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RESPONSE OF TOMATO PLANTS TO LOW PLASTIC-ZNO NANO-COMPOSITE TUNNELS COVERING AND CHITOSAN NANOPARTICLES FOLIAR SPRAYING

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ABSTRACT

A field experiment was conducted for two successive winter seasons of 2012/2013 and 2013/2014 in the farm of the Faculty of Agriculture, Moshtohor, Benha University, Egypt, to explore the effects of treating the plastic tunnels with ZnO nanoparticles on the growth parameters, yield and its quality of tomato (*Lycopersicon esculentum* Mill cv. Super Strain B). It also investigates the effects of using the foliar application of chitosan nanoparticles applied at 0.5 and 1% versus the commercial chitosan applied at the same rates on the growth parameters and the yield of tomatoes and whether these treatments could be positively/negatively affected by treating the plastic tunnels with ZnO nanoparticles. Results revealed that the tomato plants grown under nano-composite covering (PE with nano-ZnO) gave rise to vigor growth, higher yield and fruit quality compared with the tomato plants under low plastic tunnel (PE without nano-ZnO). Chitosan nanoparticles (0.5 or 1 %) increased the plant growth (plant height, fresh, dry weight and leave area), early and total yield per plant and per feddan and average fruit weight beside of improving the quality of fruits (vitamin C, acidity and total sugars) than all other treatments. Thus, using chitosan nano particles (0.5 or 1 %) under nano-composite covering (PE with nano-ZnO) is the recommended practice to attain good growth parameters and achieve early and high total yield with better quality of tomato fruits. However, the low concentration of chitosan nano-particles achieves the highest return economist in this case.

Keywords: Tomato, Chitosan, Low plastic tunnels, polyethylene (PE), Nano-ZnO, Feddan (fed. = 4200 m^2)

INTRODUCTION

Tomato (*Lycopersicon esculentum Mill*) is an important crop worldwide. It has high nutritional values e.g. a source of different classes of the antioxidants such as carotenoids, ascorbic acid, phenolic compounds, and α-tocopherol (Abushita *et al.*, 1997; Beecher, 1998).Many products of tomato are used in kitchens e.g. ketchup, juice...etc (Tahir *et al.*, 2012). Thus, tomato is considered an important crop in many markets around the world. However, the cost-price and the quality are still considered the important challenge (Wijnands, 2003).

Plastic films are employed as coverings for greenhouses or tunnels over crop rows (Lamont, 2009; Riggi *et al.*, 2011) to attain high crop yield all the year around beside of the effective use of fertilizers, and water resources under the greenhouses (Pardossi *et al.*, 2004).The optical properties of the traditional used plastic films determine the amounts of solar radiation that reaches the plants (Ham *et al.*, 1993; Heißner *et al.*, 2005).Ultraviolet (UV) radiations is considered harmful to plants and soil living organisms(HolloÂsy, 2002) and accelerates degradation of the plastic films(Kyrikou and Briassoulis, 2007). Visible light is required for the photosynthetic activity in plants(Wang *et al*., 2009), thus high transparency in this range is required in plastic films to increase crop production. Infrared (IR) radiation heats up the greenhouse(Hoffmann and Waaijenberg, 2002); therefore, high IR opacity preserves heat during night time and saves energy especially during the cold winter seasons (Espi, *et al*., 2006).

Several oxides and minerals in micrometric size have been used to improve the thermal efficiency of the greenhouse cover films; nevertheless, loss of transparency and film photo-degradation could happen (Espi, *et al*., 2006).The use of these oxides in the nano-scale provide UV shielding without affecting the transparency of the used films (Druffel *et al*., 2008).Zinc oxide introduced high ultraviolet-shielding capability preserving transparency (Espejo *et al*, 2012) by more than 95% of total UV transmission (Espejo *et al*, 2012). Moreover, such nano-technology can improve the mechanical properties of the polymeric materials. i.e increase the material modulus to attain higher bigger mechanical resistance or elongation (Balazs *et al*., 2006 and Tjong 2006).

Chitosan, a given name to the deacetylated form of chitin, is a natural biodegradable compound derived from crustaceous shells such as crabs and shrimps (Rinaudo, 2006; Baker *et al.*, 2007). It is a low acetyl form of chitin mainly composed of glucosamine, 2-amino-2- deoxy-*β*-D-glucose (Freepons, 1991). Chitosan is characterized by its polycationic nature (Bautista-Baños *et al.,* 2006),which candidate this polymer to improve plant protection (El-Hadrami *et al.*, 2010) and (Terry and Joyce, 2004). Moreover, the degraded chitin can be used as an efficient nitrogen source (Geisseler *et al.*, 2010). Thus, chitosan treatment has been shown to stimulate plant growth (Kim, 2005) and improve storability of postharvest fruits and vegetables (El Ghaouth *et al.,* 1991). In this concern, the nanoparticles of chitosan could guarantee more uniform distribution of the spray and higher effectiveness on plants.

