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Research Article
Native Andean potatoes (*Solanum tuberosum* L.): Phytonutrients in Peel, Pulp and Potato Cooking Water

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Abstract
Background and Objective: Potatoes (*Solanum tuberosum* L.) are an essential crop and are often eaten after boiling. The objective of this study was to compare the concentration of chlorogenic, neo-chlorogenic and caffeic acid in the raw and cooked peel, raw and cooked pulp and the potato cooking water of native Andean potatoes. **Materials and Methods:** The variety of potato used was the native Huagalina potato cultivated in the La Libertad Region (Peru). The phenolic compounds were extracted with a 50% aqueous solution of methanol and 0.5% acetic acid in the pulp and peel separately. The Analysis was performed by UPLC-MS/MS. Nested 3-factor design, ANOVA and Tukey tests were employed. **Results:** Cooking induced a change in phytochemical content with pulp values tending to zero, meanwhile, concentrations in potato cooking water were higher than those reported for cooked pulp, but the raw and cooked peel had the highest concentration. **Conclusion:** The phytonutrients leached into the cooking water. Concentration in mg g^{-1} dw of these metabolites were reported from highest to lowest: Raw peel, cooked peel, potato cooking water and peeled pulp. Therefore, the consumption of cooked pulp with cooked peel should be encouraged.

Key words: Phenolic, cooking, antioxidants, chlorogenic acid, boiled potato

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Chronic non-communicable diseases have become a worldwide epidemic and produce 71% of annual deaths globally. Close to 85% of deaths are of people who live in low and middle-income countries[1]. To maintain the homeostasis of our cells it is necessary to include in our diet vegetables that provide functional elements such as secondary metabolites to keep us healthy[2].

The potato (*Solanum tuberosum* L.) is a universal staple food, native to Peru, which contains essential nutrients including protein, fiber, complex carbohydrates (starch, resistant and non-resistant to digestion)[3] and secondary metabolites. The main phenolic compounds are chlorogenic acid, its isomer (neo-chlorogenic acid) and caffeic acid, which make this tuber a source of phytonutrients, with antibacterial, antioxidant, anti-hypoglycemic, anti-hypolipidemic and anti-carcinogenic properties [4-7].

Due to their high daily dietary consumption, potatoes contribute 25% of phenolic compounds[8-10] putting them in 3rd among phytonutrient contributing foods. However, this tuber is not eaten raw, like oranges and apples that are in first and second place respectively, because it needs a cooking process. This process has already been studied, but there are discrepancies in the results[11,12].

A study of 13 native Andean cultivars reported that phenolic content was significantly affected by environmental conditions of the crops but these authors considered that the most important factor that influenced the variability of phenolic compounds was the genetic factor of cultivars, the potato variety[13]. Other researchers mentioned that the tuber peel is an important source of phenolic compounds and that 50% of these are found in the peel and adjacent tissues and decrease towards the center of the tuber[14-16].

In Peru, research has been carried out on native Huagalina potatoes from La Libertad Region, to determine phenolic compounds in peel and pulp separately: Raw peel and pulp, cooked peel and pulp and in potato cooking water[17-19].

People usually consume the cooked, peeled pulp of potatoes, not knowing if it is the best source of phenolic compounds. In India, potato peels are used to treat inflamed gums and heal burns[20] and in Peru, potato cooking water is considered a traditional medicine according to ancestral customs.

The aim of the study is to compare the concentrations of chlorogenic, neo-chlorogenic and caffeic acid of the Huagalina native potato of La Libertad Region, in raw and cooked peel; raw and cooked pulp and in the potato cooking water, to demonstrate scientifically what would be the best way to consume potatoes in order to take advantage of their phytonutrients for human health.

MATERIALS AND METHODS

Experimental site: Native Huagalina potato was planted in December, 2014 and harvested in June, 2015 in 2 locations in the district and province of Santiago de Chuco, La Libertad Region-Peru: El Zuro (EZ) (3 750 m.a.s.l) and, Huayatán Alto (HA) (3 150 m.a.s.l.). The analysis was done from July to December 2015, in Nubiomol Laboratory-Universidade Federal Viçosa (Brazil).

