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RESEARCH ARTICLE

Chitosans of different molecular weight enhance potato (*Solanum tuberosum* L.) yield in a field trial

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Abstract

Physico-chemical features of chitosan affect its biological activity on plants. In this work, the influence of chitosan molecular mass in potato (*Solanum tuberosum* L.) yields was investigated. By using chitosan polymers of high (CH-1) and low (CH-2) molecular weight and a hydrolysed chitosan derivative (CHH), two experiments were performed under field conditions to determine the effect of these polymers on yields of two potato varieties, 'Call White' and 'Santana'. For this purpose, the foliar spray of low doses of the derivatives at three cultivation moments was performed and several yield variables were determined at crop harvest. All three chitosan compounds increased the performance variables determined respect to the control, depending on the variable, the dose employed and the mass of the derivative evaluated. In most variables determined, the two lowest doses (200 and 325 mg/ha) provoked the highest increments above control. Chitosans also affected distribution of mass per tuber size, particularly; in 'Santana' variety the two lowest doses enhanced the commercial tuber sizes. Among the polymers, CH-1 caused the greatest increases in performance, while, compared to the polymer, CHH provoked higher yields. In conclusion, foliar application at low doses of high molecular weight and hydrolysed chitosan enhanced potato yield between 15-30%.

Additional key words: polymer; oligo-chitosan; plant production; tubers.

Abbreviations used: DAP (days after planting); FW (fresh weight); MW (molecular weight).

Authors' contributions: Conceived and designed the experiments, performed the experiments: ABFR, DC and DGP. Acquisition, analysis, statistical analysis and interpretation of data: ABFR, DC, DGP, DM, YM and EJ. Contributed reagents/materials/analysis tools: ABFR, DM, YM and EJ. Drafting of the manuscript: ABFR and JCC. Critical revision of the manuscript for important intellectual content: JCC. Obtained funding; administrative, technical, or material support: ABFR. Supervised the work: DM and EJ. Coordinated the research project: ABFR.

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Introduction

Potato (*Solanum tuberosum* L.) is the main tubercle cultivated worldwide and its production since 2011 has reached more than 370 millions of tons annually (FAOSTAT: http://www.fao.org/faostat/en/). In Cuba, under tropical conditions, this tubercle is cultivated at sea level in about 5000-10000 ha with a yield of 20-30 t/ha·year (FAOSTAT), depending on the variety and climatic conditions. Because of this low yield compared to other world places of potato cultivation, different approaches are necessary in order to increase potato yields. Recently, we demonstrated increments in potato yields at field trials when low doses of a chitosan polymer were applied to plants by foliar spray (Morales *et al*., 2015).

Chitosan is a linear polymer consisting of glucosamine residues linked by β(1-4) amino groups which may be partially acetylated. The main source of chitosan is the chitin, which is extracted from the crustaceans' exoskeleton. Both polymers, but fundamentally the chitosan, have broad applications in various fields such as industry, medicine, cosmetics, environmental protection and agriculture, so that annually global production of these polymers is of thousands of tons (Badawy & Rabea, 2011; Deepmala *et al*., 2014).

In agriculture, chitosan and its derivatives of lower molecular weight (MW), may have broad application from biological potentialities that have been demonstrated to these compounds, such as a significant antimicrobial activity on growth and development of fungi, bacteria and oomycetes (Palma-Guerrero *et al*., 2008; Badawy & Rabea, 2011; Falcón-Rodríguez *et al*., 2012), inducing resistance in plants against potential pathogens and promoting growth and development of various crops (Ramos-García *et al*., 2009; Falcón-Rodríguez *et al*., 2012; Cabrera *et al*., 2013).

According to several reports from literature, the physico–chemical features of chitosan derivatives such as MW and degree of acetylation, affect some of their biological activities, *e.g.* pathogen inhibition (Xu *et al*., 2007; Hernández-Lauzardo *et al*., 2008; Badawy & Rabea, 2011; Falcón-Rodríguez *et al*., 2012) and eliciting plant defence responses (Cabrera *et al*., 2006; Trotel-Aziz *et al*., 2006; Falcón-Rodríguez *et al*., 2011). However, there are not reports regarding the influence of MW on plant growth and yield enhancing under field conditions.

Consequently, the aim of this work was to investigate the behaviour of yield variables on potato plants after applying chitosan derivatives of different MW by foliar spray.