The current research aimed at studying the effects of growing tomatoes under low tunnels treated with ZnO nanoparticles during two successive winter seasons. This study also investigates the effect of spraying plants with chitosan nanoparticle as a tonic on the plant growth performance, yield quantity and quality. This study also measures the outcome economical returns of this study.

MATERIAL AND METHODS

Materials of study

Chitosan: a commercial product (contains 90-95% chitosan) was supplied by Oxford Laboratory, India. Chitosan nanoparticles processed using the method described by Corradini *et al*. (2010). Nano-zinc oxide (ZnO, 20 nm), was provided by Nanotech Egypt for Photo-electronics, Bahgat group, 6 October region, Giza Governorate. Transparent low plastic tunnel of

70 cm height, 220 cm width and 70µ thickness was obtained from Hyma plastic (22, El-Obour Buildings – Salah Salem St., in front of Panorama October, Cairo, Egypt). Soil samples (0-30 cm) were collected from the experimental farm of the Faculty of Agriculture, Moshtohor, Benha University, Qalubiya Governorate, Egypt prior to seedling transplanting and analyzed for their physical and chemical properties as outlined by Jackson (1969). Physical and chemical properties of the investigated soil are shown in Table 1.

Table 1: Physical and chemical properties of the soil under study before transplanting

Soil texture				pH	EC ($dS\ m^{-1}$)	O.M (%)	$CaCO_3$ (%)	Soil available macronutrients ($mg\ kg^{-1}$)		
Sand (%)	Silt (%)	Clay (%)	Texture					N	P	K
24.4	24.6	51	Clay loam	7.9	2.16	1.41	1.53	22.5	9.1	120

The field study

This experiment was carried out during the winter seasons of the two successive seasons of 2012/2013 and 2013/2014 at the Experimental Farm, Faculty of Agriculture, Moshtohor, Benha University to study the effect of the use of chitosan and chitosan nanoparticles at 5 and 10 g L^{-1}on vegetative growth parameters, fruit yield and its quality of tomato (*Lycopersicon esculentum* Mill cv. Super Strain B) grown under low plastic tunnels (PE or PE with ZnO nanoparticles, 20 nm, 20 mg/m^2) under drip irrigation system. Tomato plants were transplanted on15th of November during the two growing seasons. The experimental treatments were arranged in a split plot design and included ten treatments with three replicates as represented in Table 2.

Table 2: Experimental design

Treatments	Description
	Under low plastic tunnels (polyethylene, PE)
T1	The control treatment (spray with distilled water).
T2	Chitosan at 0.5%.
T3	Chitosan at 1%.
T4	Chitosan nanoparticles at 0.5%.
T5	Chitosan nanoparticles at 1%.
	Under low plastic tunnels (PE with ZnO nanoparticles)
T6	The control treatment (spray with distilled water).
T7	Chitosan at 0.5%.
T8	Chitosan at 1%.
T9	Chitosan nanoparticles at 0.5%.
T10	Chitosan nanoparticles at 1%.

Each experimental plot included one ridge 1.2 m wide and 5 m long. Seedlings were selected and transplanted on two sides of the ridge and 30cm apart, 60 cm between ridges and plot area was 9 $m^2$and each plot contained 32 plants. Nitrogen (NH_4NO_3, 33.5 % N), phosphorus (Ca $(H_2PO_4)_2.CaCO_3$, 16% P_2O_5) and potassium (K_2SO_4,48 % K_2O) were used in this study. Fertilizers were added to all plots at rates of 160 kg N $fed.^{-1}$, 64 kg P_2O_5 fed^{-1} and 48 kg K_2O $fed.^{-1}$, respectively. Phosphate fertilizer was added for experimental plots during soil preparation, while NH_4NO_3 and K_2SO_4 fertilizer were added weekly within the drip irrigation system.

