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Disease Resistance and Nutritional Properties of Tuber-Bearing Native Potato Species and Old Spanish Cultivars

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ABSTRACT

Certain potato cultivars such as native potato species (NPS) from the Andes are known to have resistances to different pests and diseases. Some accessions are also interesting from a nutritional and culinary perspective. A collection of 35 NPS and 11 old Spanish accessions were analysed for *Streptomyces scabies*, *Rhizoctonia solani* and *Globodera rostochiensis*, as well as dry matter, reducing sugars, minerals, glycoalkaloid concentrations, and total antioxidant capacity. A wide variability was found between and also within the species. Most accessions showed favourable characteristics, while high concentrations values of glycoalkaloids were observed in certain accessions. The results suggest that some NPS and old Spanish accessions have a great potential for exploitation in potato breeding programmes as a source of resistances and nutritional variability.

Keywords: Antioxidant capacity, Breeding, Glycoalkaloids, Pathogens.

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INTRODUCTION

Potato is a basic food crop in many countries that produces a higher amount of energy and protein per surface area than any other food crop, including cereals. In addition, potatoes are a valuable source of carbohydrates, proteins, minerals (particularly calcium and potassium) and vitamins (Fernie and Willmitzer, 2001). Potato has probably more related wild species than any other crop, since the genus *Solanum* comprises around 2,000 species (Ruiz de Galarreta and Ríos, 2008). Among them are 189 tuber-bearing species, including one cultivated species (Spooner and Salas, 2006). It was first cultivated 6,000 to 10,000 years ago around the Titicaca Lake. In successive generations, the Andean communities obtained hundreds of cultivars, extending the potato culture to the whole Andean region and occupying the high regions of South America (Spooner and Hetterscheid, 2006). The current potato diversity is wide and more than 5,000 landraces of potatoes have been identified by the International Potato Centre (Huamán, 1986), with different shapes, colors, and chemical compositions (De Haan, 2006).

Despite some introgressions from other *Solanum* species, modern potato cultivars belong basically to the species *Solanum tuberosum* ssp. *tuberosum*. However, in South-America other tuber-bearing species are cultivated, which are called Native Potato Species (NPS). They include figure *S. juzepczukii* (3x), *S. chaucha* (3x), *S. stenotonum* (2x), *S. ajanhuiri* (2x) with the groups Yari and Ajawiri, *S. goniocalyx* (2x), *S. curtilobum* (5x), S. *phureja* (2x) and *S. tuberosum ssp. andigena* (4x). The native germplasm presents remarkable genetic diversity (Spooner *et al*., 2005), including resistances to pest and diseases (Gabriel *et*

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al., 2011) and high nutritional variability (Burgos *et al.*, 2007).

In spite of its common perception as a carbohydrate source, potatoes, particularly NPS, are also a good source of relative high quality proteins (Dijkstra *et al.*, 2003). Some of them are also great sources of vitamins, dietary fibre, and minerals (Lu *et al.*, 2001). Potato tubers also contain a variety of phytonutrients, including carotenoids and phenolic compounds. The content of bioactive compounds is affected by several environmental factors, but, in most cases, the genotype has a determining effect (Brown *et al.*, 1993). Although potato antioxidant capacity is low when compared to other vegetables (Stratil *et al.*, 2006), S*olanum* cultivated species exhibit a wide variation in total antioxidant capacity values, and higher values are usually found in genotypes with deep colored skin and flesh. Purple or red potatoes are especially rich in secondary metabolites like anthocyanins. In addition, yellow and orange fleshed potatoes are particularly rich in certain xantophyll type carotenoids, including lutein, violaxanthin and zeaxanthin (Brown, 2005).

However, most accessions of NPS present also some undesirable agronomic, nutritional, or commercial characteristics. The absence of dormancy and the presence of excessively long stolons are considered as adverse factors that appear in certain native potatoes. Extremely high total glycoalkaloid concentrations also constitute an unfavourable characteristic of certain NPS accessions. Glycoalkaloids represent a toxic group of secondary plant compounds found throughout the foliage and tubers of *Solanaceae* (Friedman, 2004). They are thought to function as the chemical defence of the plant against potential pathogens (Friedman and McDonald, 1997). The two major glycoalkaloids in potatoes are α-solanine and α-chaconine, but the ratio of α-solanine to α-chaconine varies widely among tissues, genotypes, and growing conditions (Sarquis *et al.*, 2000). These steroidal compounds are reported to exhibit both beneficial and adverse effects (Friedman *et al.*, 2005). In small amounts, these compounds contribute to potato flavour, but potatoes containing glycoalkaloids in excess are unsafe for human consumption (Van Gelder, 1988).

Following a previous paper on characterization of NPS (Ritter *et al.*, 2008), the objective of the present study was to analyze additional traits of NPS and certain old Spanish accessions including resistances to *Streptomyces scabies*, *Rhizoctonia solani,* and *Globodera rostochiensis*, dry matter, reducing sugars and minerals, as well as the concentration of glycoalkaloids and total antioxidant capacity.

MATERIALS AND METHODS

Plant Material

A total of 46 accessions representing different NPS and old Spanish potatoes belonging to *Solanum tuberosum* ssp. *tuberosum* were analyzed. Native potato accessions were acquired from International Potato Center (Lima, Peru). These were selected with the aim of maximizing the geographic coverage and genetic diversity. Spanish accessions were selected from the germplasm collection held at Neiker-Tecnalia. The commercial cultivar Desirée belonging to the species *S. tuberosum* was selected as susceptible controls in the evaluation of resistance and the cv. Agria as quality check. Details about plant material are shown in Table 1.

