Compositional Changes of Oca Tubers Following Postharvest Exposure to Sunlight

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Oca is an edible starchy tuber grown in the Andes. To improve its culinary quality, harvested oca is typically exposed to direct sunlight (sunned) for several days prior to consumption. Five native cultivars were examined to determine the changes in nutritional composition of oca as a result of sunning. This practice increased the proportions of dry matter, soluble solids, and sugars (mainly sucrose) and decreased total acids, due mainly to a large reduction in malate and glutarate. High levels of oxalate, an anti-nutritional factor, were found, ranging from 306 to 539 and 251 to 451 mg/100 g in edible matter of freshly harvested and sunned tubers, respectively. Sunning reduced oxalate levels in dry matter by an average of 26%. Further study will be necessary to fully assess the food safety of oca and to provide recommendations for maximum daily intake.

Oca (*Oxalis tuberosa* Molina) is an edible starchy tuber grown in the high Andes. Native Amerindian communities of Bolivia and southern Peru regard oca as a valuable source of food, second in importance to the potato among root and tuber crops. Oca tubers are usually baked or cooked in stews, although rural children sometimes eat them raw. Cooked oca has a mushy or floury texture depending on the starch content, and a sweet, slightly acid taste. Raw oca is tart and pleasantly crunchy.

After harvesting, oca tubers destined for direct consumption are traditionally exposed to direct sunlight for a week or two. This treatment is referred to as sunning, or *soleado*, and is known to enhance sweetness and improve culinary quality.

The chemical composition of oca has not been studied in detail, although we do know that starch accounts for the majority of tuber dry matter and represents between 5% and 21% of fresh matter (Cortes, 1978). According to Gross et al. (1989), the most important sugars occurring in oca are sucrose and glucose; there are also traces of raffinose and stachyose. Protein accounts for about 1% of fresh matter (Gross et al., 1989; Kays et al., 1979), but the quality is low (Gross et al., 1989). Oca provides a good source of vitamin C (38 mg/100 g (Collazos, 1974)), potassium, and iron (Kays et al., 1979). Recent work in New Zealand revealed high levels of soluble oxalate in oca, ranging from 92 to 221 mg/100 g edible matter (Ross et al., 1999). However, more comprehensive data on the composition of acids and sugars, which are responsible for the peculiar taste and presumably postharvest changes in sweetness and quality, are not currently available in oca.

The objective of the present study was to investigate the compositional changes

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occurring in oca during sunning. Analyses concentrated on starch, sugars, and acids as these are the most important chemical constituents in defining taste, texture, and nutritional value.

Materials and Methods

Five native cultivars of oca were selected (see Table 1), which are consumed directly, rather than processed into storable products. Single plants were grown from tubers planted in six-liter pots in an open-sided, insect-proof, quarantine greenhouse situated near Quito, Ecuador. Temperature and light conditions were close to those of the surrounding equatorial highland environment (altitude 3000 m). The pot substrate consisted of a mix of peat, sand, and volcanic soil. The plants were fertilized with a compound fertilizer, and watered as required. A randomized block design with three replications was used, with pots spaced at intervals of 40 by 70 cm. Tubers were harvested eight months after planting, when all accessions had formed mature tubers and the aerial parts of the plants had died. Half the harvested tubers of each plant were reserved for immediate chemical analysis and the other half for sunning prior to analysis.

The sunning treatment started on the day following harvest. Tubers were placed on a reflective surface (aluminum foil) in the greenhouse and left for 10 days. They were thus exposed to full sunlight and protected from rain. Temperature sensors connected to electronic ONSET “stow-away” data loggers were placed in the center of one oca tuber and in the surrounding air. Temperatures were recorded at half-hourly intervals.

Because of limited laboratory capacity, only one pooled sample from the three replications of an accession was analyzed for chemical constituents. Sugars and acids were extracted from freeze-dried samples by immersing in water at 70° C for 30 minutes. A high performance anion exchange chromatograph (HPAEC) was used to determine the levels of sugars and acids. Starch was physically extracted from fresh tuber tissue by macerating in a kitchen blender, followed by three cycles of washing and starch sedimentation. Both starch and HPAEC measurements were taken in duplicate. Soluble solids were measured with a portable refractometer and levels of dry matter were determined by freeze-drying.

Starch yields throughout this paper are expressed as the weight of air-dried starch obtained per tuber fresh weight. The water content of air-dried starch was found to range between 10% and 12%.

Results

Although their edaphic space was restricted by being pot-grown, the oca plants developed normally, showing a typical ontogenetic sequence (slow initial development followed by vigorous shoot and foliage growth, flowering, tuber bulking, and senescence). Plant and final tuber size and plant habit were comparable to those usually observed for oca under field conditions.

During sunning, maximum tuber flesh temperatures reached 35° C in the early

Table 1. Oca cultivars used in this study and their attributes.

