Soluble chitosan applied as potato seed tuber treatment and foliar sprays under subtropical and temperate conditions - effect on yield parameters and disease incidence

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Abstract

Field plot trials were conducted with soluble chitosan in subtropical conditions (Remedios, Central Cuba) and temperate conditions (Rostock, Northern Germany, Baltic coast) in the years 2003 – 2005. Chitosan was applied as seed tuber treatment, foliar spray and combination of seed tuber and foliar treatment. In Remedios infection with early blight (*Alternaria solani*) was assessed, in Rostock infection with late blight (*Phytophthora infestans*).Under subtropical conditions chitosan application improved yield parameters compared to the untreated control and also to fungicide treatments, even where early blight incidence was not reduced. In temperate conditions chitosan application could reduce late blight incidence compared to the untreated control, depending on concentration and application mode. The combination of seed tuber treatment and foliar application had the most stable effects over the three trial years. Seed treatment and foliar treatment alone were less reliable in their effects on disease incidence. Decreased late blight scores did not result in significantly improved tuber yields, which were comparable to the untreated control.

Keywords: chitosan, plant growth promoter, elicitor, potato, late blight, early blight.

Introduction

Soluble chitosan is a natural product from the chitin of crab shells of polymeric structure, made water soluble by alkaline or enzymatic deacetylisation. Chitosan has been shown to trigger physiological mechanisms in plants, which are considered to be connected with disease resistance (Roby *et al.* 1987, Hadwinger *et al.* 1994, Tiuterev 1996, Kauss 1997, Hadwiger 1999, Stange & McDonald 1999, O'Herlihy et al. 2003). After artificial inoculation with *Pytophthora infestans* zoospores the progress of late blight symptoms was significantly slowed in chitosan-treated plants (Kowalski et al. 2005). Chitinase activity elicited by chitosan is considered similar to that triggered by fungal infection (Chen *et al.* 1999 ct. in O'Herlihy *et al.* 2003). Foliar chitosan application in greenhouse plants of potato significantly decreased water loss after cutting (Kowalski et al. 2006b) and significantly decreased intercellular peroxidase activity as a marker for oxidative stress, while the content of phenolic substances and proteins remained (Kowalski et al. 2005).

Positive Effects of chitosan treatments yield and plant health have been described for tomato (Benhamou & Theriault 1992, Benhamou *et al.* 1994) cucumber (El Ghaouth 1994), wheat (Vander 1998), potato (Kowalski *et al.* 2006a, Kowalski *et al.* 2006b) and discussed as an alternative to conventional chemical plant protection (Godenrath 2000).

However, practical application of chitosan in agriculture is still very much at the beginning. The higher dependency of plant growth promoting and elicitor effects on environmental conditions such as climatic influences (Schliephake und Trautz 2001), infection pressure, and application mode may be the cause for varied performance in dependence of trial site and year under field conditions.

This paper describes the effect of soluble chitosan on potato analysing parameters of plant grow and yield of potato and incidence of late blight (*Phytophthora infestans*), early blight (*Alternaria solani*) and tuber diseases in field trials under subtropical and temperate conditions.

Materials and methods

The chitosan used throughout the trials was a soluble powder preparation (ChitoPlant, ChiPro GmbH Bremen, chitosan content 99,9 %).

Field trials under subtropical conditions. See table 1. In all field trials minitubers of cv Désirèe derived from virusfree microplants acclimatised in the greenhouse were used. Minitubers were planted in randomised plots with three replicates per treatment in the field in December on a ferralitic soil under irrigation (every third day) with 120 kg ha^{-1} N. Plot size was 10 m^2, with 25 x 90 cm spacing; sample size was 15 plants per replicate. Size of the minitubers planted was calibrated to between 21 and 30 mm diameter; treatments to break dormancy were not necessary, as minitubers sprouted within three days after coming out of cold storage. The trial site was the experimental station of Remedios, province Villa Clara (central Cuba), 22° 29' 41N / 79° 32' 45W situated 26 m above sea level; in the potato growing season December – March the average maximum temperatures are 27°C, minimum temperatures 20°C, relative humidity 80 %, with an average of 8 hours sunshine per day.