Data recorded

a) Vegetative growth characters

Five plants were taken from each plot randomly (90 days after transplanting) and plant height, leaf area per plant and total fresh and dry weight per plant were recorded.

b) Fruit yield and its components

1. Early yield per plant and per fed. (The sum of the first three pickings).
2. Total yield per plant and per fed.(All harvested fruit from each plot along the harvesting season were weighted and calculated as total fruit yield).
3. Average fruit weight.

c) Chemical constituents of fruits

1. Reducing, non-reducing and total sugars were determined according to the method of Shaffer and Hartman (1921).
2. Vitamin C and acidity were determined according to A.O.A.C. (2000)

Statistical analysis:

All obtained data were recorded on plot basis and statistically analyzed according to a split plot design. Duncan's Multiple Range Test at 5% level was used to compare between significant treatments means. All the obtained data were subjected to statistical analysis of variance according to the procedure outlined by Steel *et al.*(2006). MSTAT-C program (1988) was used for statistical computations.

RESULTS

Effect of low plastic-ZnO nano-composite tunnels covering and chitosan nanoparticles foliar spraying on plant vegetative growth parameters

Data in Table 3 show the effects of using the two types of low plastic tunnels on the growth parameters of tomato plants. In general, using nano-composite of low plastic-ZnO tunnels increased the plant growth parameters (plant height, fresh and dry weight of plant as well as leave area).

Also, foliar application with chitosan nanoparticles type generally gave the highest values of plant growth parameters comparing with commercial type of chitosan under normal low plastic tunnel. Finally, it could be concluded that supplying with chitosan as a foliar application with different types and concentrations used in this experiment gave the highest value of vegetative growth (plant height, fresh and dry weight/plant) under nano-composite of low plastic-ZnO tunnel, but the same type of low tunnel supplying with chitosan at 1 % concentration gave the highest leaves area comparing with other treatments in both seasons.

Effect of low plastic-ZnO nano-composite tunnels covering and chitosan nanoparticles foliar spraying on the tomato yield

Data recorded in Table 4reveal thatusing nano-composite of low plastic-ZnO tunnels increased the average weight of the tomato fruitsand both theearly and total fruit yield of tomatoes.

3+4

Chitosan foliar application under nano-ZnO treated tunnels increased the plant fruit weight. However, the form and the concentrations didn't give rise to any further significant increases. Concerning the early and total yields, increasing the concentrations of chitosan resulted in further increases in tomato yields. Application of chitosan nanoparticles increased tomato early and total yieldsper plant and per feddan. However, increasing the concentration seemed to be insignificant for increasing tomato yields. Also, the foliar application of chitosan nanoparticles in both concentrations (0.5 or 1 %) gave the highest early and total yield per plant and per feddan with significant differences in comparing with commercial chitosan under two types of low plastic tunnels and in both seasons.

Effect of low plastic-ZnO nano-composite tunnels covering and chitosan nanoparticles foliar spraying on the quality of tomato fruits

Data in Table 5 show that foliar application with chitosan under low plastic-ZnO nano-composite tunnels improved the quality of tomato fruits, Chitosan nanoparticles gave the best quality of tomato fruits in terms of vitamin-C, acidity reducing and non-reducing sugars with no significant differences between the two rates (0.5 and 1.0 %) of application. However, total sugar was the only parameter that increased with increasing the application rate of chitosan nanoparticles from 0.5 to 1.0 %.

While, the foliar application with commercial chitosan increased vitamin-C, acidity and reducing sugars, meanwhile no significant effects were detected for increasing the rate of chitosan application. Concerning non-reduced and total sugars, increasing the rate of commercial chitosan resulted in further improvements in the quality of the tomato fruits.

Economic evaluation:

It is clear from data presented in Table 6 that production coasts increased under nano-composite of low plastic-ZnO tunnels and net return was high in this case. Also use foliar spray with chitosan increase cost but also improves the growth and maximize productivity. On the other hand, treatments without chitosan foliar spray showed the lowest value of net return. While, the foliar application of chitosan nanoparticles in both concentrations (0.5 and 1%) gave the highest early and total yield per plant and per feddan under two types of low plastic tunnels used in this study in both seasons (Table, 4). So that, from the previous results using chitosan nanoparticles at 0.5% concentration is more economically than using it at 1% for obtaining highest early and total yield. That was cleared in the economic return of the treatment, which has been foliar spraying of plants with chitosan nano particles, 0.5% under low plastic-ZnO nano-composite tunnels (Table, 6). Which was the net return is 31868 LE as an average in both seasons.

