Investigation note

Physicochemical quality of tubers of potatoes produced with and without anti-aphid mesh

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Abstract

The physicochemical characteristics of potato tubers have been diminished by the presence of purple tip disease (PMP). Currently, the use of anti-aphid meshes is a strategy that protects plants from the insects that transmit the PMP. The objective of this work was to evaluate the physicochemical characteristics of potato tubers and their fried foods, produced with and without the protection of an anti-aphid mesh in Metepec, State of Mexico. Five genotypes were studied (Fianna, Nau, 5-10, 8-65, 99-39). The anti-aphid mesh reduced the photosynthetically active radiation 34.5% and consequently reduced the starch accumulation and the yield of potato chips. The PMP infected the plants that were not covered, so that the tubers presented internal staining and higher content of reducing sugars (19.67 g kg^{-1}) than the tubers of covered plants (4.77 g kg^{-1}); however, in both conditions the tubers had similar contents of total phenolic compounds. The protection of plants with anti-aphid mesh could be an alternative to produce tubers with acceptable quality for fresh consumption and the production of potato chips.

Keywords: anti-aphid mesh, potato chips, purple tip of the potato, reducing sugars, starch.

Reception date: January 2019
Acceptance date: March 2019

The disease of the purple tip of the potato (PMP) is a threat in many potato producing regions in Mexico and the United States of America. This disease is caused by the bacterium *Candidatus* Liberibacter solanacearum, which is transmitted by the psyllid of the potato *Bactericera cockerelli* Sulc. (Munyaneza, 2012). Tubers infected by PMP are not accepted for fresh consumption or for the production of potato chips due to internal staining that intensifies with frying (Munyaneza, 2012). The PMP also promotes the accumulation of reducing sugars (AR), amino acids and phenolic compounds in tubers (Wallis *et al*., 2014), which affect the color and flavor of potato-based foods (Rodriguez-Saona *et al*., 1997). Specific gravity (GE), dry matter (MS) and starch content are also variables of tuber quality, which influence the yield, texture and oil absorption (Vázquez-Carrillo *et al*., 2013).

Currently, the control of the PMP is based on the application of specific pesticides against the psyllid of the potato, but this strategy is very expensive since it represents around 20% of the total production costs (Rubio-Covarrubias *et al*., 2017). One solution to this problem has been the development of tolerant genotypes (Rubio-Covarrubias *et al*., 2017). Another strategy is to avoid contact of the insect vector with the plant, which is possible using anti-aphid meshes. The use of this technology has significantly increased the production of seed tubers with good phytosanitary quality and is also profitable. To date there are no studies that report the effect of the use of this technology on the quality of the tuber for the production of potato chips, which is the main destination of the potato. The objective of this work was to evaluate the physicochemical characteristics of potato tubers and their fried foods, produced with and without the protection of an anti-aphid mesh in Metepec, State of Mexico.

To address this goal, five genotypes (Fianna, Citlali, Nau, 8-65, 99-39) were grown in the open field and under an anti-aphid mesh using a complete block design with four replications. The experiment was carried out in the spring-summer cycle of 2013 in Metepec, State of Mexico. The incidence of PMP in this region is high (Rubio-Covarrubias *et al*., 2015). The average maximum and minimum temperature was 22.3 and 4.6 °C, respectively and the annual rainfall was 785.6 mm. The mesh (16 x 10 cm^{-2} wires) was held with 1 m high steel arches, installed immediately after sowing and remained until harvest. The photosynthetically active radiation (PAR) under the mesh was measured at 12:00 am at 1, 50 and 100 cm above the ground with a ceptometer (AccuPAR-LAI, modelo LP-80, METER Group, Pullman, WA, EUA).

The registered PAR values were 1 555, 1 288 and 1 022 mol m^{-2} s^{-1}, respectively. In the open field, the PAR was 1 967 mol m^{-2} s^{-1}, so the reduction under the mesh was 34.5% on average. Sowing, desiccant application, and harvesting were carried out on June 11, September 13 and September 27, respectively. The fertilization dose was 200N-200P_2O_5-200K_2O kg ha^{-1}, plus 50 kg ha^{-1} of micronutrients and 1 t ha^{-1} of chicken manure. Fungicides and insecticides (Abamectin, Imidacloprid, Pymetrozine, Bifentrhrin) were applied weekly in rotation on the foliage in both culture conditions at the doses recommended by the suppliers.

After the harvest, 20 tubers of each treatment were randomly selected, uniform in size, shape, color and free of physical damage to evaluate their physicochemical characteristics and the quality of the potato chips. The rest of the tubers were stored in a cellar at room temperature (23 ±1 °C) and with an average relative humidity of 70% for 5 months. At the end of this period, tubers with normal buds were classified as healthy tubers, while tubers with sprouted buds or unburned tubers were classified as infected tubers and the results were expressed as a percentage. The infected tubers were cut in half and the internal spotting index (IMI) was evaluated on a scale of 0 to 5, where 0 represents absence of spotting and 5 an excess of staining that covers most of the pulp of the potato (Rubio-Covarrubias *et al*., 2015; 2017).