Evaluation of Resistances against Pathogens

Tuber resistance against *Streptomyces scabies* was determined by growing five potato plants of each accession in infested soil with 40 mL of the spore suspension of an isolate from Neiker Institute (Spain) during 10 weeks according to Bouchek-Mechiche *et al.* (1998). The resistance against *Rhizoctonia solani* was analyzed

Table 1. Native Potato Species (NPS) and old Spanish accessions evaluated.

Accession code	Name	Species [a]	Origin	Skin color	Flesh color
NKD-138	Laram Ajawiri	*S. ajawiri*	Bolivia	Yellow	Yellow
NKD-139	Jancko Ajawiri	*S. ajawiri*	Bolivia	Yellow	White
NKD-126	Ojo de Buey	*S. andigena*	Peru	Brown	White
NKD-128	Huagalina	*S. andigena*	Peru	Brown	Yellow
NKD-130	Muro Shocco	*S. andigena*	Peru	Purple	Yellow-Purple
NKD-134	Pulu	*S. andigena*	Bolivia	Purple	White-Purple
NKD-135	Socco Huaccoto	*S. andigena*	Peru	Purple	Yellow
NKD-137	Sipancachi	*S. andigena*	Bolivia	Yellow	Yellow
NKD-141	Unknown-1	*S. andigena*	Peru	Yellow	Yellow
NKD-143	Wila Huaka Lajra	*S. andigena*	Bolivia	Red	Yellow
NKD-145	Puca quitish	*S. andigena*	Peru	Purple	Purple
NKD-156	Holandesa	*S. andigena*	Colombia	Red	Yellow
NKD-157	Unknown-2	*S. andigena*	Colombia	White	White
NKD-159	Camusa	*S. andigena*	Venezuela	Purple	White-Purple
NKD-160	Chimbina	*S. andigena*	Peru	Purple	Yellow-Purple
NKD-161	Negrita	*S. andigena*	Peru	Purple	White
NKD-151	Chiar Surimana o Phiñu	*S. chaucha*	Bolivia	Purple	White
NKD-163	Color Unckuna	*S. chaucha*	Peru	Red	Yellow-Red
NKD-131	Puca Huayro	*S. chaucha*	Peru	Red	Yellow-Red
NKD-153	Unknown-3	*S. goniocalyx*	Peru	Brown	Yellow
NKD-155	Kashpadana Amarilla	*S. goniocalyx*	Peru	Red	Yellow
NKD-133	Chimi Lucki	*S. juzepczukii*	Bolivia	White	White
NKD-144	Laram Canchali	*S. juzepczukii*	Peru	Purple	White
NKD-132	Chaucha	*S. phureja*	Peru	Purple	Yellow
NKD-150	Rosca	*S. phureja*	Colombia	Yellow	Yellow
NKD-127	Calhua Rosada	*S. stenotonum*	Peru	Brown	Yellow
NKD-129	Señora Warni	*S. stenotonum*	Peru	Purple	Yellow
NKD-140	Morar Nayra Mari	*S. stenotonum*	Peru	Red	Yellow-Purple
NKD-142	Yana Sucre	*S. stenotonum*	Peru	Purple	White
NKD-148	Cceccorani	*S. stenotonum*	Peru	Brown	Yellow-Purple
NKD-149	Yana Ppoccoya	*S. stenotonum*	Peru	Red	White
NKD-152	Morada Turuna	*S. stenotonum*	Peru	Red	Yellow-Red
NKD-158	Poluya	*S. stenotonum*	Peru	Purple	Yellow
NKD-164	Amarilla	*S. stenotonum*	Peru	Yellow	Yellow
NKD-154	Ucho Chaquitay	SxG [b]	Colombia	Purple	Yellow-Purple
NK-272	Cazona	*S. tuberosum*	Spain	Yellow	Yellow
NK-273	Fina de Carballo	*S. tuberosum*	Spain	Yellow	Yellow
NK-520	Fina de Gredos	*S. tuberosum*	Spain	Brown	White
NK-136	Kasta	*S. tuberosum*	Spain	Purple	Purple
NK-129	Jesus	*S. tuberosum*	Spain	Purple	Purple
NK-338	Morada	*S. tuberosum*	Spain	Purple	Purple
NK-222	Roja Riñon	*S. tuberosum*	Spain	Red	Yellow
NK-011	Alegria Oro	*S. tuberosum*	Spain	Yellow	Yellow
NK-292	Ibicenca	*S. tuberosum*	Spain	Red	Yellow
NK-201	Pedro Muñoz	*S. tuberosum*	Spain	Yellow	White
NK-515	Tramontana	*S. tuberosum*	Spain	Yellow	Yellow
NK-172	Agria [c]	*S. tuberosum*	Germany	Yellow	Yellow
NK-069	Desiree [c]	*S. tuberosum*	Netherlands	Red	Yellow

[a] S. tuberosum=S. tuberosum ssp. tuberosum, S. andigena=S. tuberosum ssp. andigena

[b] Hybrid between S. tuberosum ssp. andigena and S. goniocalyx., [c] Varieties used as controls

using five tubers of each accession inoculated in pot with under greenhouse conditions during 10 weeks at 20 °C with 16 h light period (Little *et al*., 1988). The evaluation of both resistances was based on a damage scale established by James (1971) that considers the affected tuber area. The presence of black or brown sclerotia on the tuber surface was evaluated. Partial resistance was considered if less then 10% or less then 5% of the tuber surface was covered by sclerotia from *S. scabies* and *R. solani*, respectively.

