Glycoalkaloid contents in potato leaves and tubers as influenced by insecticide application

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ABSTRACT

The field experiment was carried out during 2004–2006. The aim of the study was to determine the influence of insecticides (Actara 25 WG – 0.08 kg/ha, Regent 200 SC – 0.1 L/ha, Calypso 480 SC – three rates: 0.05; 0.075; 0.1 L/ha), used for controlling Colorado potato beetle, on total glycoalkaloid (TGA) content in potato leaves and tubers of three cultivars (Mors, Wiking, Żagiel). The insecticides significantly increased (Calypso 480 SC) or decreased (Actara 80 WG, Regent 200 SC) the TGA content in potato leaves, and increased TGA in tubers as compared with tubers harvested from the control. Leaves and tubers of cultivar Mors had the highest TGA contents, whereas Żagiel leaves and Wiking tubers had the lowest levels.

Keywords: *Solanum tuberosum* L.; TGA; potato cultivars; plant protection chemicals

At present, potato (*Solanum tuberosum* L.) tubers are one of the main food components in most European countries and therefore hold a strong position amongst the world's food crops (Camire et al. 2009, Eremeev et al. 2009, Zarzecka 2009). In Poland, potato tubers are a basic component of the everyday diet and per capita potato consumption is 112 kg per year. In the EU countries the consumption ranges between 36–124 kg (Dzwonkowski et al. 2011). Also in the USA potato consumption is high and averages 63 kg per capita, and among 34 fruits and vegetables, potato is the third source of antioxidants (Chun et al. 2005).

Potato tubers are rich in high-quality protein, essential vitamins, minerals and trace elements (Karim et al. 1997, Camire et al. 2009). Nevertheless, *Solanum tuberosum* L. contains glycoalkaloids – natural toxic substances present in plants of the Solanaceae family. High total glycoalkaloid (TGA) levels are found in tissues with intensive metabolic processes – in fruit, leaves, stems, tubers, tuber eyes, jacket, sprouts and damaged tissues (Percival and Dixon 1996, Pęksa et al. 2002). Possibly, the main function of glycoalkaloids is to protect plants from bacterial and fungal diseases as well as from pests (Colorado potato beetle, wireworms) (Lachman et al. 2001, Didier et al. 2003, Miller et al. 2003). Potato cultivars with glycoalkaloid levels not exceeding 200 mg/kg fresh weight of tubers (including jacket) are generally recognised as safe for human consumption; however, the concentration above 100 mg/kg fresh weight affects the taste of tubers (Friedman et al. 1997, Karim et al. 1997, Mazurczyk and Lis 2000, Jansky 2010). The tubers of Polish potato cultivars contain between 12 and 159 mg/kg glycoalkaloids, German cultivars have values ranging between 20 and 220 mg/kg, American – 20 to 130 mg/kg and British – 36 to 142 mg/kg (Dale and Mackay 2007, Nowacki 2009). The total glycoalkaloid level in tubers is mainly influenced by genetic factors (Percival and Dixon 1996, Mazurczyk and Lis 2000, Trawczyński and Wierzbicka 2011), weather conditions of a given season (Hamouz et al. 2005, Zarzecka and Gugała 2007, Trawczyński and Wierzbicka 2011) and agrotechnological factors (Pęksa et al. 2002, Zarzecka and Gugała 2003, Żołnowski 2010, Wierzbicka 2011).

There is a paucity of research on the effect of insecticides on the chemical composition of potato. Hence, the aim of the present work was to determine glycoalkaloid contents in potato leaves and tubers following an application of systemic insecticides to control the Colorado potato beetle (*Leptinotarsa decemlineata* Say).