Material and methods

Plant material and chitosan compounds

Potato tubers of about 45 mm of size from two varieties, 'Call White' and 'Santana', were provided by Brunswick producers association (Canada) to be used as vegetative seeds for the experiment.

Chitosan polymers of different MW in acidic solutions were tested according to each experiment. In the 'Santana' variety experiment, polymers of high (CH-1) and low (CH-2) molecular weight, obtained with basic desacetylation from chitin, were tested. In the experiment with 'Call White', the derivatives tested were CH-1 and a hydrolysed (CHH) from this polymer, prepared by an enzymatic hydrolysis with papain. Main characteristics of chitosan derivatives are shown in Table 1.

Experimental procedure

Field trials were conducted at the Field Department (22.892 latitude, -81.953 longitude, and 120 m altitude) of the National Institute of Agricultural Sciences, Mayabeque, Cuba. The experimental soil is Udic Rhodustalf with pH=6.7, organic material=1.2%, carbon content=0.70%, available P=436 ppm and K=0.23 $cmol_c$/kg (Hernández *et al*., 2014).

Table 1. Features of chitosan derivatives used on biological experiments

Chitosan derivatives	Molar mass [a]	Degree of acetylation[b]
CH-1	124 kDa	13.7 %
CH-2	66.4 kDa	15.2 %
CHH	13.2 kDa	Not determined

[a]Average of molar mass determined by viscosimetry (Parada *et al*., 2004). [b]Degree of acetylation determined by infrared spectroscopy (Roberts, 1992).

Potato tubers were planted in the first half of January of the seasons 2011/12, 2012/13 and 2013/14, and experiments were harvested in the first half of April. Tubers emerged around 10 days after planting (DAP). Climatic variables averaged day/night temperature 28.0/16.7^{o}C and relative humidity 87.9/49.1% respectively, while daily average rainfall was 2.0 mm.

Exogenous chitosan derivatives (CH-1, CH-2, and CHH) of different MWs were applied by foliar spray, depending of every potato variety, at 31, 45 and 59 DAP using the following doses: 200, 325 and 558 mg/ha, respectively. At harvest (97 DAP), all tubers from every plant sample were quantified by number and fresh weight (FW) per tuber size by plant and total for every treatment. In addition, yield per treatment was estimated starting from tubers FW.

A random blocks design was employed in the experiment with three replicates per treatment. Blocks had 4 lines of 5 m each with a plantation distance of 0.9 × 0.25 m (44,444 plants/ha). To evaluate the variables, 20 plants per replicate were randomly collected from the two lines inside each block. Data from each experiment were analysed by a bifactorial ANOVA (factors: chitosan derivative and doses, 2×3) with a reference control (dose 0). According to factors interaction, the resulting means were compared through the Duncan´s multiple range test for $p \leq 0.05$, using the SPSS program, vers. 19. Experiments were repeated in the same season of three different years with similar behaviour of treatments. Because of this, tables in the manuscript show processed results of only one season experiments (2012).

Irrigation in the three crop cycles studied was performed by the spray technique using machine central pivot. Regular phytosanitary and cultural attentions were applied to the experiments according to the Cuban technical norms for potato (Deroncelé *et al*., 2000).

Table 2. Tuber number per plant in the 'Santana' potato variety according to tuber size, after application of two chitosan polymers (CH-1, CH-2).

Polymers	Tuber size (mm)				
	< 28	28-35	35-45	45-55	> 55
			Treatments means from bifactorial analysis		
CH-1 558 mg/ha	0.27 bc	0.1 b	0.8	1.7	1.23 b
CH-1 325 mg/ha	0.4 ab	0.23 ab	1.4	1.4	1.24 b
CH-1 200 mg/ha	0.4 ab	0.4 a	1.13	1.7	1.73 a
CH-2 558 mg/ha	0.2 c	0.23 ab	1.47	1.63	1.47 ab
CH-2 325 mg/ha	0.17 c	0.17 b	0.93	1.6	1.47 ab
CH-2 200 mg/ha	0.57 a	0.1 b	1.30	1.57	1.53 ab
Factorial SE	0.058	0.058	0.22 NS	0.12 NS	0.14
			Chitosan derivative effect		
CH-1	---	---	0.96 b	1.67	---
CH-2	---	---	1.39 a	1.53	---
Derivative SE	---	---	0.12	0.065 NS	---
			Dose effect		
558 mg/ha	---	---	1.12	1.68	---
325 mg/ha	---	---	1.25	1.55	---
200 mg/ha	---	---	1.15	1.57	---
Dose SE	---	---	0.015 NS	0.08 NS	---
			Control intervals= X ± (SE × 1.96)		
Reference control	0.29± 0.11	0.24± 0.11	1.17± 0.43	1.2± 0.23	1.06± 0.27