For detecting resistance against the nematode *Globodera rostochiensis*, virulence group Ro1, a bioassay in the greenhouse using five tubers as replicates was performed as a pot test with infected soil with 30 cysts per pot leading to an infestation density of 10 to 20 juveniles per gram of soil following the methodology described by Ruiz de Galarreta *et al*. (1998). Pots were watered lightly and evenly and plants were grown at 20 °C for 10 weeks. Susceptible accessions were identified visually by observing females on the roots according to Rousselle-Bourgeois and Mugniéry (1995). An accession was defined as resistant, if less than 5 cysts appeared in each of the replicates, and as partially resistant, if multiplication rates were less than 10% compared to the susceptible control in each pot.

Determination of Dry Matter, Reducing Sugars, and Minerals

Estimation of dry matter (DM) after drying was performed according to Gould (1999) and calculated as the ratio between dry and fresh mass. Reducing sugars were quantified using a standardized spectrophotometrical procedure with DNS (3, 5-Dinitrosalicylic acid) as reactive (Sumner, 1921). Total reducing sugar concentration (RS) was calculated following the relation between absorbance and sugar content described by Barredo and Ritter (1992). Samples were analyzed for P, Ca, K, Mg, Na, Zn, and Fe using ICP-OES spectrometry (AOAC, 2012). Mineral composition was evaluated by acid digestion at 140 °C in 70% $HNO_3/HClO_4$ and ICP-OES using an ARL 3580B ICP (ARL, Switzerland). Least significant differences were estimated. All analyses were performed with the SAS package.

Antioxidant Capacity and Glycoalkaloids

The total antioxidant capacity (TAC) of potato tubers was determined by ORAC (Oxygen Radical Absorbance Capacity) standardized assay (Cao *et al*., 1993). In the ORAC method, a sample is added to the peroxyl radical generator AAPH (2,2'-Azobis-(2-Amidinopropane)-dihydrochloride) and inhibition of the free radical action is measured using the fluorescent compound, B-phycoerythrin or R-phycoerythrin (Cao *et al*., 1995). Glycoalkaloids were analyzed by extraction with acetic acid and determined by HPLC. Lyophilized, completely desprouted, and ground samples were extracted with the extraction solution (water/acetic acid/ sodium hydrogen sulphite 95+5+0.5, v/v/w) for 15 min (Hellenäs *et al*., 1995). Glycoalkaloids were eluted with the HPLC mobile phase (acetonitrile/0.022 M potassium phosphate buffer, pH 7.6, 55:45 v/v). The HPLC separation was carried out by a HyperClone 5 μm ODS phase (C18; Phenomenex) in a 150×4.6-mm column. Quantification was made by UV-detection at 202 nm using a flow rate of 1.5 mL/min (Knauer Instruments, HPLC pump Smartline 1000) and comparison with areas of the external standards, α-solanine and α-chaconine. Total glycoalkaloid concentration (TGA) results were calculated and expressed as mg TGA/kg fresh weigh (FW), by summing up the contents of α-solanine and α-chaconine (Haase, 2010).

RESULTS

The results of resistance screenings against *S. scabies*, *R. solani* and *G. rostochensis* are shown in Table 2. Only 12 accessions were

Table 2. Resistances, dry matter (DM) and reducing sugar concentrations (RS) in Native Potato Species and old Spanish accessions.