Table 1. Seed tuber and weekly foliar treatment with soluble chitosan in the field plot trial in Remedios, Villa Clara Province, Central Cuba

Soluble chitosan treatment				
Seed tuber	Foliar	Trial year 2001/02	2002/03	2003/04
0	0	cv Désirèe	cv Désirèe	cv Désirèe
0	1,0 g l^{-1}	cv Désirèe	cv Désirèe	cv Désirèe
1.0 g l^{-1}	0	cv Désirèe	cv Désirèe	cv Désirèe
1.0 g l^{-1}	1,0 g l^{-1}	cv Désirèe	cv Désirèe	cv Désirèe

Weekly foliar sprays with soluble Chitosan commenced two weeks after emergence and were continued until day 60 after planting. Untreated plants and plants treated chemically (Fungicide regime following instructions of Sanidad Vegetal Nacional: copper oxicloride 2nd week after emergence, 3rd and 10th week Maneb, 4th week Zineb, 5th week Macozeb, 6th and 11th week Ridomil MZ, 7th week Tilt CE 25, 8th week benomyle (Fundazole), 9th week Silvacur combi) served as control.

Incidence of early blight (*Alternaria* spp.) was assessed 60 days after planting. Tubers were harvested 80 days after planting, 10 plants per repetition, counted, weighed and evaluated for tuber diseases common scab (*Streptomyces scabies, Fusarium spp*., *Rizoctonia solani*, *Sclerotium rolfsi*, *Phoma spp*.), counting the numbers of tubers affected.

Evaluation of plant growth under subtropical conditions. Parameters of field growth (fresh weight, dry weight, shoot length and water loss 1 hour after cutting the stems) were recorded 45 days after planting.

A ranking system was used as described by Kowalski et al. (1999a) with the following modifications*:* The treatment with the significantly highest fresh and dry weight and shoot length respectively was ranked 1, the next lower 2 and so on. The treatment with the lowest water loss were ranked 1, the next higher 2 and so on.

Dry matter contents (DM %) of the control and those treatments not significantly differing from the control were assigned rank 2; treatments with lower DM % received rank 3, with higher DM % rank 1.

The sum of all ranks allocated to the treatment (Sum of ranks) was calculated, the lowest Sum of ranks representing highest plant quality.

Field trials under temperate conditions. See Table 2. In all field trials certified seed tubers of cv Adretta were planted in randomised plots with four replicates per treatment in the at the end of April on a sandy loam with 80 kg ha^{-1} N. Plot size was 10 m^2, with 30 x 75 cm spacing; sample size was 20 plants per replicate for evaluation of late blight. Size of the minitubers planted was calibrated to between 35 and 55 mm diameter. The trial site was the experimental station of Rostock university, 53°55'5"N / 12°16'41"E situated 0 m above sea level; in the potato growing season Mai– August the average maximum temperatures are 20.0 °C, minimum temperatures

11.2°C, relative humidity 81 %, with an average of 8.2 hours sunshine per day. In 2005 cv Alegria and cv Meridian were also planted.

Weekly foliar sprays with soluble Chitosan commenced three weeks after emergence and were continued until 50 % of the foliage was affected by late blight. Untreated plants and plants treated chemically (Akrobat, Shirlan) served as control.

Incidence of late blight was assessed at three successive evaluation dates in July, estimating percentage of leaf area affected using an evaluation key adapted from James, 1971.

Tubers were harvested 80 days after planting, 10 plants per repetition, counted, weighed and evaluated for common scab. Common scab was evaluated with a six scale key of lesion depth and diameter (0 = no scab, 1 = scab not raised, diameter < 10 mm, 2 = scab not raised, diameter >10 mm, 3 = scab raised, diameter < 10 mm, 4 = scab raised, diameter >10 mm, 5 - pithy scab). Each evaluation score was multiplied with the corresponding number of tubers of the sample, and the valued summed.

Table 2: Seed tuber and weekly foliar treatment with soluble chitosan in the field plot trial in Rostock, Northern Germany

Soluble chitosan treatment				
Seed tuber	Foliar	Trial year		
		2003	2004	2005
0	0	cv Adretta	cv Adretta	cv Adretta, Alegria, Meridian
0	0.1 g l^{-1}	cv Adretta	cv Adretta	cv Adretta
0	1.0 g l^{-1}	-	cv Adretta	cv Adretta
0.1 g l^{-1}	0	cv Adretta	cv Adretta	cv Adretta
0.1 g l^{-1}	0.1 g l^{-1}	cv Adretta	cv Adretta	cv Adretta, Alegria, Meridian
1.0 g l^{-1}	0	cv Adretta	cv Adretta	cv Adretta
1.0 g l^{-1}	1.0 g l^{-1}	cv Adretta	cv Adretta	cv Adretta, Alegria, Meridian
5.0 g l^{-1}	0	cv Adretta	cv Adretta	cv Adretta
5.0 g l^{-1}	5.0 g l^{-1}	cv Adretta	cv Adretta	cv Adretta, Alegria, Meridian

Statistical Analysis. For statistical analysis the SPSS statistical package was used. Analysis of variance (oneway anova) was carried out, using the Tukey test at P<0.05 to compare means.