The color of the pulp was evaluated in terms of luminosity with a Hunter Lab colorimeter (MiniScan XE Plus 45/0-L; Reston, VA, USA) (Vázquez-Carrillo *et al*., 2013) and specific gravity (GE) with the method reported by Gould (1999). The humidity and the starch content were determined with the methods 44-15.02 and 76-13.01 of the AACC International (2017), respectively. The dry matter (MS) was calculated as 100-(%) moisture. The extraction and quantification of reducing sugars (AR) (glucose and fructose) and sucrose was carried out according to the method reported by Castañeda-Saucedo *et al*. (2012). The content of total phenols was determined with the Folin-Ciocalteu method reported by Singleton *et al*. (1999).

French fries were prepared as reported by Vázquez-Carrillo *et al*. (2013), using 1.2 mm thick potato flakes, edible vegetable oil at 180 °C and a frying time of 3 min. The yield, fracturability and luminosity were evaluated with the methods reported by the same authors. All analyzes were done in triplicate. The treatment design was 2 x 5 asymmetric factorial, where in the first factor was the culture condition (covered plants and plants not covered) and the second factor was the genotype (Fianna, Citlali, Nau, 8-65, and 99-39). The results were analyzed with an analysis of variance, comparison of means with the Tukey test ($p\leq 0.05$) and Pearson correlation using the SAS version 9.0 package.

The analysis of variance showed significant effects of the culture condition (C), the genotype (G) and the interaction C x G on all the variables, except for the GE and the content of total phenols (Table 1).

Table 1. Mean squares and statistical significance of the analysis of variance of the physicochemical characteristics of the tuber and the quality of potato chips of plants covered and not covered with anti-aphid meshes.

FV	TI	TS	IMI	LT	GE	MS	Starch	AR	Saccharose	FT	RendChip	LChip	Fract
Condition (C)	22606**	22606**	5.6**	5.5**	0.001**	3127.5**	6566.7**	1110**	18.2**	334.6	636.2**	164.3**	2.4**
Genotype (G)	118.7**	118.7**	0.3**	4**	0.001	935.9**	736.6**	231.4**	4.5**	37459.2**	980.5**	275.6**	0.3**
C x G	118.7**	118.7**	0.3**	0.4*	0.001	48**	80.8**	83.6**	3.7**	2727.6*	281.6**	19.9**	0.1**

FV= source of variation; TI= infected tubers; TS= healthy tubers; IMI= index of internal staining, LT= tuber luminosity; GE= specific gravity; MS= dry matter; AR= reducing sugars; FT= total phenols; RendChi= yield of potato chips; LChip= brightness of potato chips; Fract= fracturability. *= $p\leq 0.05$, **= $p\leq 0.01$.

The covered plants were not infected with the PMP, so that no tuber showed internal staining and all had normal shoots, while the uncovered plants had different percentages of infected tubers (Table 2).

Table 2. Physicochemical characteristics of the tuber and potato chips of plants covered and not covered with anti-aphid mesh.

Factor		TI (%)	TS (%)	IMI	LT	GE	MS ($g\ kg^{-1}$)	Starch ($g\ kg^{-1}$)	AR ($g\ kg^{-1}$)	Saccharose ($g\ kg^{-1}$)	FT ($mg\ 100g^{-1}$)	RendChip ($g\ kg^{-1}$)	LChip	Fract (N)
Genotype	Fianna	39.4a	10.6e	0.95a	79.9b	1.077a	186b	137b	6.75e	17c	345.78d	25.9a	61.07a	2.4d
	Nau	26e	23.9a	0.3d	80.65a	1.075a	162c	120d	8.95d	9.7d	531.55b	23.3bc	53.86b	2.9b
	8-65	35.9c	14c	0.25e	80b	1.072a	182.2b	127.7c	10.12b	19.2b	591.95a	23.8b	52.6b	3.1a
	Citlali	36.7b	13.3d	0.45c	79.4b	1.075a	192.2a	149.7a	9.68c	24.5a	558.25ab	25.5a	62.32a	2.6c
	99-39	30d	20b	0.7b	77.99c	1.07a	157.7c	116.5d	25.62a	17.7bc	471.18c	22.2c	41.55c	2.6c
Condition	With mesh	0b	100a	0b	80.11a	1.068b	163.7b	112b	4.77b	8.1b	503.83a	23.6b	57.15a	2.4b
	Without mesh	67.2a	32.8b	1.1a	79.07b	1.08a	188.4a	148.4a	19.67a	27.2a	495.65a	24.7a	51.41b	3.1a

TI= infected tubers; TS= healthy tubers; IMI= internal staining index; LT= tuber luminosity; GE= specific gravity; MS= dry matter; AR= reducing sugars; FT= total phenols, RendChip= yield of potato chips; LChip= brightness of potato chips; Fract= fracturability. Means with different letters in the same column are different (Tukey, $p \leq 0.05$).