5+6

DISCUSSION

Using nano-composite of low plastic-ZnO tunnels increased plant growth parameters, average weight of the fruits, early and total yield of tomatoes beside of improving the quality of the tomato fruits. Probably, ZnO nanoparticles improved the physical properties of plastic tunnel for protecting plants from cooling injury at low temperature condition e.g. increasing the benefit of infrared rays and low penetration of ultraviolet rays according to Espejo *et al.* (2012). Many investigators reported that using chitosan as foliar spray increased vegetative growth, yield and quality of vegetable crops (Abdel-Mawgoud *et al.,* 2010*;* Ghoname *et al.,* 2010 and Fawzy*etal.,*2012). The results obtained therein, reveal that chitosan application under nano-ZnO treated tunnels resulted in further significant increases in plant growth parameters and tomato yield quantity and quality. Similar results were reported on tomato (Shafshak *et al*., 2008) and strewberry (Abdel-Mawgoud *et al*., 2010). They attributed such effects to the constituents of the chitosan which comprises amino acids, vitamins, antioxidants, mineral constituents, poly saccharide. Such constituents play significant roles in cell formation, cell division and elongation, consequently increased the plant growth. Nanoparticles of chitosan seemed to be more effective in improving plant growth parameters, yield quantity and quality. These particles (diameter<30 nm) enter directly into plant leaves through stomata (Grover *et al*., 2012) resulting in further improvements in plant growth (Abdel-Mawgoud *et al*., 2010). Increasing the concentration of chitosan nanoparticles increased tomato early and total yields; however, such increases were insignificant. Thus, using chitosan nanoparticles at 0.5% concentration is considered more economically than using it at 1% for obtaining highest early and total yield. It is worthy to mention that the effect of chitosan on plant growth and tomato yield seemed to be minimal under the normal low plastic tunnels not-treated with ZnO nano particles. Probably chitosan undergoes degradation with UV radiation (Wasikiewicz *et al*., 2005).

CONCLUSION

In conclusion, treating the plastic tunnels with ZnO nanoparticles could significantly improve the plant growth performance and the yield of tomatoes grown under plastic tunnels. Moreover, such a treatment can improve the effectiveness of chitosan on the growth of tomatoes. However, special concerns should be considered for the nano-applications of chitosan as effective treatment for improving the entry of chitosan into leaf stomata and could be considered economically when considering lower concentrations to attain high yield production.

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إستجابة نباتات الطماطم للتغطية بالأقبية البلاستيكية المنخفضة المعالجة بأكسيد الزنك المتناهى الصغر والرش الورقى بالشيتوزان المتناهى الصغر

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أجريت تجربة حقلية لعامين متتاليين ٢٠١٣/٢٠١٢ و٢٠١٤/٢٠١٣ خلال موسم الشتاء في مزرعة كلية الزراعة بمشتهر جامعة بنها، مصر، لإستكشاف آثار إستخدام الأقبية البلاستيكية المنخفضة (البولي إثيلين أو البولي ايثيلين معالج بأكسيد الزنك المتناهي الصغر) على النمو، وكمية المحصول وجودة ثمار الطماطم صنف سوبر سترين بى. والتحقق أيضا من أثر الرش الورقى بجزيئات الشيتوزان المتناهى الصغر بتركيز ٠.٥ و ١٪ ومقارنة ذلك بالرش بالشيتوزان التجارى بنفس التركيزات على نمو ومحصول الطماطم وما إذا كانت هذه المعاملة يمكن أن تؤثر إيجابا أو سلبا على النباتات النامية تحت الأنفاق البلاستيكية المنخفضة والمعالجة بأكسيد الزنك المتناهى الصغر. وقد كشفت النتائج أن نباتات الطماطم المنزرعة تحت الأقبية البلاستيكية المنخفضة المعالجة بأكسيد الزنك المتناهى الصغر قد أعطت أكبر نمو، وأعلى إنتاجية وأفضل جودة للثمار مقارنة مع نباتات الطماطم تحت الأقبية البلاستيكية المنخفضة العادية (الغير معالجة بأكسيد الزنك المتناهى الصغر). وكذلك فإن الرش بجزيئات الشيتوزان المتناهى الصغر (٠.٥٪ أو ١٪) أدى إلى زيادة نمو النبات (إرتفاع النبات – الوزن الطازج والجاف والمساحة الورقية) والمحصول المبكر والكلي للنبات والفدان ومتوسط وزن الثمرة إلى جانب تحسين جودة الثمار (فيتامين سى والحموضة والسكريات الكلية) مقارنة بكل المعاملات الأخرى. وبالتالى، نجد أن استخدام جزيئات الشيتوزان المتناهى الصغر بأى من التركيزين (٠.٥٪ أو ١٪) وتحت الغطاء البلاستيكى المعالج بأكسيد الزنك المتناهى الصغر هى المعاملة الموصى بها والتى تحقق مواصفات نمو جيدة و أكبر محصول مبكرا و كلي مع أفضل جودة لثمار نباتات الطماطم، إلا أن التركيز الأقل يحقق أعلى عائد إقتصادى فى هذه الحالة.