Factor analysis was carried out using Varimax Rotation.

Results

Subtropical conditions 2003 – 2005 (Table 3). All chitosan treatments of cv. Désirèe, including seed tuber treatment alone, showed improved plant development, as expressed by lower Sums of Ranks, compared to the untreated control, and also to the chemically treated control plants. Foliar fresh and dry weight were significantly increased; in the trial years 2004 and 2005 dry matter content was significantly increased and waterloss after cutting decreased significantly, also in comparison with chemical treatment. Of the chitosan treatments foliar treatment and combined foliar + seed tuber treatment had better plant development than seed tuber treatment alone.

Table 3. Effect of application of soluble chitosan to seed tuber and/or as foliar sprays under subtropical conditions on morphological and physiological parameters, tuber number and yield and disease incidence of potato *Solanum tuberosum* L. c.v. Désirèe (mean values followed by differing letters differ significantly at $P < 0.05$)

Field trial year/ parameters	Control		Fungicide		Chitosan treatment 1.0 g l-1					
					Seed tuber		Foliar		Seed + foliar	
2003										
Fresh weight g	96.7 a	4	119.25 b	3	133.1 bc	2	146.5 c	1	153.8 c	1
Dry weight g	16.5 a	3	18.5 a	3	18.5 a	3	20.4 ab	2	22.2 b	1
Stem length cm	27.0 a	3	28.5 ab	2	30.7 ab	2	35.0 b	1	33.0 b	1
Dry matter %	17.1 a	2	15.5 a	2	14.0 a	2	13.9 a	2	14.4 a	2
Waterloss %	8.7 a	1	7.4 a	1	7.4 a	1	6.6 a	1	4.7 a	1
Sum of ranks		13		11		10		7		6
Tuber number/ plant	3.2 a		4.7 b		3.9 ab		4.1 b		4.3 b	
Tuber yield g/plant	430.0 a		670.0 c		451.3 a		500.0 ab		530.0 b	
Alternaria leaf spot %	34.0 a		34.7 a		33.8 a		39.0 a		33.8 a	
Tuber disease % *	2.0 b		0.7 a		1.5 ab		1.5 ab		1.6 ab	
2004										
Fresh weight g	98.8 a	3	109.7 a	3	164.5 b	2	194.2 c	1	218.2 c	1
Dry weight g	22.0 a	3	26.6 a	3	42.3 b	2	77.1 c	1	84.9 c	1
Stem length cm	30.3 a	2	32.0 a	2	32.1 a	2	35.7 b	1	35.8 b	1
Dry matter %	22.3 a	2	24.3 ab	2	25.4 b	1	39.4 c	1	38.9 c	1
Waterloss %	11.5 b	2	10.6 b	2	10.7 b	2	7.3 a	1	4.9 a	1
Sum of ranks		12		12		9		5		5
Tuber number/ plant	3.9 a		5.4 b		5.9 c		7.0 d		7.3 d	
Tuber yield g/plant	409.8 a		422.0 b		439.0 b		583.0 c		575.2 c	
Alternaria leaf spot %	71.5 c		12.2 b		58.5 b		63.0 bc		60.2 b	
Tuber disease % *	0.6 a		0.2 a		1.3 a		2.5 a		1.8 a	
2005										
Fresh weight g	156.0 a	4	162.1 b	3	165.5 c	2	168.0 d	1	169.3 d	1
Dry weight g	48.8 a	5	54.05 b	4	55.2 bc	3	57.3 cd	2	57.8 d	1
Stem length cm	31.4 a	3	31.3 a	3	34.9 b	2	36.3 c	1	37.0 c	1
Dry matter %	31.3 a	2	33.4 bc	1	33.3 bc	1	34.1 c	1	34.1 c	1
Waterloss %	10.9 b	2	13.0 c	3	6.7 a	1	7.0 a	1	6.8 a	1
Sum of ranks		16		14		9		6		5
Tuber number/ plant	6.1 a		6.7 b		7.1 c		7.6 d		7.8 d	
Tuber yield g/plant	543.2 a		570.2 b		578.5 bc		588.0 cd		594.0 d	
Alternaria leaf spot %	47.8 c		39.5 a		44.5 bc		45.0 bc		42.2 ab	
Tuber disease % *	1.4 b		0.1 a		0.6 ab		0.6 ab		0.4 ab	

