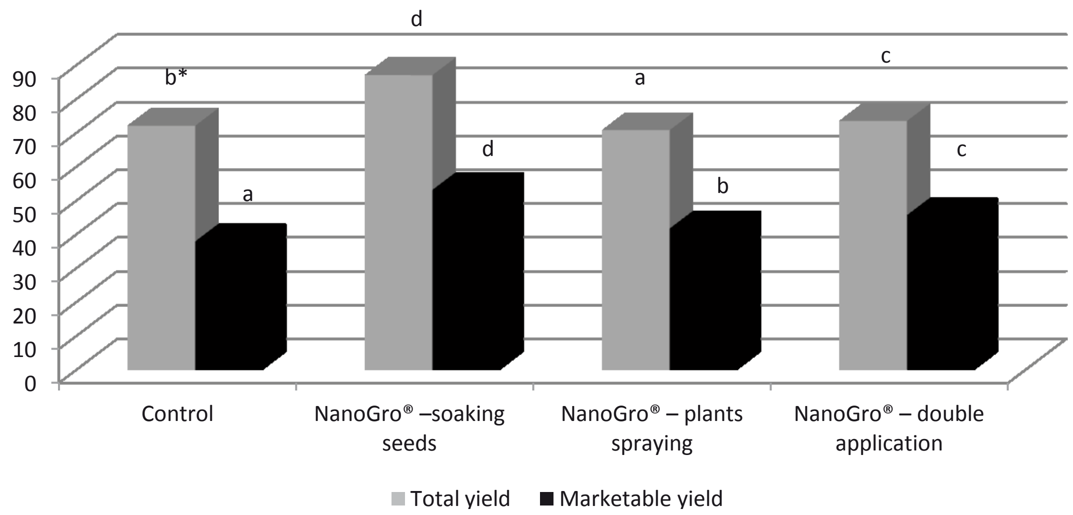
Objects		Stem thickness at the base (mm)					
		middle of flowering			end of vegetation		
		2011	2012	Mean	2011	2012	Mean
Control		12.59 a*	11.48 a	12.04 a	16.05 a	16.78 a	16.41 a
NANO-GRO®	seed soaking	14.57 b	13.33 b	13.95 b	19.64 bc	16.10 a	17.87 a
	plant spraying	13.80 ab	10.92 a	12.36 a	17.79 ab	16.28 a	17.03 a
	double application	15.12 b	13.48 b	14.30 b	20.56 c	16.40 a	18.48 a

*abbreviations: see Table 1

Table 3. The influence of NANO-GRO® stimulator on tomato stem thickness at the top

Objects		Stem thickness at the top (mm)					
		middle of flowering			end of vegetation		
		2011	2012	Mean	2011	2012	Mean
Control		4.80 c*	4.52 ab	4.66 b	6.08 c	4.98 a	5.53 a
NANO-GRO®	seed soaking	5.01 c	4.91 b	4.96 b	5.62 bc	5.54 b	5.08 a
	plant spraying	3.60 a	4.48 ab	4.04 a	5.20 ab	5.36 ab	5.28 a
	double application	4.03 b	4.34 a	4.18 a	4.84 a	5.26 ab	5.05 a

*abbreviations: see Table 1



*Means followed by the same letters are not significantly different at p = 0.05

Figure 1. The influence of NANO-GRO® stimulator on tomato total and marketable yield (t ha^{-1})

Measurements made at the end of the growing season confirmed this trend only in 2011.

In examining the influence of NANO-GRO® application method on the thickness of the stem at the top (flowering last cluster level), different trends were observed in 2011 (Tab. 3). As compared to the control, sprayed plants as well as those from the double application were characterized with a thinner stem at the top. In 2012, this trend continued, but these differences were not statistically confirmed.

A significant influence of the NANO-GRO® application method on the total and marketable yield of tomato was recorded (Fig. 1). The highest total yield was found in plants from the soaked seeds. The marketable yield was higher in all of the plants treated with NANO-GRO® than in the control, with the highest coming from plants with soaked seeds (an increase of 40.15% compared to

Table 4. The influence of NANO-GRO® stimulator on chemical composition of tomato fruits