Chemical reagents: Pure HPLC grade standards were purchased from Sigma-Aldrich (USA): Chlorogenic, neo-chlorogenic and caffeic acids.

Experimental treatment

Extraction: The following aqueous extraction solution (ES) was prepared: 50% methanol and 0.5% acetic acid[17-19]. The phenolic compounds were extracted from the peel, pulp and cooking water separately: Raw peel (CCEZ, CCHA), cooked peel (CBEZ, CBHA), raw pulp (PCEZ, PCHA), cooked pulp (PBEZ, PBHA) and cooking potato water of lyophilized slices (SPEZ, SPHA), from whole potato (RPEZ, RPHA).

Analysis by UPLC-MS/MS: Extracts were automatically injected (5 µL) into the UPLC-MS/MS system, an Agilent 1200 Infinity Series equipment coupled to a triple Quadrupole Mass Spectrometer (QqQ) model 6430 Agilent Technologies.

Statistical analysis: A nested design of 3 factors was applied with the concentration values of chlorogenic, neo-chlorogenic and caffeic acids: (1) Place of origin (EZ, HA), (2) Part (peel or pulp), (3) Treatment (cooked or uncooked) in potato peel and pulp and 2 factors for the cooking water of the potatoes: (1) Place of origin (EZ, HA), (2) Treatment (fresh, lyophilized slices SP and stored whole potato RP), with 3 replications. The homogeneity of variances was checked using the modified Levene test, an analysis of variance (ANOVA) because of significant differences and Tukey test was applied. All the statistical analysis was performed with a confidence level of 95%.

RESULTS

Phyto-nutrients in raw and cooked peel: Cooking induced changes in phytochemical content, the results showed different concentrations of chlorogenic, neo-chlorogenic and caffeic acid in raw peel and cooked peel. For potatoes cultivated in EZ, the concentration of the aforementioned phytonutrients decreased after cooking. The same happened for HA, with the exception of neochlorogenic acid (Fig. 1).

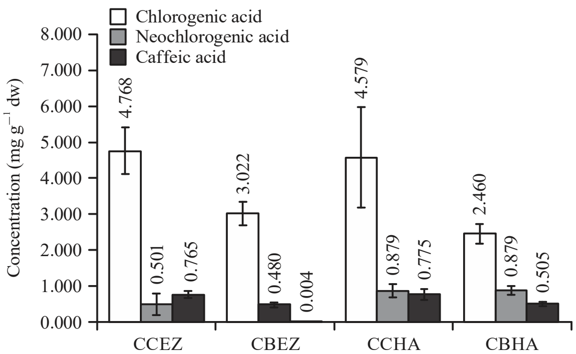

Fig. 1: Chlorogenic, neo-chlorogenic and caffeic acid in raw peel and cooked peel of Huagalina potato

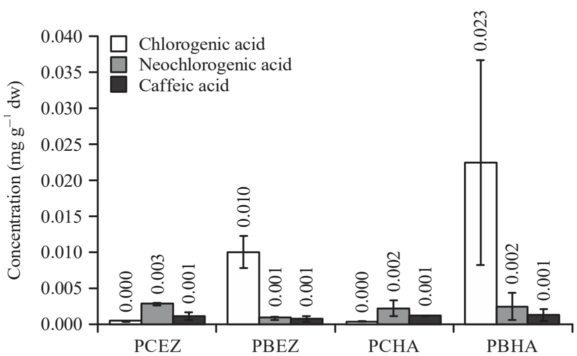

Fig. 2: Chlorogenic, neo-chlorogenic and caffeic acid in raw pulp and cooked pulp of Huagalina potato

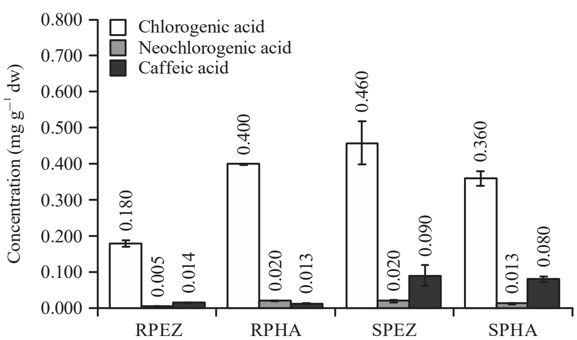

Fig. 3: Content of chlorogenic acid, neo-chlorogenic acid and caffeic acid in potato cooking water of lyophilized slices and whole potato