* *Fusarium spp., Sclerotium rolfsii, Rizoctonia solani, Phoma spp., Streptomyces scabies*

Tuber numbers were increased in all chitosan treatments compared to the untreated control, in 2004 and 2005 also compared to fungicide treatment. Tuber yields also were increased compared to the untreated control, for the foliar and combined seed tuber and foliar spray this was significant in all three trial years, for seed tuber treatment alone this was significant in 2004 and 2005.

Foliar treatment alone and combined seed tuber and foliar chitosan treatment showed the overall best plant growth and also the highest yields, compared to the untreated as well as fungicide treated plants.

Alternaria solani leafspots were reduced significantly in the seed tuber treatment in 2004 and the combined seed + foliar treatment 2004 and 2005 compared to the untreated control, but the effect of a chemical treatment was not achieved.

While in two trial years incidence of tuber disease (*Fusarium spp.*, *Rizoctonia solani*, *Sclerotium*, *Phoma spp*, *Streptomyces scabies*) was generally low, it was significantly lower in the chemical control, compared to the untreated control, while the chitosan treatments did not differ significantly from either.

Temperate conditions 2003 – 2005 (table 4). Combined seed tuber and foliar treatment with 1.0 und 5.0 g l^{-1} soluble chitosan led to significantly decreased late blight lesions in the trial years 2003 and 2005 in cv. Adretta; 2004 no differences between chitosan treatments and untreated control were apparent. Foliar treatment alone with 0.1 und 1.0 g l^{-1} decreased late blight incidence in the trial year 2005, but not in 2003 and 2004.

Table 4: Effect of application of soluble chitosan to seed tuber and/or as foliar sprays under temperate conditions on yield parameters and disease incidence of potato *Solanum tuberosum* L. c.v. Adretta

Field trial year/ parameters	Control	Fungicide	Chitosan treatment g l^{-1}							
			foliar		seed tuber			seed and foliar		
			0.1	1.0	0.1	1.0	5.0	0.1	1.0	5.0
2003										
Late blight 1	5.1 b	0.8 a	5.4 b	6.2 b	4.7 b	3.1 ab	3.5 ab	3.7 ab	1.5 ab	2.4 ab
Late blight 2	52.6 d	5.0 a	70.6 e	53.0 d	49.2 d	48.2 cd	47.8 cd	40.4 bcd	30.0 b	33.2 bc
Late blight 3	85.8 cd	10.0 a	90.1 d	88.8 d	87.9 cd	84.8 cd	84.2 cd	84.9 cd	77.5 bc	76.0 b
Late blight %	47.8 cd	5.3 a	55.4 d	49.3	47.3 cd	45.4 bc	45.2 bc	43.0 bc	36.3 b	37.2 b
Common scab	188.6 b	131.6 ab	121.0 a	111.0 a	187.5 b	156.2 ab	159.1 ab	121.7 a	124.7 a	134.9 ab
Tuber number/plant	9.2 a	10.2 a	9.6 a	8.8 a	9.4 a	8.6 a	9.1 a	9.7 a	9.4 a	9.7 a
Tuber yield g/plant	840.8 a	1000.0 b	847.1 a	859.6 a	813.9 a	839.4 a	820.0 a	835.9 a	835.5 a	892.0 a
2004										
Late blight 1	12.7 a	1.5 b	10.7 a	6.2 a	7.3 a	13.0 a	11.3 a	10.7 a	12.9 a	9.8 a
Late blight 2	57.3 a	9.0 b	61.3 a	52.2 a	54.1 a	59.0 a	60.6 a	55.8 a	55.5 a	53.8 a
Late blight 3	76.6 a	10.0 b	74.4 a	74.7 a	71.9 a	76.6 a	75.2 a	74.7 a	73.1 a	72.7 a
Late blight %	48.9 a	6.8 b	48.8 a	44.4 a	44.4 a	49.5 a	49.0 a	47.1 a	47.2 a	45.4 a
Common scab	170.2 a	132.0 a	149.0 a	157.1 a	128.2 a	120.2 a	138.5 a	139.4 a	144.9 a	150.1 a
Tuber number/plant	10.5 ab	11.5 ab	10.7 ab	11.9 b	11.4 b	11.7 b	9.5 a	10.9 ab	10.3 ab	11.1 ab
Tuber yield g/plant	721.9 a	953.5 b	745.3 a	760.9 a	764.1 a	774.7 a	707.0 a	797.8 a	765.8 a	842.5 ab
2005										
Late blight 1	18.3 d	1.6 a	9.9 bc	9.3 bc	14.3 cd	11.1 bcd	11.4 bcd	9.6 bc	5.0 b	6.8 bc
Late blight 2	39.0 d	10.0 a	22.0 bc	25.6 bcd	32.1 cd	31.8 cd	27.8 bcd	30.3 cd	16.6 b	14.7 ab
Late blight 3	56.0 e	10.0 a	45.1 cde	42.2 cd	54.2 de	53.3 de	45.8 cde	46.0 cde	37.5 bc	27.5 b
Late blight %	37.8 e	7.2 a	25.7 bcd	25.7 bcd	33.5 de	32.0 de	28.3 cde	28.6 cde	19.7 bc	16.3 b
Common scab	142.8 b	101.8 ab	133.0 ab	120.0 ab	80.1 ab	71.2 ab	63.5 a	94.2 ab	85.7 ab	114.5 ab
Tuber number/plant	11.5 a	12.0 a	10.8 a	11.1 a	10.9 a	10.9 a	10.6 a	10.8 a	10.5 a	10.2 a
Tuber yield g/plant	599.0 a	771.4 b	611.7 a	581.2 a	429.9 a	440.7 a	414.6 a	609.4 a	624.1 a	641.9 a