Chemical composition	Year	Control	NANO-GRO® seed soaking	NANO-GRO® plant spraying	NANO-GRO® double application
Dry matter (% f.w.)	2011	6.08 a*	6.25 a	6.04 a	6.01 a
	2012	5.51 a	5.51 a	5.54 a	5.94 b
	Mean	5.79 a	5.89 a	5.79 a	5.98 a
Total sugars (% f.w.)	2011	2.50 b	2.33 a	2.28 a	2.34 a
	2012	2.04 a	2.16 b	2.01 a	2.32 c
	Mean	2.27 a	2.25 a	2.15 a	2.33 a
Vitamin C (mg 100 g^{-1} f.w.)	2011	28.90 d	22.70 b	22.10 a	27.90 c
	2012	10.77 a	12.77 b	14.87 c	15.80 c
	Mean	19.83 a	17.74 a	18.49 a	21.85 a
Acidity (%)	2011	0.42 a	0.42 a	0.44 b	0.35 a
	2012	0.35 a	0.35 a	0.42 a	0.35 a
	Mean	0.39 a	0.39 a	0.43 a	0.35a
Lycopene (mg 100 g^{-1} f.w.)	2011	5.51 ab	6.44 bc	6.82 c	4.61 a
	2012	5.83 bc	4.54 ab	5.92 c	4.29 a
	Mean	5.67 bc	5.49 b	6.37 c	4.45 a
β-caroten (mg 100 g^{-1} f.w.)	2011	1.72 a	2.60 c	1.95 b	1.76 a
	2012	0.75 ab	0.69 a	0.81 b	0.71 a
	Mean	1.23 a	1.64 c	1.38 b	1.23 a

*Means followed by the same letters within rows are not significantly different at p = 0.05

Table 5. The influence of NANO-GRO® stimulator on mineral composition of fruits (mg 100 g^{-1} f.w.)

Mineral composition	Year	Control	NANO-GRO®		
			seed soaking	plant spraying	double application
K	2011	244.4 b	264.2 c	244.8 b	237.5 b
	2012	181.8 ab	175.5 a	209.6 c	194.8 bc
	Mean	213.1 a	219.9 c	227.2 d	216.2 b
Ca	2011	11.80 b	15.00 c	9.50 a	12.10 b
	2012	25.77 b	20.57 a	21.03 a	21.20 a
	Mean	18.78 c	17.78 bc	15.26 a	16.65 ab
Mg	2011	11.70 c	20.57 a	21.03 a	11.20 ab
	2012	10.73 b	10.90 a	11.60 bc	9.34 a
	Mean	11.22 a	10.02 a	10.53 a	10.27 a
P	2011	11.90 ab	12.40 b	11.00 ab	10.60 a
	2012	16.37 b	13.58 a	15.64 b	13.73 a
	Mean	14.13 b	12.99 ab	13.32 ab	12.17 a

*Means followed by the same letters within rows are not significantly different at p = 0.05

the control). Marketable yield increased by 16.33% in the plants from the double application.

The method of NANO-GRO® application had small and non repeating effect in the years of the study on chemical composition of the fruit (Tab. 4). The content of soluble sugars in the fruits of all NANO-GRO® plants was lower compared to the control in 2011. In 2012, it was 5.88 and 13.72% higher in fruits from plants with treated seeds and plants with double application, respectively, than the control. In 2011, we observed a decrease in the vitamin C content of fruits in all plants treated with NANO-GRO® stimulator compared to the control. In 2012, vitamin C increased under the influence of the NANO-GRO® stimulator, with the largest value in fruits from sprayed plants and plants with double application (an increase of 38.06 and 46.70%, respectively, in relation to the control).

There was a significant effect of the method of NANO-GRO® application on the content of the carotenoid pigments in the tomato fruits (Tab. 4). There was a positive influence of spraying plants with the stimulator on the lycopene content. The mean for all years of β-carotene content was higher than in the control in fruits from plants with the application of NANO-GRO® on seeds and in objects where the plants were sprayed.

The content of macroelements in tomato fruits depends on the method of NANO-GRO® application (Tab. 5). On average for the two years of the study, the potassium level increased under the influence of the stimulator, mostly in the fruits of sprayed plants, and reached a level of 227.2 mg 100 g^{-1} f.w. On the other hand, a decrease of calcium and potassium content in the fruits was observed as compared to the levels in the control. The magnesium level did not change under NANO-GRO® application.

DISCUSSION

NANO-GRO® is a stimulator of plant growth and development. According to the producer, after a few days of preparation application the included elements activate plant defense mechanisms by stimulating signaling molecules, which in turn alert the cell about the change. The plant response to NANO-GRO® is to grow hormone production. After some time, the rapid growth and development of the plant's aboveground parts and its root system takes place. Research conducted by the producer showed that the transplants of Batory F_1 tomato cultivar from seeds soaked with NANO-GRO® tended to reduce total plant growth parameters, including lower plant weight, smaller height and the diameter of the stem and the number of the leaves in comparison to transplants from untreated seeds (Babik and Panasiuk 2008). Jankowski et al. (2013) also observed a tendency of the decrease length of grasses seedlings after the application of NANO-GRO® stimulator; however, the results were not statistically confirmed. These observations were confirmed in the present experiment. The method of NANO-GRO® application had a significant impact on the growth of tomato plants. It was noted that the application of the stimulator at an early stage of development (for seeds) resulted in the plant beginning to develop intensively after passing through the activation phase. This pattern was confirmed in plant height and the thickness at the base and the top of the stems of tomato measurements. Applying NANO-GRO® stimulator early (on seeds) resulted in significantly better plant growth in comparison to the plants where the stimulator was used at a later phase (in the form of spraying on the plants). Hernández-Herrera et al. (2014) showed that foliar application of liquid seaweed extracts effectively stimulated tomato seedlings growth.