الكلمات الدالة: الطماطم ، الشيتوزان، الأقبية البلاستيكية المنخفضة ، البولي إيثيلين ، أكسيد الزنك المتناهى الصغر، الفدان = ٤٢٠٠ م^{2}

Table 3: Effects of low plastic-ZnO nano-composite tunnels covering and chitosan nanoparticles foliar spraying on the plant growth parameters of tomato, during the winter seasons of 2012/2013 and 2013/2014.

	Treatments	Plant height (cm) 1st season	Plant height (cm) 2nd season	Fresh weight (g/plant) 1st season	Fresh weight (g/plant) 2nd season	Dry weight (g/plant) 1st season	Dry weight (g/plant) 2nd season	Leave area (cm²/plant) 1st season	Leave area (cm²/plant) 2nd season
Under low plastic tunnels (PE)	The control treatment (spray with distilled water)	47.13 cd	45.33 d	179.12d	169.15f	24.21c	24.16c	873f	867f
	Chitosan at 0.5%	46.97 cd	47.13 cd	181.97d	180.40e	25.95bc	25.72c	962de	946e
	Chitosan at 1%	47.44 cd	47.86 bc	181.40d	182.67e	26.72b	25.95c	946e	953e
	Chitosan nanoparticles at 0.5	48.78 bc	49.28 b	215.77b	204.76d	27.78b	27.24b	953e	962e
	Chitosan nanoparticles at 1%	50.12 b	51.34 a	218.46b	217.62c	26.24b	28.58b	1003d	1005d
Under low plastic tunnels (PE with ZnO nanoparticles)	The control treatment (spray with distilled water)	46.33 d	47.97 bc	199.52c	178.52e	24.33c	25.33c	967d	973de
	Chitosan at 0.5%	52.59 a	51.73 a	239.76a	241.42b	30.21a	31.42a	1205c	1225c
	Chitosan at 1%	52.16 a	52.63 a	247.67a	248.91ab	30.16a	30.61a	1227c	1234c
	Chitosan nanoparticles at 0.5	53.11 a	53.16 a	253.55a	255.75a	31.25a	31.43a	1268b	1289b
	Chitosan nanoparticles at 1%	53.28 a	53.34 a	252.44a	257.75a	31.18a	31.44a	1331a	1342a

Means of the same column followed by the same letter were not significantly different according to Duncan MRT at 5%.

Table 4: Effects of low plastic-ZnO nano-composite tunnels covering and chitosan nanoparticles foliar spraying on yield and its components of tomato, during the winter seasons of 2012/2013 and 2013/2014.

	Treatments	Average fruit weight (g) 1st season	Average fruit weight (g) 2nd season	Early yield (kg/plant)) 1st season	Early yield (kg/plant)) 2nd season	Early yield (ton/fed) 1st season	Early yield (ton/fed) 2nd season	Total yield (kg/plant) 1st season	Total yield (kg/plant) 2nd season	Total yield (ton/fed) 1st season	Total yield (ton/fed) 2nd season
Under low plastic tunnels (PE)	The control treatment (spray with distilled water)	64.43g	63.82d	0.222g	0.201f	5.296g	4.870g	0.582d	0.571d	8.928g	8.664g
	Chitosan at 0.5%	91.22e	90.80c	0.299e	0.297d	7.132e	7.042e	0.747c	0.731c	10.871f	10.864ef
	Chitosan at 1%	98.80d	96.60c	0.305e	0.301d	7.276e	7.208e	0.822c	0.801c	11.670e	11.208e
	Chitosan nanoparticles at 0.5	111.97c	113.70b	0.341d	0.326d	8.142cd	7.802de	1.048b	1.031b	15.704d	15.078cd
	Chitosan nanoparticles at 1%	117.60b	115.30b	0.352d	0.337cd	8.428c	8.106d	1.076b	1.064b	15.748cd	15.524c
Under low plastic tunnels (PE with ZnO nanoparticles)	The control treatment (spray with distilled water)	81.62f	84.62c	0.277f	0.257e	6.608f	6.248f	0.724c	0.711c	10.326f	10.408f
	Chitosan at 0.5%	123.90a	125.20a	0.349d	0.348c	8.030d	8.112d	1.095b	1.088b	16.204bc	16.028c
	Chitosan at 1%	125.80a	125.60a	0.406c	0.396b	9.288b	9.428c	1.155b	1.124b	16.640b	16.962b
	Chitosan nanoparticles at 0.5	128.40a	127.90a	0.437b	0.444a	10.402a	10.616b	1.286a	1.274a	19.204a	19.008a
	Chitosan nanoparticles at 1%	128.20a	128.10a	0.476a	0.481a	10.204a	11.462a	1.304a	1.295a	19.774a	19.546a