Accession code	*S. scabies* [a]	*R. solani* [a]	*G. rostochiensis* [b]	DM (%)	RS (%)
NKD-138	**10**	**5**	S	22.0±1.3*	1.10±0.12*
NKD-139	25	**5**	S	23.9±1.1	1.05±0.10
NKD-126	**0**	10	S	21.6±1.0	1.01±0.18
NKD-128	**10**	**1**	S	21.8±1.3	0.66±0.15
NKD-130	**10**	10	S	23.2±0.9	0.87±0.15
NKD-134	**0**	**5**	S	24.9±0.9	0.49±0.10
NKD-135	50	10	S	19.7±1.3	0.59±0.13
NKD-137	50	15	S	23.8±1.0	**0.15±0.12**
NKD-141	**10**	10	S	23.2±0.8	**0.17±0.13**
NKD-143	**10**	10	S	**26.3±0.6**	0.37±0.11
NKD-145	**10**	**1**	S	21.2±1.3	1.10±0.16
NKD-156	25	10	S	22.7±1.3	0.93±0.17
NKD-157	**10**	**1**	S	**29.3±1.1**	0.63±0.17
NKD-159	25	**1**	S	22.6±1.2	**0.16±0.15**
NKD-160	50	10	S	**26.7±1.1**	0.25±0.12
NKD-161	25	10	**PR**	**28.2±0.8**	0.49±0.12
NKD-151	25	10	S	19.5±1.1	0.53±0.11
NKD-163	25	10	S	20.8±1.3	0.23±0.09
NKD-131	25	10	S	23.3±0.7	0.77±0.11
NKD-153	**10**	10	S	**26.7±0.8**	0.50±0.18
NKD-155	**10**	10	S	**28.4±0.8**	0.28±0.17
NKD-133	25	10	**PR**	22.4±1.1	1.00±0.16
NKD-144	50	**5**	S	**26.8±1.0**	1.04±0.08
NKD-132	**10**	10	S	20.6±1.1	0.42±0.11
NKD-150	**0**	10	S	19.0±1.1	0.47±0.06
NKD-127	**10**	10	S	**26.2±0.9**	**0.17±0.14**
NKD-129	50	15	S	24.2±1.1	0.28±0.10
NKD-140	**10**	10	S	25.3±1.2	0.26±0.12
NKD-142	**10**	**5**	S	**26.4±1.0**	0.46±0.11
NKD-148	25	**1**	S	**27.1±1.1**	0.34±0.19
NKD-149	25	10	S	24.1±1.0	0.36±0.17
NKD-152	50	10	S	24.6±1.3	0.24±0.15
NKD-158	**10**	**1**	S	25.2±1.3	0.28±0.12
NKD-164	25	10	S	23.3±0.9	0.91±0.12
NKD-154	**10**	10	S	20.0±1.0	1.05±0.08
NK-272	25	**5**	S	20.8±0.8	0.32±0.09
NK-273	**10**	**5**	S	19.3±0.7	0.31±0.12
NK-520	**0**	10	S	21.5±0.7	0.31±0.15
NK-136	25	10	**PR**	20.5±1.1	0.23±0.12
NK-129	**10**	**1**	**PR**	21.8±1.0	0.21±0.07
NK-338	25	15	**PR**	20.8±1.0	0.34±0.15
NK-222	**10**	15	S	**27.2±1.0**	0.32±0.11
NK-011	**0**	15	**PR**	19.8±1.3	0.55±0.09
NK-292	**10**	10	S	20.1±1.2	0.49±0.15
NK-201	25	**5**	S	20.4±1.0	0.56±0.16
NK-515	25	15	S	23.7±0.8	0.30±0.07
NK-069	50	15	S	-	-
NK-172	-	-	-	22.4±1.1	0.26±0.11
LSD (0.05)				1.65	0.05

[a] Expressed as percentage of affected tuber area; [b] S: susceptible PR: partially resistant R: resistant;

In bold**:** accessions resistant or partially resistant

In bold**:** accessions with dry matter >26% and reducing sugars content <0.20%.

- Not evaluated

* Each value is expressed as the mean ± standard error (n=3)

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susceptible to all assayed pathogens. A total of 5 accessions were resistant and 19 partially resistant against the bacteria *S. scabies* (≤10% tuber area affected) according to Bouchek-Mechiche *et al.* (1998). Resistance against *S. scabies* were found in accessions of the species *S. goniocalyx*, *S. phureja*, *S. stenotonum*, *S. tuberosum* ssp. *andigena*, *S. tuberosum* ssp. *tuberosum* and the hybrid *SxG*. For *R. solani*, 15 accessions belonging to the species *S. juzepczukii*, *S. stenotonum*, *S. tuberosum* ssp. *andigena* and *S. tuberosum* ssp. *tuberosum* were identified as totally or partially resistant (≤5% tuber area affected). Partial resistance to the nematode *G. rostochensis* (Ro1) was detected in four accessions belonging to *Solanum tuberosum ssp. tuberosum* and in the NPS accessions NKD-161 (*Solanum tuberosum ssp andigena*) and NKD-133 (*Solanum juzepczukii*). The old Spanish accession NK-129 (*Solanum tuberosum* ssp. *tuberosum*) was the only accession that showed total or partial resistances against the three tested pathogens.

Table 3 shows the observed variation in DM and RS concentrations. A wide degree of variation in DM was observed, varying between 19.0% and 29.3%. The highest values of DM (>26%) were found in both entries of *S. goniocalix*, in one *S. juzepczukii* in four *S. tuberosum* ssp. *andigena* accessions (NKD-160, NKD-161, NKD-157 and NKD-143), in three *S. stenotonum* accessions, and in the old Spanish accession NK-222 (*S. tuberosum* ssp. *tuberosum*). The lowest DM values were detected in most of the accessions belonging to *S. chaucha*, *S. stenotonum*, *S. tuberosum* ssp. *tuberosum* and in the hybrid SxG.

A large variation in reducing sugars (RS) concentration was also observed between, as well as within, *Solanum* species, ranging from 0.19% to 1.10%. The accessions which contained higher RS levels belonged to *S. ajanhuiri* and *S. juzepczukii* species, but also the accession NKD-154 (hybrid between *S. tuberosum* ssp. *andigena* and *S. goniocalyx*) contained high amounts or RS. Low RS levels were detected in accessions NKD-137, NKD-159 and NKD-157, belonging to *S. tuberosum* ssp. *andigena*. Most of the accessions belonging to *S. stenotonum*, *S. phureja*, *S. goniocalyx*, *S. chaucha* and *S. tuberosum* ssp. *tuberosum* presented medium RS values. However, exceptions could also be found in these species, such as NKD-164 belonging to *S. stenotonum*, and NK-011 and NK-201 belonging to *S. tuberosum* ssp. *tuberosum*.