Collector number	Common name	Country and locality	Altitude (m)	Latitude	Longitude	Comments
ECU-1018	Not available	Ecuador, Los Dos Puentes, Loja	2130	03°59'S	79°13'W	Varieties typical of the country of origin
ECU-1025	Oca amarilla	Ecuador, Baber, Loja	2660	03°36'S	79°11'W	—
CA-5054	Kile	Peru, Chamis, Cajamarca	3100	07°09'S	78°30'W	—
MU-028	Ch'iyara apilla	Peru, Collini - Uta Uyu, Puno	3900	16°19'S	69°18'W	Good culinary quality
HN-1146	Oca amarilla	Argentina, Colanzulí, Salta	3700	22°53'S	65°12'W	Especially sweet

afternoon, and were about 10° C higher than maximum air temperatures. Minimum tissue temperatures occurred at dawn and varied between 7 and 10° C.

Composition of freshly harvested oca tubers.

Dry matter and physically extractable starch accounted for 10.4–14.3% and 5.2–9.2% of freshly harvested edible matter, respectively (Table 2). Total sugars comprised 2.1–3.6% and total organic acids amounted to 2.6–3.4% of fresh matter. Of the total sugars in freshly harvested tubers, about half was sucrose and about a quarter each of fructose and glucose. Among the organic acids, glutarate and malate were most abundant and tartarate least. There were notable differences between accessions, especially regarding the content of starch, total sugars, and single acids. Accessions ECU-1025 and CA-5054, which had the highest dry matter and starch content, were also high in total sugars, but had average acidity. HN-1146 had almost twice the oxalate content of CA-5054, but its total acid content was only 11% higher. This suggests the existence of considerable variation in the acid profiles of different oca cultivars. However, the statistical significance of these results cannot be determined due to the fact that only one pooled sample was studied.

Light-microscopic inspection of tuber tissue taken from all five accessions, from both freshly harvested and sunned tubers, yielded no evidence of the presence of insoluble oxalate crystals.

Compositional changes due to sunning

Sunning resulted in several substantial changes in tuber composition, which were broadly consistent across accessions in magnitude and direction. Table 2 shows compositional changes for fresh, edible matter. In comparison with freshly harvested tubers, sunning increased dry matter content through water evaporation, soluble solids, and total sugars, but sharply

Table 2. Chemical composition and attributes of freshly harvested versus sunned oca tubers (per 100 g edible matter).

Variable	**Unit**	**Range**	**Range**	**ECU-1018**		**ECU-1025**		**CA-5054**		**MU-028**		**HN-1146**	
		fresh	**sunned**	**Fresh**	**Sunned**	**Fresh**	**Sunned**	**Fresh**	**Sunned**	**Fresh**	**Sunned**	**Fresh**	**Sunned**
Dry matter	g	10.4-14.3	16.1-20.0	13.2	16.1	13.6	17.9	14.3	20.0	12.6	16.1	10.4	16.3
Starch	g	5.2-9.2	2.2-6.5	7.6	5.7	9.2	6.5	8.2	3.3	5.5	2.2	5.2	2.8
Soluble solids	°Brix	6.2-9.2	6.7-9.7	7.8	8.3	6.2	6.7	9.2	9.7	8.0	8.6	7.2	7.7
Total sugars	mg	2119-3635	2910-5870	2119	2910	3635	5043	3073	5870	3517	4796	2662	4407
Sucrose	mg	1208-1826	1901-3955	1208	1901	1525	2879	1791	3956	1826	3015	1377	2496
Fructose	mg	477-1085	553-1217	477	553	1085	1217	745	1023	903	956	666	922
Glucose	mg	433-1025	456-988	433	456	1025	948	538	892	787	825	618	988
Organic acids	mg	2567-3385	937-1970	2838	1225	3164	938	3045	1693	2567	1519	3385	1970
Glutarate	mg	1071-1578	121-516	1430	189	1443	121	1578	224	1071	365	1350	516
Malate	mg	636-1088	139-660	636	217	946	139	804	660	764	300	1088	452
Oxalate	mg	306-539	251-451	397	410	403	251	306	389	336	406	539	451
Succinate	mg	270-315	294-364	315	294	315	317	300	364	312	358	270	360
Tartarate	mg	57-138	56-191	59	115	57	110	57	56	84	90	138	191

decreased levels of starch and organic acids. For example, sugar levels almost doubled in CA-5054 and HN-1146, while total acids in ECU-1025 were reduced to less than a third of the level in freshly harvested material. The decrease in acids was due to large reductions in glutarate and malate, typically to less than 30% of the values of freshly harvested oca, whereas oxalate, succinate, and tartarate showed a slight overall increase. This increase was probably due to a concentration effect resulting from dehydration of the sunned tubers.

In contrast to fresh matter, dry matter analysis (Table 3) showed a reduction in levels of oxalate and succinate in all five accessions, whereas tartarate was reduced in three accessions. Similar tendencies were seen for sugars. Fructose and glucose concentrations were generally higher in the edible matter of sunned tubers compared with freshly harvested material (Table 2), whereas analysis of dry matter (Table 3) showed that both sugars tended to diminish in sunned tubers. Sucrose accounted for most of the increase in total sugars after sunning, in both edible matter and dry matter.