Phytonutrients in raw and cooked pulp: As can be seen in Fig. 2, the scale of the "y" axis was100 times smaller than the scale used for the peels in Fig. 1. The raw and cooked pulps were not a good source of these metabolites. Within this scale, the highest content of chlorogenic acid was found in the cooked pulp of HA (0.023 mg g^{-1} dw) and the lowest value in the cooked pulp of EZ (0.010 mg g^{-1} dw), both values tending to zero.

Phytonutrients in potato cooking water of lyophilized slices and whole potato: Metabolite concentrations in potato cooking water were higher than those reported for cooked pulp. The highest concentration of chlorogenic acid was found in potato cooking water from SPEZ (lyophilized slices) and RPHA (whole potato) while the highest values of caffeic acid are found in lyophilized slices EZ and HA. Neo-chlorogenic acid values tended to zero in all cases (Fig. 3).

Nested Anova for peel, pulp and potato cooking water: In all cases a significant difference was reported for the types of sources studied. From both localities concentrations of the metabolites were different in raw peel and pulp, cooked peel and pulp and cooking water from whole potato and lyophilized slices (Table 1).

Nested Tukey for raw and cooked peel and pulp: According to the results, the highest concentrations of chlorogenic acid was found in the CCEZ (4.768 mg g^{-1} dw), neo-chlorogenic acid in CCHA and CBHA (0.879 mg g^{-1} dw), caffeic acid in the raw peel of HA and EZ (0.775 mg g^{-1} dw). The raw and cooked pulps were the ones with the lowest concentration of these metabolites (Table 2).

Nested Tukey test for potato cooking water: The highest concentrations of chlorogenic acid were found in potato cooking water from RPHA (0.462 mg g^{-1} dw), neo-chlorogenic acid in RPHA (0.021 mg g^{-1} dw), caffeic acid in RPHA (0.094 mg g^{-1} dw). These values were higher than those found in the raw and cooked pulp (Table 3).

Table 1: Nested ANOVA results for peel, pulp and potato cooking water

Metabolites	Source*	Source**	Results
Chlorogenic acid	Treatment part (treat)	Presentation origin (pres)	Significant difference
Neochlorogenic acid	Part (treat) origin (part, treatment)	Presentation origin (pres)	Significant difference
Caffeic acid	Treatment part (treat) origin (part, treatment)	Presentation origin (pres)	Significant difference

*Peel and pulp: Treatment (treat): Raw-cooked, Part: Peel and pulp, Origin: EZ-HA, **Potato cooking water: Presentation (pres): Freeze-dried slices(SP)-whole potato stored (RP), Origin: EZ-HA

Table 2: Nested Tukey, in raw and cooked peel; raw and cooked pulp

Origin (part, treatment)	Chlorogenic acid (mg g^{-1} dw)	Neochlorogenic acid (mg g^{-1} dw)	Caffeic acid (mg g^{-1} dw)
(Raw peel) CCEZ,	4.768^{a}	0.501^{a,b}	0.765^{a}
(Raw peel) CCHA	4.579^{a,b}	0.879^{a}	0.775^{a}
(Cooked peel) CBEZ	3.022^{b,c}	0.480^{b}	0.004^{c}
(Cooked peel) CBHA	2.460^{c}	0.879^{a}	0.505^{b}
(Cooked pulp) PBHA	0.023^{d}	0.002^{c}	0.001^{c}
(Cooked pulp) PBEZ	0.010^{d}	0.001^{c}	0.001^{c}
(Raw pulp) PCEZ	0.000^{d}	0.003^{c}	0.001^{c}
(Raw pulp) PCHA	0.000^{d}	0.002^{c}	0.001^{c}