Common scab *Streptomyces scabies* symptoms were significantly decreased in the foliar and combined seed tuber + foliar treatments in the trial year 2003. In the following trial years tubers of all chitosan treatments had lower common scab scores than the untreated control, however the differences were not significant. Fungicide treatment also led to a decrease of common scab scores.

Tuberisation in chitosan treatments was the same as in the untreated controls; tuber yields in the combined seed tuber + foliar treatments were higher in all three trial years, however this was not significant.

Temperate conditions, three cultivars, trial year 2005 (table 5). During the season 2005 the varieties cv Alegria and Meridian were additionally trialled with the combined seed tuber + foliar treatment. Decreased late blight affection was found for only one assessment date in cv. Alegria with 5 g l^{-1}; the average late blight score was lower, but not significantly. For cv Meridian significantly decreased blight scores were assessed with 1 g l^{-1} und 5 g l^{-1} chitosan compared to the untreated control; these values remained significantly higher than the fungicide treatment. Seed tuber + foliar treatment of 0.1 g l^{-1} did not reduce late blight in Alegria and Meridian.

Table 5. Influence of combined seed tuber and foliar application of soluble chitosan on yield parameters and disease incidence in two *Solanum tuberosum* varieties (cv Alegria and Meridian) under temperate conditions in the trial year 2005

cv	Control	Fungicide	Chitosan-treatment g l^{-1} seed tuber + foliar		
			0.1	1.0	5.0
Alegria					
Late blight 1	6.2 ab	2.2 a	10.2 b	7.6 ab	4.8 ab
Late blight 2	20.3 b	3.0 a	24.0 b	20.2 b	15.1 ab
Late blight 3	37.1 c	8.0 a	36.4 c	38.8 c	24.7 b
Late blight %	21.2 b	4.4 a	23.5 b	22.2 b	14.9 b
Common scab	76. b	10.6 a	54.6 ab	73.6 ab	51.ab
Tuber number/plant	11.9 a	11.0 a	11.3 a	9.0 a	11.0 a
Tuber yield g/plant	636.6 abc	922.8 d	671.0 abc	554.4 ab	667.3 abc
Meridian					
Late blight 1	5.1 ab	2.7 a	6.2 b	2.6 a	2.9 a
Late blight 2	21.6 c	10.5 a	21.4 c	17.8 bc	14.9 ab
Late blight 3	39.1 d	9.6 a	33.6 cd	28.6 bc	20.7 b
Late blight %	21.9 c	7.6 a	20.4 c	16.3 b	12.8 b
Common scab	80.6 ab	129.8 b	53.0 a	59.8 a	71.5 ab
Tuber number/plant	15.3 a	14.9 a	16.7 a	14.9 a	16.8 a
Tuber yield g/plant	731.8 ab	914.5 c	761.7 ab	716.2 a	828.7 abc