Differences in the mineral composition are shown in Table 3. Generally, NPS had higher mineral concentrations than the old Spanish accessions. High P concentrations were found in *S. goniocalyx*, *S. ajanhuiri* and certain *S. tuberosum* ssp. *andigena* accessions (NKD-134, NKD-157, and NKD-160). Accessions of *S. goniocalyx* showed larger concentrations of macronutrients K, Mg, and Na, and high K values were found in some cultivars of *S. tuberosum* ssp. *andigena*. Also, in microelement assays for Fe and Zn, a wide variation was detected in the tubers of these species. Lowest Zn and Fe concentrations were found in 3 *S. tuberosum* ssp. *andigena* accessions (NKD-145, NKD-137 and NKD-161). Besides, some accessions with high contents of both elements could be found such as NKD-157, NKD-160 and NKD-134. The highest levels of Zn were observed in NKD-138, whereas the highest values of Fe were found in NKD-157 and NKD-151 belonging to *S. chaucha*.

Figure 1 represents the observed variation in TAC and standard errors with a range from 9.29 to 56.00 µmol TE g^{-1} FW. In most cases, NPS accessions showed higher antioxidant capacities than the old Spanish ones. In particular, one accession belonging to the species *S. tuberosum* ssp. *andigena* (NKD-159), and another from *S. stenotonum* (NKD-158), revealed the highest antioxidant capacity values.

Figure 2 shows that the total TGA of tubers vary widely between 28.0 and 991.1 mg kg^{-1} FW. The highest TGA values were found in two *S. tuberosum* ssp. *andigena* accessions (NKD-156 and NKD-157) and in

Table 3. Mineral concentrations in Native Potato Species and old Spanish accessions.

Accession code	P	K	Ca	Mg	Na	Zn	Fe
NKD-138	**121±1.2**	**668±3.5**	15.8±0.5	33.5±0.6	2.32±0.11	**0.92±0.08**	1.08±0.10
NKD-139	107±1.0	574±3.0	12.9±0.3	**36.5±0.8**	1.60±0.09	0.58±0.04	0.94±0.09
NKD-126	104±0.9	499±2.9	9.4±0.4	28.9±0.6	1.87±0.10	0.33±0.03	0.72±0.08
NKD-128	109±1.3	636±2.7	14.6±0.5	23.9±0.7	1.97±0.13	0.37±0.02	0.51±0.03
NKD-130	70±1.1	314±3.0	16.9±0.4	14.4±0.7	2.30±0.15	0.32±0.04	0.49±0.04
NKD-134	**135±1.2**	**801±3.4**	**22.6±0.7**	**42.1±0.9**	**5.43**±0.18	**0.73±0.06**	0.82±0.05
NKD-135	90±1.2	404±2.8	11.9±0.4	28.4±0.5	3.83±0.13	0.30±0.02	0.36±0.02
NKD-137	61±1.0	435±3.0	9.1±0.3	20.3±0.6	2.76±0.10	0.25±0.01	0.21±0.02
NKD-141	84±0.8	435±3.1	18.9±0.4	26.1±0.6	3.76±0.14	0.43±0.03	0.36±0.04
NKD-143	93±1.1	468±2.7	11.9±0.3	25.8±0.7	3.71±0.14	0.53±0.04	0.57±0.06
NKD-145	66±1.0	325±2.9	9.1±0.6	16.3±0.4	1.75±0.09	0.25±0.01	0.30±0.02
NKD-156	68±1.2	468±3.2	8.9±0.3	22.3±0.5	2.46±0.11	0.30±0.02	0.28±0.03
NKD-157	**140±1.4**	**879±3.4**	17.0±0.5	**44.8±0.6**	3.26±0.12	**0.86±0.07**	**4.89±0.16**
NKD-159	103±1.0	**691±3.0**	12.2±0.6	**39.1±0.7**	2.72±0.11	0.65±0.06	1.24±0.11
NKD-160	110±1.3	659±2.7	12.8±0.6	31.5±0.7	2.20±0.08	**0.78±0.07**	0.99±0.10
NKD-161	108±0.8	627±3.2	8.1±0.3	26.4±0.5	3.76±0.12	0.22±0.02	0.24±0.03
NKD-151	104±0.6	605±3.0	8.6±0.2	25.5±0.8	1.82±0.08	0.59±0.03	**4.29±0.14**
NKD-163	74±1.1	524±2.8	6.3±0.3	25.8±0.6	1.33±0.07	0.21±0.02	0.51±0.04
NKD-131	116±0.9	520±3.1	12.5±0.5	35.3±0.6	2.18±0.06	0.56±0.04	0.71±0.04
NKD-153	**121±1.3**	618±2.9	**20.1±0.5**	31.5±0.7	**4.18**±0.16	0.36±0.03	0.45±0.06
NKD-155	117±1.2	631±2.8	**21.2±0.6**	30.5±0.9	**7.01**±0.15	0.57±0.04	0.61±0.05
NKD-133	109±1.2	513±3.4	9.1±0.3	29.3±0.4	1.77±0.09	0.41±0.04	0.69±0.06
NKD-144	84±0.7	440±3.0	**25.9±0.4**	25.5±0.5	0.97±0.03	0.46±0.03	**2.32±0.11**
NKD-132	64±0.7	424±3.1	14.4±0.3	17.1±0.3	0.47±0.04	0.37±0.04	1.13±0.09
NKD-150	77±0.8	493±2.5	14.1±0.3	25.4±0.5	2.71±0.12	0.29±0.02	0.54±0.06
NKD-127	86±1.0	518±2.8	10.2±0.4	27.0±0.6	2.06±0.10	0.29±0.01	0.55±0.07
NKD-129	73±1.1	460±3.0	17.3±0.6	18.6±0.4	0.93±0.14	0.44±0.03	1.12±0.10
NKD-140	92±1.2	476±3.1	17.5±0.5	21.3±0.5	3.63±0.16	0.58±0.03	0.51±0.06
NKD-142	95±1.2	531±3.3	8.3±0.3	25.1±0.5	**4.36±0.16**	0.60±0.04	0.76±0.04
NKD-148	112±1.4	536±3.0	7.3±0.2	35.1±0.7	1.77±0.08	0.43±0.04	0.88±0.07
NKD-149	92±1.0	514±3.0	10.5±0.3	26.6±0.5	1.99±0.09	0.42±0.05	0.56±0.05
NKD-152	51±1.1	360±2.8	14.8±0.3	13.1±0.3	0.98±0.08	0.32±0.03	0.75±0.06
NKD-158	89±1.2	545±2.9	12.2±0.4	27.0±0.4	1.90±0.10	0.40±0.03	1.39±0.09
NKD-164	89±0.7	536±3.0	11.2±0.4	31.0±0.5	2.18±0.12	0.32±0.02	0.56±0.06
NKD-154	95±1.0	499±3.1	12.3±0.5	28.1±0.5	2.69±0.10	0.35±0.03	1.35±0.11
NK-272	58±0.6	377±3.1	11.2±0.4	16.2±0.2	0.94±0.05	0.35±0.04	0.96±0.08
NK-273	68±0.7	391±2.6	7.0±0.2	16.1±0.3	0.72±0.03	0.38±0.04	0.69±0.07
NK-520	73±0.7	398±2.9	11.9±0.4	17.8±0.2	0.32±0.03	0.44±0.03	1.38±0.12
NK-136	50±0.6	310±2.8	10.6±0.3	13.1±0.2	0.88±0.06	0.33±0.02	0.70±0.08
NK-129	53±0.6	366±2.7	18.6±0.6	16.5±0.3	1.05±0.04	0.42±0.04	0.82±0.07
NK-338	60±0.8	421±3.1	14.3±0.3	22.2±0.6	0.18±0.02	0.38±0.04	1.10±0.09
NK-222	55±1.0	274±3.0	9.1±0.2	17.9±0.4	0.62±0.04	0.33±0.04	0.79±0.07
NK-011	53±0.9	312±3.0	9.9±0.3	17.8±0.3	0.65±0.04	0.38±0.03	0.68±0.05
NK-292	63±1.0	337±2.7	15.1±0.5	21.5±0.4	0.31±0.03	0.65±0.06	**1.65±0.12**
NK-201	41±0.8	260±2.5	8.5±0.2	12.3±0.3	0.30±0.02	0.21±0.02	0.53±0.04
NK-515	65±1.1	337±2.8	10.6±0.3	19.9±0.4	1.41±0.06	0.35±0.03	0.89±0.06
NK-172	85±1.2	450±3.1	11.8±0.4	22.3±0.5	1.03±0.06	0.37±0.01	0.77±0.06
LSD (0.05)	13.93	7.98	1.76	1.29	0.30	0.31	0.42