The averages that do not share a letter are significantly different

Table 3: Nested Tukey test for potato cooking water

Origin (presentation)	Chlorogenic acid (mg g^{-1} dw)	Neochlorogenic acid (mg g^{-1} dw)	Caffeic acid (mg g^{-1} dw)
Whole potatoes (RPHA)	0.462^{a}	0.021^{a}	0.094^{a}
Lyophilized slices (SPEZ)	0.404^{a,b}	0.020^{a}	0.089^{a}
Lyophilized slices (SPHA)	0.368^{b}	0.013^{b}	0.015^{b}
Whole potatoes (RPEZ)	0.181^{c}	0.006^{c}	0.013^{b}

The averages that do not share a letter are significantly different

DISCUSSION

The results of this research into native Andean Huagalina potatoes showed that when the peel was cooked, 63% of chlorogenic acid in the raw peel (4.768 mg g^{-1} dw = 100%), was retained, 8% was recovered in the potato cooking water and only 0.2% in the cooked pulp. When the peel was cooked, 66% of caffeic acid from the raw peel (0.765 mg g^{-1} dw = 100%), was retained, 12% was recovered in the potato cooking water and 0.13% in the cooked pulp. The highest concentration of the metabolites studied was found in the raw peel, cooked peel and the potato cooking water. It is important to mention that this concentration could be improved by changing the potato/water ratio from 1/3 to 1/2, 1/1. The fact is that when eating peeled pulp a significant amount of phenolic acid are lost because the peel is either thrown out as waste or used in animal feed.

It is possible to explain that the higher level of phenolic compounds in the cooking water rather than in the pulp occurs during the boiling process when the contact between the peels and water is more significant. There is a high transfer of analytes as these are leached into the hot water as the mechanical action of boiling contributed to a higher leaching action[12]. The difference in concentrations for raw peel and pulp, cooked skin and pulp and potato cooking water could be assumed to be because of thermal processing that affects not only chemical composition and physical structure but also the intake of bioactive compounds. Another reason could be the different environmental conditions of the crops on the two sites (HA and EZ). It is important to note that in this study, the monitoring of weather conditions was not enough to determine if the different climatic conditions of each locality affected the concentration of phenolic compounds. Previous research publications reported that cultivars were significantly affected by environmental conditions of cultivation, but the profile of phenolic compounds was the same, only concentrations varied[21-23].

Recent publications justified the importance of consuming both the pulp and the peel of cooked potatoes. Consuming phenolic and fiber from peel and resistant starch from the pulp improve the microbiota of the intestine, thus contributing to gastrointestinal health. These are metabolized by the bacteria of the intestine raising the levels of short-chain fatty acid that develop anti-inflammatory properties in the intestine[24-26] and can attack colon cancer cells.[27]. Drinking potato fresh juice decreases the clinical impact of peptic ulcers, which is a problem that affects many people and its primary cause is infection by *Helicobacter pylori* which can trigger gastric cancer. It has also been demonstrated *in vitro* that the potato peel extract has a protective role in the liver and brain cells against oxidative stress, retaining the levels of antioxidant enzymes[28-30].

Therefore, there is a critical need to raise awareness of the health benefits of consuming cooked pulp with peel, as well as to develop programs that encourage the preparation of meals that include potatoes with their peels and also the consumption of cooking water. It is also crucial to develop varieties that are rich in these metabolites and the native Andean potatoes could be considered to be a rich source of alleles for the development of modern varieties whose objective is not only economic but to increase the supply of phyto-nutrients. It is imperative to continue with research on the mechanisms between potato consumption and its effects on human health like bio-accessibility and bioavailability *in vivo*.

CONCLUSION

In this study, the concentration in mg g^{-1} dw of chlorogenic, neo-chlorogenic and caffeic acid in the native Andean Huagalina potato was found to be, from higher to lower: Raw peel, cooked peel, cooking water and cooked pulp. The fiber and the phenolic compounds of the cooked peel and the resistant starch of the cooked pulp improve the action of these phyto-nutrients which help prevent degenerative diseases in our organism. That is why it is necessary to continue with this study *in vivo*.

SIGNIFICANCE STATEMENT

This study discovered that consuming cooked potato pulp with peel can be beneficial to prevent degenerative diseases. This study will help the researchers to uncover critical areas of bioavailability and bioaccessibility of phytonutrients for potato peel, pulp and cooking water that other researchers were not able to explore before. Thus a new theory for the way we should consume cooked potatoes in the diet may be found.

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