MATERIAL AND METHODS

The field experiment was carried out at the Agricultural Experimental Station of the Siedlce University of Natural Sciences and Humanities, Poland, in three replications during 2004–2006. The experiment was established on the soil originating from light clay sands, characterized by low to average available phosphorus content, low to high potassium content, high to very high magnesium content and pH 5.06–5.72. The experiment was set up in a randomized sub-block design including two factors: factor I – three potato cultivars: Wiking, Mors and Żagiel (Table 1), and factor II – six methods of Colorado potato beetle control including insecticides: (1) control treatment with no chemical control; (2) Actara 25 WG (thiametoksam) at the rate of 0.08 kg/ha; (3) Regent 200 SC (fipronil) 0.1 L/ha; (4) Calypso 480 SC (thiacloprid) 0.05 L/ha; (5) Calypso 480 SC (thiacloprid) 0.075 L/ha; (6) Calypso 480 SC (thiacloprid) 0.1 L/ha. In the time when the experiment was initiated, there was no recommendation regarding the rate of Calypso 480 SC, thus the amount of 0.05–0.1 L/ha was applied. At present, the recommended rate is 0.075–0.1 L/ha. The plot area was 15 m^2. Farmyard manure (25 t/ha) and mineral fertilization at the following rates: 100 kg N (ammonium nitrate 34%), 44.0 kg P (superphosphate 40%) and 124.5 kg K (potassium salt 60%) per hectare were applied on a regular basis. Potato tubers were planted manually in the third decade of April at a spacing of 0.675 × 0.37 m. Potatoes were harvested at the technological maturity stage in the first and second decades of September.

Climatic conditions varied over the growing periods of potato cultivation (Table 2). Samples of potato leaves (10 leaves from central part of a stalk) for chemical analyses were taken from each treatment at the flowering stage in July (after chemical treatments). Samples of potato tubers (50 tubers) were taken from each of the plots during harvest and stored at 10–12°C, for 8–10 days. Chemical analyses were performed using fresh material from 10 representative tubers in three replications. The glycoalkaloid contents in leaves and tubers were determined by the Bergers colorimetric method (Bergers 1980). Fresh potatoes were homogenized; then, 150 mL of ethanol were added to a 50 g sample and extraction in a water bath was performed at 90°C. Next, the filtered extract was evaporated at 60°C using a rotary evaporator to the volume of 5 mL. After addition of 50 mL of 10% acetic acid and centrifuging, the liquid part was poured into a flask, the sediment was poured to the supernatant (solution above the sediment) and 4 mL of ammonia were added (NH_3) to adjust to pH = 10. The flask was heated in a water bath (70°C) for 20 min, then cooled at 4°C for 3 h and centrifuged. The sediment was dissolved in 5 mL 7% phosphoric acid (H_3PO_4). Next, 0.2 mL of the solution were mixed with 2 mL of 85% phosphoric acid with paraformaldehyde (30 mg/L) and mixed again. After 40 min, absorption was recorded at the wavelength of 600 nm (solution colour changes to blue and then gets lighter). The amount of potato total glycoalkaloids was calculated based on the α-solanine standard curve. The results of the analyses are given as mg per 1 kg of fresh matter.

The data obtained were statistically analyzed using the analysis of variance and the differences between means were determined using the Tukey's test at the significance level of $P = 0.05$.

RESULTS AND DISCUSSION

The Colorado potato beetle is the main pest reducing potato yields. It can be effectively con-

Table 1. Characteristics of potato cultivars (Głuska and Zgórska 1996, Nowacki 2009)

Cultivars	Registration year	Group of earliness	Total yield (t/ha)	Total glycoalkaloids in tubers (mg/kg)	Water requirements	Soil requirements
Wiking	1999	medium early	37.0	39.0	medium	medium
Mors	1997	medium early	35.2	83.0	medium	medium
Żagiel	2001	medium early	42.8	46.0	medium-large	medium-large

Table 2. Weather conditions during the potato growth period in 2004–2006 at the Agricultural Experimental Station, Poland

Year	Month						Mean monthly value
	April	May	June	July	August	September	
Air temperature (°C)							
2004	8.0	11.7	15.5	17.5	18.9	13.0	14.1
2005	8.7	13.0	15.9	20.2	17.5	15.0	15.0
2006	8.4	13.6	17.2	22.3	18.0	15.4	15.8
Mean for the period 1981–1995	7.7	10.0	16.1	19.3	18.0	13.0	14.0
Rainfall (mm)							
2004	35.9	97.0	52.8	49.0	66.7	19.5	320.9
2005	12.3	64.7	44.1	86.5	45.4	15.8	268.8
2006	29.8	39.6	24.0	16.2	228.1	20.9	358.6
Mean for the period 1981–1995	52.3	50.0	68.2	45.7	66.8	60.7	343.7
Sielianinov's hydrothermic coefficients							
2004	1.50	2.69	1.14	0.90	1.14	0.50	1.24
2005	0.47	1.60	0.92	1.51	0.84	0.35	1.00
2006	1.18	0.99	0.47	0.24	4.18	0.45	1.26