Figure 1 shows oca starch grains of freshly harvested and sunned tubers, illustrating a reduction in grain size, which suggests starch degradation in the sunned material.

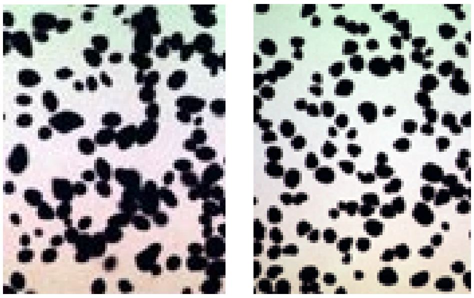

Figure 1. Oca starch granules of freshly harvested (left) and sunned (right) oca tubers, cultivar ECU-1025, at the same magnification.

Discussion

This study is the first to provide extensive data on the carbohydrate and organic acid composition of freshly harvested oca tubers. It is also the first to address the compositional changes associated with sunning, a traditional postharvest technique to render the tubers more palatable. The oca cultivars used in this study are morphologically diverse and represent different agro-ecologies found in Argentina, Ecuador, and Peru. These data are therefore not constrained by using geographically limited material and allow inference to be made concerning oca throughout the species range.

In agreement with earlier studies (Cortes, 1978; Gross et al., 1989; Kays et al., 1979), oca was shown to consist mostly of

Table 3. Effect of sunning on oca tuber composition relative to dry matter.

Variable	Range (% dry matter)		Relative change due to sunning (%) (freshly harvested = 100%)				
	Freshly harvested	Sunned	ECU-1018	ECU-1025	CA-5054	MU-028	HN-1146
Starch	43-68	14-36	61	53	29	32	34
Total sugars	16-28	18-30	113	105	136	107	106
Sucrose	9-14	12-20	129	143	158	129	116
Fructose	4-8	3-7	95	85	98	83	88
Glucose	3-8	3-6	86	70	119	82	102
Organic acids	20-32	5-12	35	23	40	46	37
Glutarate	8-13	0.7-3.2	11	6	10	27	24
Malate	5-10	0.8-3.3	28	11	59	31	27
Oxalate	2.1-5.2	1.4-2.8	85	47	91	95	54
Succinate	2.1-2.6	1.8-2.2	76	76	87	90	85
Tartarate	0.4-1.3	0.3-1.2	160	147	70	84	89

starch (about 50% of total dry matter) and sugars. Sucrose was the most important sugar followed by fructose and glucose. Acidity in oca is not only attributable to oxalate, but also to other organic acids, particularly glutarate and malate. However, oxalate is the most important acid from a dietary point of view, being an anti-nutritional factor. Dietary oxalate binds to calcium, preventing it from being used for essential functions in human metabolism. In addition, oxalate forms insoluble salts with calcium, which can lead to the development of kidney stones (Holmes et al., 1995).

Levels of oxalate in freshly harvested (306–539 mg/100 g edible matter) and in sunned oca (251–451 mg/100 g) (Table 2), were considerably higher than those found in most other starchy staples (<100 mg/100 g). Only aroids such as taro (*Colocasia esculenta*) have similarly elevated oxalate levels; however, most of the oxalate in these species occurs as insoluble calcium salts (Holloway et al., 1989). In contrast, Ross et al. (1999) found that oxalate in oca appears in its soluble form. The present study supports these findings, as oxalate crystals were not observed in oca tissue when viewed under the microscope.

Oxalate ranges in this study were 2–2.5 times greater than those reported in field-grown material in New Zealand (Ross et al., 1999). Oxalate levels are known to be influenced by environmental factors, particularly nitrogen fertilization, and this raises the question of whether cultivation in pots led to the high levels observed in this study.

Although high, the levels of oxalate found in oca in this study are still only half those reported for wild and cultivated species in the Amaranthaceae, Chenopodiaceae, and Polygonaceae (Libert and Franceschi, 1987; Guil et al., 1997). These leaf vegetables are considered safe for human consumption in moderation. Furthermore, oca is mostly baked or boiled before being consumed, procedures that are known to significantly reduce oxalate levels (Ross et al., 1999).

Further studies to identify the bio-availability of oxalate in oca are needed before final nutritional recommendations can be made. The findings of this study suggest that, at the current state of knowledge, it would be premature to promote oca for regular and high consumption, as the oxalate intake would be considerable and could pose health risks especially for infants.

This study suggests that sunning oca tubers results in considerable compositional changes. These improve the eating quality of oca through an increased sugar content and reduced acidity. Unfortunately, the anti-nutritional factor oxalate is one of the compounds least affected by these changes. Nevertheless, oxalate intake per consumed oca dry matter would, in the case of the five accessions studied, have been reduced through sunning to 47–95% of the initial values (mean: 74%).

Much oca is processed into *khaya*, a dry, storable product with a similar density to cork. This has a bland, floury taste when reconstituted with water and cooked. Processing oca involves a number of steps, including freezing, leaching, squeezing and drying. Processing aims to remove most of the solutes from the tuber, and is probably very efficient in removing oxalates. The compositional changes that occur during processing of oca would be worthy of further study.

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