Different letters among treatments indicate significant differences in the test of multiple rank of Duncan for $p \leq 0.05$. NS: not significant. SE: standard error

Results

Chitosan derivatives applied by foliar spray caused changes in the yield variables determined on both potato varieties of this experiment. In most of the variables tested, interaction among factors was found in the bifactorial ANOVA applied for these cases. The resulting treatment means from the interaction among factors are shown in the tables.

Chitosan polymers of high (CH-1) and low (CH-2) MW were compared on 'Santana' variety. In the number of tubers, interaction between factors were found for the highest and the two lowest tuber sizes while no factors interaction was found for 35-45 and 45-55 sizes (Table 2). In these two last cases, when analysing the effect of chitosan factor, significant influence of CH-2 respect to CH-1 was detected just in the size of 35-45 to enhance the number of tubercles in plants. For both sizes no influence of doses was detected.

The two lowest tuber sizes were no affected by foliar spray of both chitosans when compared to the reference control, except for the lowest dose of CH-2. Conversely, for the highest size (> 55 mm), the lowest dose of CH-1 and all doses for CH-2 augmented the number of tubers above control.

Both chitosan derivatives tested (CH-1 and CH-2) caused changes in the tuber mass respect to control, depending on the tuber size (Table 3). There was interaction between chitosan and dose factors for all sizes evaluated, except for the size of 45-55. When analysing separately the contribution of every factor, no significant influence was found for any factor.

Generally speaking, for the two lowest tuber sizes, there were no increments in tuber mass in chitosan treatments compared to control; rather, the mass decreased in the size of 28-35 mm, in particular, with significant differences for CH-1 at the three doses tested and for CH-2 in the lowest one.

In the size of 35-45 mm, the highest dose of CH-1 decreased tuber mass respect to the control, while just the lowest dose of CH-2 significantly enhanced the mass of the tubers in about 9%. The following commercial size (45-55 mm) was not influenced by treatments. In addition, the separate influence of chitosans and doses in this size was not significant (Table 3).

In the greatest commercial size (>55 mm) the mass of the tubers augmented significantly with all chitosan treatments tested (Table 3). The highest increments were achieved with the two lowest doses of CH-1 and the lowest dose of CH-2, without significant differences

Table 3. Tuber mass (g) per plant, according to tuber sizes (mm), in the 'Santana' potato variety, when two chitosan polymers (CH-1, CH-2) were applied

Polymers	Tuber size (mm)				
	< 28	**28-35**	**35-45**	**45-55**	**> 55**
	Treatments means from bifactorial analysis				
CH-1 558 mg/ha	2.33 b	1.25 c	60.93 b	284.59	347.86 b
CH-1 325 mg/ha	2.17 b	2.67 bc	125.48 a	261.79	468.33 ab
CH-1 200 mg/ha	0.93 b	3.83 bc	113.33 ab	289.07	498.13 a
CH-2 558 mg/ha	1.83 b	6.22 ab	96.05 ab	276.44	410 ab
CH-2 325 mg/ha	1.67 b	7.78 a	88.33 ab	260	403.33 ab
CH-2 200 mg/ha	7.67 a	0.50 c	145.53 a	268.43	431.67 ab
Factorial SE	0.63*	1.18 *	17.25 *	15.41 NS	39.83*
	Chitosan derivative effect				
CH-1	---	---	---	276.6	---
CH-2	---	---	---	266.75	---
Derivative SE	---	---	---	11.46 NS	---
	Dose effect				
558 mg/ha	---	---	---	275.42	---
325 mg/ha	---	---	---	274.3	---
200 mg/ha	---	---	---	270.74	---
Dose SE	---	---	---	11.46 NS	---
	Control intervals= X ± (SE × 1.96)				
Reference control	4.88± 1.23	7.8± 2.31	99.9± 33.81	177.6± 30.2	263.8± 78.06

Different letters among treatments indicate significant differences in the test of multiple rank of Duncan for $p \leq 0.05$. NS: not significant. SE: standard error

between them. Mass increments, in this case, were between 1.6 and 1.9 fold higher than the control, which did not receive any treatment.