All plants where NANO-GRO® was used were characterized by a higher marketable yield than the control objects. It was found that the method of stimulator application had a significant effect on yield. Plants from NANO-GRO® soaked seeds were characterized by the highest yield both total and marketable, while plants that were sprayed with the stimulator had the lowest. Kocira at al. (2015) confirmed the positive influence of NANO-GRO® in research on common bean yielding. The authors stressed that the use of the stimulator improved common bean yield and its nutraceutical potential, however, the final effect was strongly depended on the method of application. The best method was seed soaking combined with single spraying. Many authors have written about the beneficial effects of stimulators on plant yield. Mäkelä et al. (1998) observed an increase of the yielding of plants where a foliar application of a stimulator was carried out. The authors used glycinobetaine, a novel product from sugar beet which improved crop stress tolerance. They noticed that tomato plants grown under saline or heat stress yielded better when they received glycinobetaine. The time of application was very important. Yield increased especially when a stimulator was applied during midflowering. Gajc-Wolska et al. (2009) reported that the biostimulator Goteo increased the total and marketable tomato yield, whereas BM 86 did not influence yielding. Dobromilska and Gubarewicz (2008), examining the influence of Bio-algeen S-90 on berry tomatoes (sprayed three times), showed that objects with a stimulator had a significantly higher total and marketable yield. In the producer's experiments a tendency for better yielding of tomatoes whose seeds had been primed and seedlings were additionally sprayed with NANO-GRO® was observed, but these observations were not statistically validated (http://agrarius.eu/). Kocira et al. (2015) noticed a positive effect of NANO-GRO® in a form of soaking seeds and plant spraying in various combinations on common been seeds weight and the number of pods. Janas (2012) found a positive influence of the NANO-GRO® stimulator bioconditionned presowing on seeds, on garden rocket seed yield.

The effect of NANO-GRO® on the chemical composition of tomato fruits was small and varied in different years. On average for the two years of the study, there was no negative impact of the NANO-GRO® stimulator on the level of dry matter, soluble sugars, vitamin C and acidity compared to the content of these components in the fruits of the control plants. Nowicka-Połeć and Kunicki (2013) found out the positive influence of NANO-GRO® foliar application on broad bean plants on starch content in seeds. In studies on the effects of other bio-stimulators (Goteo and BM 86) used as watering and spraying plants form on the nutritional value of tomato fruits, Gajc-Wolska et al. (2010) noticed a significant decrease in sugars, vitamin C and carotenoids content in comparison to control. There was no influence of those bio-stimulators on dry mater content. In the present investigation, carotenoid pigments depended on the method of NANO-GRO® application. As far as lycopene concerned, a higher amount of this pigment was found in fruits from sprayed plants in comparison to the ones with soaked seeds, whereas the highest amount of β-carotene was found in fruits from plants with soaked with stimulator seeds. Gajc-Wolska et al. (2009) did not find a significant influence of the applied preparations (Goteo, BM 86) on tomato pigments, which were mostly cultivar depended.

In the present study, the results indicate that the content of phosphorus and calcium in tomato fruits from plants treated with NANO-GRO® decreased whereas the potassium level increased in comparison to the control. The application of the stimulator did not affect the level of magnesium. Gajc-Wolska et al. (2010) observed the effect of other bio-stimulators (Goteo and BM 86) on the level of macronutrients in the fruits of four field crop cultivars of tomato. The authors showed that the potassium and calcium content increased, and phosphorus decreased in comparison to the control under the influence of the application of bio-stimulators.

The differences in results are various in all years. There are no researches explaining the mechanism of NANO-GRO® action on the chemical composition of tomato fruit but comparing the results to other stimulators or other plant species not fully explain obtained data. Therefore, further researches combining various method of NANO-GRO® application are necessary.

CONCLUSIONS

1. The use of NANO-GRO® on seeds stimulated the development of tomato plants, particularly plant height and thickness at the base.
2. A significant influence of NANO-GRO® application on total and marketable yield was found. The highest yield came from plants with NANO-GRO® soaked seeds, and was slightly lower in plants with double application.
3. The highest lycopene content compared to the control was obtained in fruits from plants sprayed with NANO-GRO®.
4. Content of phosphorus and calcium in tomato fruits from plants treated with NANO-GRO® decreased whereas the potassium level increased in comparison to the control.

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AUTHOR CONTRIBUTIONS

E.J. – designed experiment, performed measurement during vegetation, analytical measurements, statistical analysis and contributed to manuscript writing in 60%. A.A. – performed measurement during vegetation, analytical measurements and contributed to manuscript writing in 40%.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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