All values are expressed as mg/100 g fresh weight. **In bold:** accessions which have the four highest values for macro and microelements content, * Each value is expressed as the mean ± standard error (n=3)

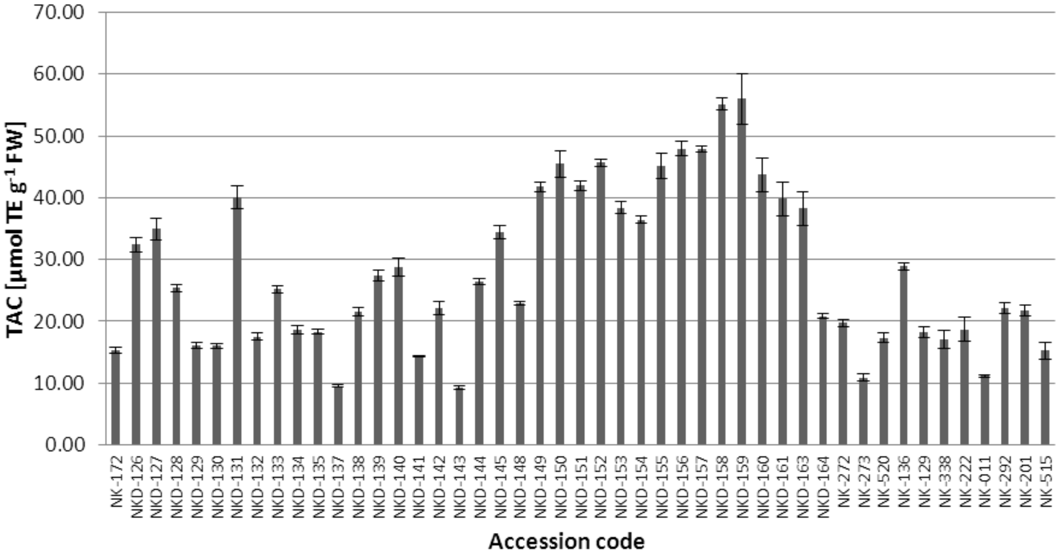

Figure 1. Total antioxidant capacity (TAC) in Native Potato Species and old Spanish accessions.