Generally speaking, low number of tubers was obtained in this variety (Table 4). However, beyond the non-differences at tuber size level, in the total number of tubers per treatment there were significant differences respect to control. The results show that the lowest dose (200 mg/ha) applied with both chitosan polymers, enhanced this variable respect to control with an increment of about 29% and 20% for CH-1 and CH-2, respectively. In addition, the highest dose of CH-2 enhanced the tuber number in 19% respect to control.

When analysing the effect of the polymers on the total mass per plant, increments above the control were obtained with the two lowest doses of both polymers, particularly; the highest increase was obtained with CH-1 at 200 and 325 mg/ha with a magnification of more than 1.30 fold relative to the control (Table 4), while the lowest dose of CH-2 provoked a significant increment of about 1.18 fold compared to control.

The yield per hectare for each treatment was estimated from the fresh mass of tubers, in accordance with the spacing of plants used in the design. In the 'Santana' variety, the bifactorial analysis for treatments was not significant. When analysing individual effects of factors (chitosan derivative and dose), no significant influences were found (Table 4). The two lowest doses of CH-1 and the intermediate dose of CH-2 caused significant increments of yield above control, between 17 and 32%.

In the experiment in 'Call White' variety, foliar application of CH-1 and CHH caused changes in the number of tubers per plant, depending on the type of chitosan, the dose employed and tuber size analysed (Table 5). In all sizes tested, interaction between factors was found.

In the smallest size, tuber number was significant enhanced respect to control for the three doses of both derivatives. However, in the second lowest size (28-35 mm), all chitosan treatments except the lowest dose of CHH decreased tuber number respect to control. In commercial tuber sizes, increments respects to control were detected for tubers higher than 55 mm for the polymer at the intermediate dose and the hydrolysed chitosan with the two highest doses; however, in the size of 45-55 mm, most of the chitosan treatments significantly augmented the tuber number (Table 5). The highest increments were achieved by the lowest doses of both derivatives tested with 1.6 to 1.8 fold augmentation. In addition, all chitosan treatments in the intermediate size enhanced tuber number respect to control. Both derivatives (CH-1, CHH) with the

Table 4. Total number and mass (g) of tubers per plant and estimated yield (t/ha) by treatment with CH-1 and CH-2 in the ‘Santana’ variety.

Treatments	Tubers per plant		Estimated yield(t/ha)
	Total number	Total mass	
	Treatments means from bifactorial analysis		
CH-1 558 mg/ha	2.03 b	719.7 b	31.98
CH-1 325 mg/ha	2.28 ab	894.3 a	36.70
CH-1 200 mg/ha	2.68 a	900.67 a	40.03
CH-2 558 mg/ha	2.47 a	772.17 ab	34.32
CH-2 325 mg/ha	2.3 ab	797.33 ab	35.43
CH-2 200 mg/ha	2.5 a	803.33 ab	33.96
Factorial SE	0.13	47.56	2.46 NS
	Chitosan derivative effect		
CH-1	---	---	36.24
CH-2	---	---	34.57
Derivative SE	---	---	1.49 NS
	Dose effect		
558 mg/ha	---	---	33.15
325 mg/ha	---	---	36.07
200 mg/ha	---	---	36.99
Dose SE	---	---	1.77 NS
	Control intervals= X ± (SE × 1.96)		
Reference control	2.07± 0.25	679.7± 93.22	30.21± 4.82

Different letters among treatments indicate significant differences in the test of multiple rank of Duncan for $p \leq 0.05$. NS: not significant. SE: standard error

Table 5. Tuber number per plant, according to tuber sizes (mm), in the ‘Call White’ potato variety, treated with two chitosan derivatives (CH-1, CHH).