Chitosan treatments did not significantly influence common scab scores of the harvested tubers compared to the untreated control. In the fungicide control of cv. Alegria the common scab score was significantly decreased compared to the untreated control, but not in comparison with the chitosan treatments. In cv Meridian the common scab score of the fungicide control was increased, this was significant compared to the chitosan treatments 0.1 g l^{-1} und 1 g l^{-1}.

Tuber numbers and yields of cv. Alegria and Meridian were not significantly influenced by the chitosan treatments; only in the fungicide treatments were yields higher compared to the untreated control.

Discussion

Under subtropical conditions chitosan treatment led to an increase in yield parameters compared to the untreated control, and in two trial years also compared to fungicide treatment. This effect cannot be due to the reduction of disease incidence as *Alternaria* leaf spot incidence was reduced only by the combined treatment in 2004 and 2005. While the fungicide treatment did not reliably reduce early blight incidence, it also had higher yields than the untreated control. Plant growth promoting substances, including chitosan, have been shown to influence stress responses, such as peroxidase production (Kowalski et al. 2005). Foliar and stem fresh mass were increased with resulting increase in assimilating biomass. Decreased water loss after cutting in chitosan treatments indicates a generally enhanced stress resistance against the effect of high temperatures and temporary drought periods. Fungicides can cause similar metabolic changes (Wu and von Tiedemann 2002), however the fungicide treatment did not improve the plant growth parameters analysed.

Weekly foliar treatment and combined seed tuber- and foliar chitosan application showed the highest increase in yield parameters and is the treatment of choice, as in all three years yield parameters lay somewhat higher than in foliar treatment alone, albeit not significantly so, and because it has been shown that seed treatment alone has already a positive effect (Fig. 1).

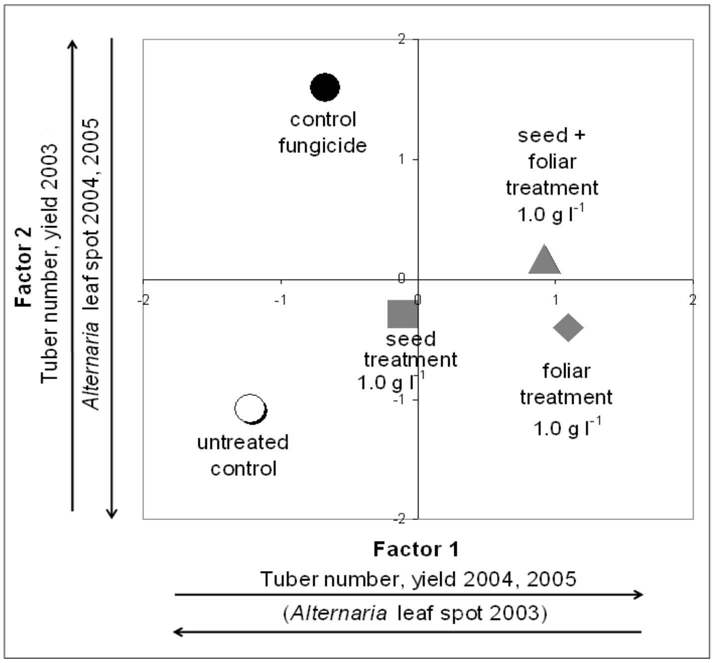

Figure 1. Factor analysis summarising three trial years (2003 - 2005). Yield parameters and early blight incidence in soluble chitosan treatments under subtropical conditions. Variation accounted for: 88,7 % (Factor 1 = 69,7 % Factor 2 = 19,0 %) .

The effect of chitosan under temperate conditions on yield and plant health depended on concentration and application mode (fig 2), and differed between cultivars (fig 3). Combined seed tuber and foliar treatment had the most reliable effect on plant foliar health considering all three trial years. However, slightly reduced late blight incidence did not result in a yield advantage under temperate conditions. Best control of late blight and highest yields were achieved with fungicides.

Multivariate (Factor) analysis over all trial years and with three varieties indicate that Chitosan may have slight effects on yield parameters also in temperate conditions; these mechanisms may be more strongly expressed under conditions of increased stress, as caused by the higher temperatures in subtropical regions.