Rubio-Covarrubias *et al*. (2013, 2015) reported similar results regarding the incidence of PMP and internal spotting of the tubers for the same genotypes under open field conditions. These results confirmed the resistance of the Nau, 8-65 and Citlali genotypes to the internal staining of the tubers caused by the PMP. The luminosity of the pulp presented values between 77.59-80.78 (Table 2). High values of this variable indicate a whiter pulp, ie. with absence of internal staining as a result of the presence of PMP or absence of enzymatic obscuration caused by the presence of a high content of phenols and peroxidases.

These values were only found in tubers from covered plants, which also had absence of internal staining. All tubers of genotypes from uncovered plants had higher values of GE, MS and starch, compared to the tubers of covered plants (Table 2). The low values of specific gravity (GE), dry matter (MS) and starch of the tubers of covered plants were attributed to the reduction of 34.5% of the PMP.

The anti-aphid mesh reduced the solar radiation intercepted by the plants, which caused a decrease of the photosynthetic activity and consequently of the accumulation of starch in the tubers. The low starch accumulation influenced a lower amount of dry material and density of the tubers. These results agree with that reported by Chen and Setter (2003), who found that the number of cells, the concentration of glucose and the net accumulation of biomass in potato tubers were reduced when the plants were shaded with a double layer plastic mesh. High correlations were observed between GE and MS (r= 0.68; $p \leq 0.01$), GE and starch (r= 0.77; $p \leq 0.01$) and between MS and starch (r= 0.93; $p \leq 0.01$), similar to those reported by Vazquez-Carrillo *et al*. (2013).

The content of AR and sucrose in tubers was 1.01-40.91 and 2.2-3.5 g kg^{-1} fresh weight (pf), respectively (Table 2).

Stark and Love (2003) state that, as a general rule, the biosynthesis of sugars and starch have an inverse tendency, that is, any crop or environmental factor that influences the increase in starch content will reduce the sugar content and vice versa. This research yields results revealed a different trend, the tubers of uncovered plants had a higher content of starch and also higher content of reducing sugars and sucrose (Table 2) this was a consequence of the PMP. Wallis *et al*. (2014) and Rubio-Covarrubias *et al*. (2017) reported that the infected tubers accumulate more reducing sugars as a consequence of metabolic alterations produced by the infection caused by *Candidatus* Liberibacter solanacearum.

The genetic resistance to the infection was also clearly observed in the accumulation of AR since the tubers of genotype 99-39 accumulated the highest amount of these compounds. The tubers for the production of potato chips should have values of GE$\geq$ 1.08, MS$\geq$ 20%, AR$\leq$ 0.035% pf and sucrose $\leq$0.15% pf (Stark and Love, 2003). Although some genotypes had GE> 1.08 and MS on average 20%, they also had high contents of AR and sucrose, which limits their use for the production of potato chips. The content of total phenols was found between 338.6-619.1 mg 100 g^{-1} pf (Table 2). The accumulation of phenolic compounds is also a symptom of PMP infection (Wallis *et al*., 2014; Rubio-Covarrubias *et al*., 2017), so it was expected that the tubers of uncovered plants had a higher content of these compounds However, no significant effect of the culture condition on the total phenol content was observed.

This implies that the environmental conditions that were presented under the mesh could cause some stress to the plants inducing the production of phenolic compounds. Ghasemzadeh *et al*. (2010) reported that some plants increase their production of phenols and flavonoids when they are grown under covers due to the low temperatures that can occur under these conditions; nevertheless, a more detailed study of the influence of the microenvironment generated under the mesh in different periods of the day on the accumulation of this type of compounds in potato tubers is required.

The MS and the starch content directly affected the performance of potato chips and their texture. Tubers from uncovered plants had a higher yield of potato chips and higher values of fracturability (Table 2). The correlations that corroborated this trend were: potato chips-GE (r= 0.54; $p\leq$ 0.05), potato chips-MS (r= 0.8; $p\leq$ 0.001) and potato chips-starch yield (r= 0.7; $p\leq$ 0.001). The content of AR had a negative influence on the luminosity of the potato chips (r= -0.74, $p\leq$ 0.001), which coincides with that reported by Rodríguez-Saona *et al*. (1997); Vázquez-Carrillo *et al*. (2013). Potato chips from uncovered plants, when infected with PMP, had more AR and sucrose, which favored the production of dark brown chips.

Conclusions

With the use of an anti-aphid mesh, plants free of PMP disease were obtained, but the photosynthetically active radiation decreased the accumulation of dry matter, mainly starch, reducing the yield of potato chips and the fracturability; favorably, a lower content of reducing sugars and sucrose was synthesized, compared to the uncovered culture. The culture conditions did not cause significant differences in the accumulation of total phenolic compounds in the tubers; however, the causes of this accumulation are different and require a more detailed study. In general, it was observed that the use of an anti-aphid mesh can be an alternative for the production of potato tubers for fresh consumption and even for the production of potato chips.

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