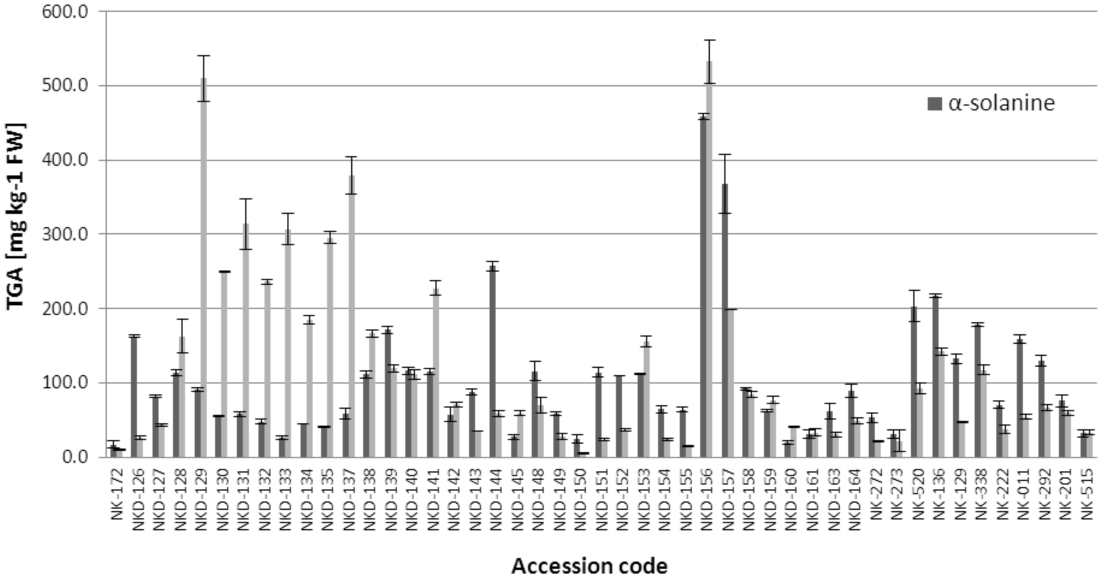

Figure 2. Total glycoalkaloid contents (TGA) in Native Potato Species and old Spanish accessions.

one *S. stenotonum* accession (NKD-129). The lowest TGA levels were observed in the species *S. ajawiri*, *S. phureja*, in the hybrid SxG and in some accessions belonging to *S. tuberosum* ssp. *tuberosum* (`NK-129, NK-338 and NK-201) and *S. stenotonum* (NKD-140, NKD-149 and NKD-164).

The concentration of α-solanine in the 46 cultivars ranged from 16.0 to 459.1 mg kg^{-1} FW and of α-chaconine from 6.4 to 532.3 mg kg^{-1} FW (Figure 2). The α-chaconine:α-solanine ratio observed in the collection shows a wide variability. Some of the evaluated *S. tuberosum* ssp. *andigena* accessions presented high α-chaconine:α-solanine ratios (NKD-130, NKD-134 and NKD-135). However, other accessions showed low ratios (NKD-126 and NKD-143), reflecting the large variation in this species. The lowest α-chaconine:α-solanine ratios were found in *S. chaucha* and *S. tuberosum* ssp. *tuberosum*. Some accessions belonging to *S. goniocalyx* (NKD-155), *S. juzepczukii* (NKD-144), and the hybrid SxG also showed low α-chaconine:α-solanine ratios.

DISCUSSION

The potato crop is affected by many pests and diseases that cause substantial damages in the field, loss of crops in storage, or affect the quality of the tubers. Managing these pathogens requires crop rotations, utilization of pesticides and other practices that are costly to farmers or environmentally unsafe. However, it may also be possible to confer resistance by transferring a naturally found resistance gene to potato cultivars of interest by conventional hybridization, if possible, or transgenic approaches.

Many complex or partial resistances against *S. scabies*, *R. solani* and *G. rostochensis* were found among the 46 potato accessions of our study. Some old Spanish potatoes also showed very interesting resistances. *S. tuberosum* ssp. *tuberosum* accessions such as NK-129, NK-136, NK-011, NK-273, NK-520 and NK-292 showed resistances to one or more pathogens. Moreover, the purple fleshed cultivar NK-136 was also resistant to *P. infestans* in leaves (Ritter *et al*., 2008). The use of these materials instead of *Solanum* wild species could accelerate breeding programmes, due to the absence of interspecific hybridization barriers.

In addition, higher DM values were found among cultivated NPS, particularly in *S. tuberosum* ssp. *andigena* accessions. RS concentrations vary widely between, and also within, potato species. In fact, the concentration of glucose and fructose vary depending on variety and storage conditions (Amrein *et al*., 2003). These monosaccharides are responsible for the darkening of potato after-cooking and are also implicated in the formation of toxic and carcinogenic acrylamide in the Maillard reaction during frying (Williams, 2005). Mineral analyses have demonstrated that macroelements contents are generally higher in NPS. Moreover, the highest Zn and Fe levels have been found in NPS accessions, but certain old Spanish potatoes also showed high concentrations. Antioxidant capacity assays revealed that NPS had higher TAC values. It is surprising that the highest TAC values were found in yellow or partially purple fleshed accessions, such as NKD-150, NKD-152, NKD-155, NKD-160 and NKD-158, NKD-159 and NKD 160, while none of the purple fleshed accessions showed outstanding values. Brown *et al*. (2007) also observed that diploid and triploid accessions had larger total carotenoid contents than tetraploids and detected higher lipophilic ORAC values in diploid species. André *et al*. (2009) observed comparable TAC values in 13 native Andean potato accessions.