Hydrothermic coefficient value: up to 0.5 strong drought; 0.51–0.69 drought; 0.70–0.99 mild drought; ≥ 1 no drought

trolled by an application of chemical insecticides which, however, can affect *Solanum tuberosum* chemical composition (Fidalgo et al. 2000). The data obtained for the parameters studied showed that an application of insecticides changed the chemical composition of both potato leaves and tubers (Tables 3 and 4).

Glycoalkaloid content in potato leaves. The average TGA content in potato leaves was 927.1 mg/kg fresh matter, ranging from 598.9 to 1388 mg/kg (Table 3). When determined in leaves, it was similar to the levels reported by Andreu et al. (2001). Żołnowski (2001) found that glycoalkaloid content in potato leaves tested during the growing season amounted to 1848 mg/kg, and was around 50 times higher than the level determined in tubers after harvest.

The insecticides applied to the control the Colorado potato beetle increased (Calypso 480 SC) or decreased (Actara 80 WG, Regent 200 SC) TGA contents in leaves as compared with the control. To the best of our knowledge, the avail-

Table 3. Total glycoalkaloid contents in potato leaves after chemical treatment (mg/kg fresh matter)

Treatment	Cultivar			Year			Mean
	Wiking	Mors	Żagiel	2004	2005	2006	
(1) Control	785.1	1377	598.9	962.8	892.3	905.5	929.2
(2) Actara 80 WG 0.08 kg/ha	777.7	1377	611.0	966.7	904.4	894.4	921.8
(3) Regent 200 SC 0.1 L/ha	783.9	1376	613.8	968.3	917.5	887.8	924.5
(4) Calypso 480 SC 0.05 L/ha	800.9	1380	609.8	965.0	923.1	902.2	930.1
(5) Calypso 480 SC 0.075 L/ha	800.7	1380	612.9	966.7	929.3	897.8	931.3
(6) Calypso 480 SC 0.1 L/ha	800.3	1388	615.6	971.1	934.8	897.8	934.6
Mean	791.4	1379.7	610.3	966.7	916.9	897.6	927.1

$LSD_{0.05}$ between: insecticides – 4.3; cultivars – 19.0; years – 19.0, interaction insecticides × years = 25.4

Table 4. Total glycoalkaloid contents in potato tubers (mg/kg fresh matter)

Treatment	Cultivar			Year			Mean
	Wiking	Mors	Żagiel	2004	2005	2006	
(1) Control	41.6	124	51.2	58.4	71.9	86.0	72.1
(2) Actara 80 WG 0.08 kg/ha	42.2	127	53.4	60.8	73.3	88.2	74.1
(3) Regent 200 SC 0.1 L/ha	42.3	126	52.8	60.0	72.8	88.2	73.7
(4) Calypso 480 SC 0.05 L/ha	42.0	125	51.3	58.8	72.5	87.5	72.9
(5) Calypso 480 SC 0.075 L/ha	42.6	126	51.7	59.7	72.8	88.2	73.6
(6) Calypso 480 SC 0.1 L/ha	43.0	127	52.8	59.8	72.9	90.1	74.3
Mean	42.30	125.7	52.23	59.58	72.70	88.03	73.43

$LSD_{0.05}$ between: insecticides – 1.9; cultivars – 6.2; years – 6.2, interaction insecticides × cultivars = 8.0

able literature lacks information on the impact of insecticides on changes in glycoalkaloid content of potato leaves.