Treatments	Tuber size (mm)				
	< 28	28-35	35-45	45-55	> 55
	Treatments means from bifactorial analysis				
CH-1 558 mg/ha	1.03 a	0.3 bc	1.52 b	1.70 a	1.2 b
CH-1 325 mg/ha	0.73 ab	0.6 b	2.23 a	1.83 a	2.06 a
CH-1 200 mg/ha	0.6 b	0.43 bc	1.53 b	1.83 a	1.73 a
CHH 558 mg/ha	0.93 ab	0.37 bc	1.63 b	1.67 a	2.1 a
CHH 325 mg/ha	0.67 ab	0.22 c	1.77 b	0.94 c	2.23 a
CHH 200 mg/ha	0.93 ab	0.7 ab	1.63 b	2.07 a	1.83 a
Factorial SE	0.12	0.11	0.14	0.136	0.17
	Control intervals= X ± (SE × 1.96)				
Reference control	0.25± 0.23	0.83± 0.21	1.23± 0.27	1.15± 0.27	1.68± 0.33

Different letters among treatments indicate significant differences in the test of multiple rank of Duncan for $p \leq 0.05$. SE: standard error

intermediate dose, reached 1.8 and 1.44 fold increments, respectively.

The effect of the polymer and the hydrolysed chitosan on the total mass per plant caused significant differences in all the five tuber sizes (Table 6). Increments above the control were found with, at least, one chitosan treatment in every size, except for the 28-35 mm, where several treatments reduced the mass respect to control. In the commercial sizes, the intermediate dose of the polymer and the three doses of the hydrolysed chitosan enhanced tuber mass in the size 35-45. In the size 45-55 all chitosan treatments, except CHH at 325 mg/ha, caused increments above control between 38 and 75%. In the highest size, just the chitosan polymer at 325 mg/ha and the hydrolysed chitosan at 558 mg/ha significantly enhanced tuber mass by 18 and 24% respectively, above control.

Table 6. Tuber mass (g) per plant, according to tuber sizes, in the 'Call White' potato variety, when applied with two chitosan derivatives (CH-1, CHH).

Treatments	Tuber size (mm)				
	< 28	**28-35**	**35-45**	**45-55**	**> 55**
	Treatments means from bifactorial analysis				
CH-1 558 mg/ha	3.33 b	5.5 bc	92.33 c	231.67 a	278.33 c
CH-1 325 mg/ha	6.67 ab	10.67 abc	147.67 a	225 a	533.83 ab
CH-1 200 mg/ha	4.67 ab	13.61 ab	92.50 c	230 a	433.33 ab
CHH 558 mg/ha	8.33 ab	4.67 bc	103.33 bc	216.67 a	561.67 a
CHH 325 mg/ha	5.67 ab	2.67 c	125.67 ab	123.33 c	505 ab
CHH 200 mg/ha	8.67 a	16.67 a	110 bc	275 a	470 ab
Factorial SE	1.54	2.79	9.05	23.86	40.56
	Control intervals= X ± (SE × 1.96)				
Reference control	1.5± 3.02	14.23± 5.47	77.64± 17.74	156.5± 46.77	452.85± 79.5

Different letters among treatments indicate significant differences in the test of multiple rank of Duncan for $p \leq 0.05$. SE: standard error

When analysing the effect of chitosan derivatives on the total number of tubers per plant (Table 7), significant increments above the control were obtained just with the lowest doses of CHH, which caused about 15% increment respect to control.

Both chitosan derivatives affected the tuber mass compared to control, depending on the doses applied (Table 7). CH-1 did not enhance tuber mass above control, while the highest and the lowest doses of CHH augmented significantly this variable by 13-16%.

In the estimated yield from 'Call White' experiment there was interaction between factors in bifactorial analysis (Table 7). Compared to control CH-1 did not enhance the yield while the CHH at the highest and lowest dose augmented yield above control by 22 and 19%, respectively.

Discussion

In the last two decades it has been widely reported the potential of chitosan macromolecules in their antimicrobial action, the induction of resistance in plants against pathogens, promoting crops growth and development, and protection against various abiotic stresses (Badawy & Rabea, 2011; Falcón *et al*., 2012; Deepmala *et al*., 2014). This paper presents the first published results related to the promotion of yields in the potato crop in field experiments by applying different chitosan derivatives.