Means of the same column followed by the same letter were not significantly different according to Duncan MRT at 5%.

Table 5: Effects of low plastic-ZnO nano-composite tunnels covering and chitosan nanoparticles foliar spraying on quality of tomato fruits, during the winter seasons of 2012/2013 and 2013/2014.

	Treatments	Vitamin C (mg/100 g FW)		Acidity (mg/100 cm^3)		Reducing sugars		Nun-reducing sugars (mg/100 g FW)		Total sugars	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Under low plastic tunnels (PE)	The control treatment (spray with distilled water)	22.33c	22.40d	212.31e	211.9g	3.246f	3.242e	1.988b	1.887e	5.234f	5.129f
	Chitosan at 0.5%	23.24b	23.13cd	243.11c	241.5e	3.238f	3.332e	2.051a	1.934cde	5.289f	5.266e
	Chitosan at 1%	23.16b	23.2bc	254.44c	249.8d	3.477d	3.481d	1.983b	1.944bcd	5.46e	5.425d
	Chitosan nanoparticles at 0.5	23.36b	23.31bc	249.55c	253.7d	3.652c	3.652c	1.944bc	1.965bc	5.596d	5.617c
	Chitosan nanoparticles at 1%	23.48b	23.5bc	255.20c	258.1c	3.734b	3.714bc	1.887d	1.979bc	5.621d	5.693c
Under low plastic tunnels (PE with ZnO nanoparticles)	The control treatment (spray with distilled water)	23.23b	23.11cd	225.70d	225.1f	3.341e	3.253e	1.934cd	1.907d	5.275f	5.160f
	Chitosan at 0.5%	23.94b	23.84b	292.74b	293.3b	3.786b	3.797b	1.911cd	1.917d	5.697c	5.704c
	Chitosan at 1%	23.78b	23.98b	294.90b	295.4b	3.877a	3.847ab	1.965b	1.988b	5.842b	5.835b
	Chitosan nanoparticles at 0.5	24.77a	24.74a	309.90a	297.6b	3.852a	3.876ab	1.979b	2.000a	5.831b	5.876b
	Chitosan nanoparticles at 1%	24.83a	24.79a	296.22b	308.6a	3.937a	3.925a	2.003ab	2.051a	5.940a	5.976a

Means of the same column followed by the same letter were not significantly different according to Duncan MRT at 5%.

Table 6: Economic evaluation of cultivated tomato plants as affected by the combination between low plastic tunnel types and chitosan foliar treatments during the winter seasons of 2012/2013 and 2013/2014.

	Treatments	Total income (LE/fed.)		Production costs (LE/fed.)		Net return (LE/fed.)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Under low plastic tunnels (PE)	The control treatment (spray with distilled water)	26784	25992	19450	19450	7334	6542
	Chitosan at 0.5%	32612	32592	24250	24250	8362	8342
	Chitosan at 1%	35010	33624	29050	29050	5960	4574
	Chitosan nanoparticles at 0.5	47112	45234	24450	24450	22662	20784
	Chitosan nanoparticles at 1%	47244	46572	29250	29250	17994	17322
Under low plastic tunnels (PE with ZnO nanoparticles)	The control treatment (spray with distilled water)	30978	31224	20450	20450	10528	10774
	Chitosan at 0.5%	48612	48084	25250	25250	23362	22834
	Chitosan at 1%	49920	50886	30050	30050	19870	20836
	Chitosan nanoparticles at 0.5	57612	57024	25450	25450	32162	31574
	Chitosan nanoparticles at 1%	59322	58638	30250	30250	29072	28388

Tomato fruit price was 3,000 LE/ton

Solid yields of tomato fruit in the pest treatments were (19.774and 19.546 ton./fed.) and tomato fruit in the control treatment were (8.928and 8.664 ton/fed.) in 2013 and 2014 seasons, respectively.