The leaves of the cultivars studied contained significantly different TGA levels, the highest average content was determined in the variety Mors – 1380 mg/kg, lower in Wiking – 791.4 mg/kg, and the lowest in Żagiel – 610.3 mg/kg. The differences between all the cultivars were statistically confirmed. Andreu et al. (2001) found that levels of glycoalkaloids in the leaves of the cultivar Pampeana INTA were five times higher than in Bintje. Also, the years when our experiments were conducted influenced TGA content in potato leaves. The highest TGA content was determined in 2004 under the coolest and humid weather from April to July. In our study, an interaction between the insecticides and weather conditions was found in the study years, as well as between the cultivars and years, which means the cultivars responded differently to weather conditions during the growing season (Tables 3 and 5).

Glycoalkaloid content in potato tubers. TGA content in potato tubers ranged between 37.8 and 155 mg/kg fresh matter and significantly depended on the insecticides applied to control the Colorado potato beetle, cultivars and weather conditions in the study years (Tables 4 and 5). The insecticides increased TGA contents as compared with the control without insecticides. A significantly higher TGA content was found following the application of the insecticides Actara 80 WG and Calypso 480 SC at the rate of 0.1 L/ha. Hamouz et al. (2004, 2005) observed a tendency of organic potatoes to accumulate higher amounts of glycoalkaloids as compared to conventional tubers. In contrast, Wierzbicka (2011) did not find a significant impact of pesticides on glycoalkaloid content. However, she noted an influence of weather conditions and cultivars. Other workers observed increased glycoalkaloid levels in potato tubers following an application of herbicides (Zarzecka and Gugała 2007) and in egg-plant fruits following an application of nematicides (Bajaj and Mahajan 1980).

Table 5. Total glycoalkaloid contents in potato leaves and tubers depending on cultivar (mg/kg fresh matter)

Year	Leaves			Mean	Tubers			Mean
	Wiking	Mors	Żagiel		Wiking	Mors	Żagiel	
2004	834.7	1352	713.3	966.7	38.5	102	37.8	59.6
2005	784.6	1390	576.0	916.9	49.4	120	49.1	72.7
2006	755.0	1396	541.7	897.6	39.0	155	69.8	88.0
Mean	791.4	1379.3	610.3	927.1	42.30	125.7	52.23	73.43

$LSD_{0.05}$ for leaves – between: cultivars – 19.0; years – 19.0; interaction cultivars × years – 32.9; $LSD_{0.05}$ for tubers – between: cultivars – 6.2; years – 6.2; interaction cultivars × years – 11.4

Genetic properties of the tested cultivars significantly determined glycoalkaloid contents. The highest and the lowest TGA levels were found for Mors (on average, 125.8 mg/kg) and Wiking (on average 42.30 mg/kg). All the cultivars had increased TGA contents following the application of insecticides. It was confirmed by an interaction of cultivars and insecticides. Many papers (Percival and Dixon 1996, Mazurczyk and Lis 2000, Zarzecka and Gugała 2003, Trawczyński and Wierzbicka 2011, Wierzbicka 2011) proved a significant effect of potato cultivar on this characteristic. Also, weather conditions in the study years significantly changed concentrations of glycoalkaloids (Table 5). The lowest TGA levels were determined in potatoes cultivated in 2004 when the weather conditions were similar to the average multi-year conditions. The highest TGA content was determined in the tubers growing during the wet and warm year 2006. Analysis of variance showed statistically significant differences between years and insecticides as well as years and cultivars. In all the study years, there was a tendency for TGA contents to increase following an application of insecticides. Moreover, a different response of cultivars to moisture and temperature conditions was observed. In 2004, the lowest levels of TGA were accumulated by the three cultivars, whereas in 2006 Mors and Żagiel, and in 2005 Wiking had the highest TGA contents. The interaction indicates that the cultivars responded differently to the insecticides and weather conditions in the study years. An impact of weather conditions on the level of glycoalkaloids was also found in the studies carried out by Lachman et al. (2001), Pęksa et al. (2002), Zarzecka and Gugała (2007), Trawczyński and Wierzbicka (2011) and Wierzbicka (2011).

In the experiment discussed in this paper, TGA levels did not exceed 200 mg/kg fresh weight of tubers. The three cultivars examined are thus safe for human consumption.

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