Experimental results showed that all chitosans tested, independently of MW, enhanced some yield variable, depending on the dose tested. Generally, in most variables determined, the two lowest doses, but specially 200 mg/ha, provoked the highest increments above control. For instance, this was clearly appreciated in tuber number, mass per plant (mainly for tuber size higher than 55 mm) and yield estimation for the 'Santana' variety, where the two chitosan polymers were compared. This result agrees with a previous research of chitosan (CH-2) dose responses on 'Spunta' variety, where the best increments on yield were found at doses between 150 and 300 mg/ha (Morales *et al*., 2015).

Chitosans also affected distribution of mass tubers per tuber size. Particularly, in 'Santana' variety the two lowest doses, on both polymers tested, significantly enhanced the tuber mass between 1.6 and 1.9 fold above control level for the highest commercial size. This is a very important result from a practical point of view.

Concerning the influence of MW, when the two polymers were compared ('Santana' experiment), chitosan of high MW (CH-1) provoked the highest increments respect to the low MW polymer (CH-2), for instance, for tuber mass and estimated yield. However, in the experiment with 'Call White', better increments were achieved with the hydrolysed chitosan than with the polymer for the three variables tested, particularly for the commercial size of 35 to 45 and 45 to 55 mm. The aforementioned means that MW can affect yield promotion even when applying low doses of chitosan derivatives. From our results, high MW chitosan (CH-1) and oligochitosans (CHH) enhanced better yield above control. However, results are influenced by differences on variety responses. In order to clearly elucidate chitosan MW influence, further investigations are needed by comparing all chitosan derivatives in the same biological material.

Influence of chitosan MW on biological activities has been extensively investigated in literature. It seems that this influence depends on the kind of biological activity, the type of organism and even the part of the organism (Cho *et al*., 2008; Badawy & Rabea, 2011; Falcón *et al*.,

Table 7. Total number and mass (g) of tuber per plant and estimated yield (t/ha) by treatment with CH-1 and CHH in the 'Call White' variety.

Treatments	**Tubers per plant**		**Estimated yield (t/ha)**
	Total number	**Total mass**	
	Treatments means from bifactorial analysis		
CH-1 558 mg/ha	3.03 b	627.17 b	28.87 b
CH-1 325 mg/ha	3.16 b	749.23 ab	35.47 ab
CH-1 200 mg/ha	3.06 b	785.67 a	34.92 ab
CHH 558 mg/ha	3.16 b	905.33 a	40.23 a
CHH 325 mg/ha	3.10 b	835.00 a	37.11 a
CHH 200 mg/ha	3.51 a	880.67 a	39.14 a
Factorial SE	0.095	47.7	2.4
	Control intervals= X ± (SE × 1.96)		
Reference control	3.05± 0.186	781.5± 93.49	32.95± 4.7

Different letters among treatments indicate significant differences in the test of multiple rank of Duncan for $p \leq 0.05$. SE: standard error

2011). The effect of chitosan MW on growth and yield promotion has been less reported and mainly focused in the first stage of plant growth (Cho *et al.*, 2008).

The plant response to the application of chitosan polymer of higher mass (CH-1) was different, according to the variety used, for the distribution of the tuber mass per size and for enhancing yield; while in 'Santana' the lowest doses caused yield increments of 21 and 32%, no increments above control were detected for 'Call White' variety.

The mechanism through which the chitosan causes the increase in potato yields is not known. Previous works reported actions of chitosan as fertilizer, taking into account the amino groups of the polymer or antitranspirant effect through promoting stomata closure and activation of other physiological processes (Chibu *et al.*, 2002; Ohta *et al.*, 2004; Iriti *et al.*, 2009). However, in the above cases, the dose used is much higher than that used in the present work and could justify such actions. So far, we know of no studies where, such low doses, that might be more related to hormonal or growth regulator actions, have been investigated. Future research should be directed to elucidate the mode of action of this polymer applied at so low doses.

However, in our previous work (Morales *et al.*, 2015), low doses of chitosan applied at 30 and 50 days after tuber plantation, caused increments in the number of leaves by plant at the 70 days. From a greater leaf area on the plant it can be inferred a higher photosynthetic activity that may lead to an increase at tuber yield level in the plant. In addition, previous works of chitosan application in other species have also reported an increase in the level of photosynthetic pigments and photosynthesis in general (Dzung, 2011).

In conclusion, foliar application at low doses (200-325 mg/ha) of high molecular weight and hydrolysed chitosan enhanced potato yield. Therefore, foliar application of chitosan may be recommended for potato producers to augment about 15-30% yields.

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