Wild potato species tend to have significantly higher glycoalkaloid concentrations (Smith *et al*., 1996). Also, many cultivated NPS accessions belonging to the species *S. juzepczukii*, *S. curtilobum*, *S. ajawiri*, *S. stenotonum* and *S. tuberosum ssp. andigena* are known to have elevated total glycoalkaloid values. In fact, Andean farmers have developed a freeze drying process which is commonly used not only for conservation but also for reducing the gycoalkaloid contents of bitter tubers (Burgos *et al*., 2008). Higher glycoalkaloid contents were mainly observed in accessions belonging to the native species *S. tuberosum* ssp. *andigena*. Total glycoalkaloid concentrations found in several NPS and old Spanish accessions were extremely high compared to other studies (Hellenäs, 2001; Kirui *et al*., 2009; Savage *et al*., 2000), although it should be noted that our results are based on a single year . In fact, 45.65% of the samples contained more than the recognised safety limit of 200 mg TGA kg^{-1} FW (OECD, 2002) and four accessions exceeded even 400 mg TGA kg^{-1} FW. Knuthsen *et al*. (2009) analyzed 386 potato samples, representative of the Danish market, and only 3 of them contained more than 200 mg TGA kg^{-1} FW (0.77%).

The principal glycoalkaloids found in potatoes are α-solanine and α-chaconine, comprising about 95% of total glycoalkaloids (Sotelo and Serrano, 2000). In most cases, the contribution of α-chaconine to total glycoalkaloid content of tubers was high. This observation coincides with the results obtained by Eltayeb *et al*. (2003), Friedman (2006) and Tajner-Czopek *et al*. (2008). However, some old Spanish potato accessions showed relatively high concentrations of α-solanine.

The potential of NPS for generating additional income for local farmers through commercial exploitation has been recognised and promoted by several institutions and organisations. In fact, many native potatoes have very suitable characteristics for potato breeding. The introduction of resistances and quality traits from cultivated native species is easier because wild species are usually difficult to grow in high latitudes and generally do not produce suitable tubers. The amounts of dry matter and minerals and the antioxidant capacity found in certain accessions may contribute to the diffusion of favourable nutritional properties. Some of them have also an exotic appearance, texture, and flavour which may be particularly attractive to consumers.

Despite the fact that in Europe and USA native potatoes cannot compete with modern *S. tuberosum* ssp. *tuberosum* varieties, there is an increasing demand for special and exotic products like Tunta, Tikapapa and also Jalca Chips, which is a snack made from multicoloured native tubers (Devaux *et al*., 2010). Purple or red coloured potatoes such as Purple Pelisse, Blue Congo, and Purple Majesty are becoming popular in some innovative restaurants and delicatessen markets. Tasty yellow fleshed potatoes derived from *S. phureja* cultivars are also appreciated. However, some properties of NPS may potentially imply disadvantages for plant breeders and risks for human health. For example, introgressions from NPS can generate potato clones with unfavourable dormancy periods, high glycoalkaloid contents in tubers, much lower yields, late tuberization, small or misshaped tubers, and other negative features. Therefore, potato breeders have to consider the sum of individual characteristics when working with exotic germplasm in order to introgress the desired characteristics from an NPS accession, while minimizing detrimental traits.

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مقاومت به امراض و خاصیت های غذایی سیب زمینی های غده ای بومی و رقم های قدیمی اسپانیایی

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چکیده

مقاومت به امراض و آفات بعضی رقم های سیب زمینی مانند سیب زمینی های گونه های بومی از (رشته کوه های) آند (Andes) شناخته شده است. برخی از این نمونه های ثبت شده از لحاظ خاصیت غذایی و پخت و پز مورد توجه هستند. در این پژوهش، به منظور شناخت مقاومت به *Streptomyces scabies* ، *Rhizoctonia solani* و *Globodera rostochiensis* و نیز تعیین تولید ماده خشک، قندهای احیا شونده، مواد کانی ،غلظت *glycoalkaloid* ، و ظرفیت آنتی اکسیدان کل، مجموعه ای از ۳۵ سیب زمینی گونه های بومی و ۱۱ نمونه ثبت شده از ارقام قدیمی اسپانیایی بررسی شد. نتایج حاکی از تنوع زیاد در میان و در بین گونه های مطالعه شده بود. بیشتر نمونه ها ویژگی های مطلوبی نشان دادند در حالی که در برخی از آن ها غلظت های *glycoalkaloid* بالا بود. بر پایه این نتایج می توان گفت که بعضی سیب زمینی های گونه های بومی و ارقام قدیمی اسپانیایی به عنوان منبع مقاومت به امراض و ارزش غذایی برای کاربرد در برنامه های اصلاح ژنتیکی استعداد زیادی دارند.

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