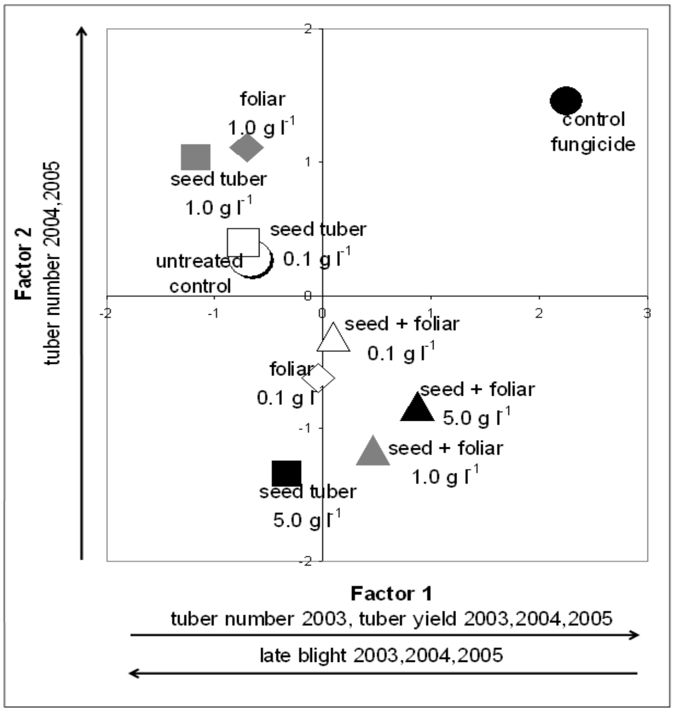

Figure 2. Factor analysis summarising results of the trial years 2003 – 2005 for yield parameters and late blight incidence under temperate conditions. Variation accounted for: 90,6 % (Factor 1 = 64,7 % Factor 2 = 14,2 % Factor 3 (common scab 2003) 11,8 %)

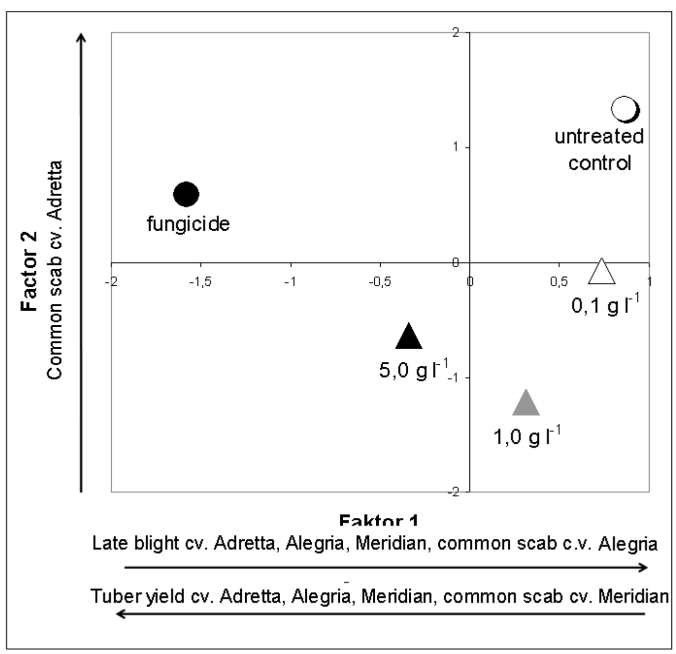

Figure 3. Factor analysis summarising results of three varieties in the trial year 2005 for yield parameters and disease incidence under temperate conditions. Variation accounted for: 93,3 % (Factor 1 = 62,5 % Factor 2 = 30,8 %)

Chitosan can be a useful additive to apply to potato as part of a strategy to reduce fungicide input, which also includes agronomic components and cultivars with improved horizontal resistances to major diseases, namely late and early blight (Darsow 2002 a,b, Darsow 2004). In such a strategy it is necessary to consider the interaction between plant growth promoting effects of chitosan and climatic conditions and varieties, and the dependency on the application mode (concentration, application to seed tuber and foliage). Good agricultural practice is the base for such a strategy involving chitosan or other substances with plant growth promoting and elicitor effects. The potential of chitosan to improve seed tuber quality (Kowalski *et al.* 2006b) can also contribute to the proposed composite strategy.

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