# Session VIII

# Biofortification and adding value for food and health in root and tuber crops

## *Lead lecture*

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|---|---|
| *Pfeiffer, W.H.* | Breeding crops for better nutrition |

## *Invited speakers*

| | |
|---|---|
| *Ceballos, H* | Process increasing carotenoid contends in cassava roots |
| *Dixon, B.M.* | Testing retention of pro-vitamin A carotenoid in locally cassava products |
| *Tammaharjo, S.* | Testing the bioability of Pro vitamin A carotenoids in biofortified cassava |
| *Ospina, B.* | Product development and marketing in Brazil and Colombia: Lessons from Agrosalud |
| *Low, J.* | Introduction: Micronutrient malnutrition and health. |
| *Mwanga, R.* | OFSP varieties for Eastern Africa |
| *Andrade, M.* | OFSP varieties for Southern Africa |
| *Sreekanth, A.* | OFSP varieties for South Asia |
| *Xie, K.* | OFSP varieties for East Asia |
| *Gruneberg, W.* | OFSP varieties for Latin America |

## *Oral presentations*

| | |
|---|---|
| Rodriguez, Elsa | Consumers preferences for potatoes with quality attributes in Argentina |
| De Haan, Stef | The effect of process and environment on the nutritional value of Chuño |
| Tumwegamire, Silver | Agronomic and molecular characterization of orange-fleshed East African sweetpotato landraces |
| Vimala, Bai | Carotenoid retention in Bellow – fleshed cassava Turing processing sweetpotato cultivars |
| Sopade, Peter | Physico-chemical and functional properties of Australian sweetpotato cultivars |
| zum Felde, Thomas | Screening for total carotenoids, b-carotene, iron, zinc, starch, individual sugars and protein in sweetpotato germplasm Accessions by near-infrared reflectance spectroscopy (NIRS) |

| | | |
|---|---|---|
| | Tomlins, Keith | Consumer acceptance of bread containing biofortified orange flesh sweet potato. |
| | Oyunga-Ogubi, Mary | Street foods in Nairobi, Kenya: Their role as a source of micronutrients in low income groups. |
| | Roskruge, Nick | The foods of Rongo-marae-roa, sustaining the Māori of NewZealand |
| | Vimala, Bai | Seasonal variation of carotenoids in orange-fleshed sweetpotato (*Ipomoea batatas* (L) Lam) |

## *Posters*

| | | |
|---|---|---|
| 09 | Burgos, Gabriela | Concentration of vitamin C, carotenoids and polyphenolics in cooked potatoes. |
| 10 | Burgos, Gabriela | Using a color chart to screen for high β-carotene in OFSP breeding |
| 11 | Eyzaguirre, Raul | Selection limits for dry matter, β-carotene, iron and zinc in low dry matter orange flesh sweetpotatoes (OFSP) using a 8 x 8 diallel |
| 12 | Gruneberg, Wolfgang | Dialelic analysis of sweetpotato clones for yield and concentration of carotene, iron and zinc |
| 13 | Lukonge, Everina | Current status of orange-fleshed sweetpotato breeding in Tanzania |
| 14 | Namutebi, Agnes | Darkening in open-air sun dried orange-fleshed sweetpotato products being promoted for their high pro-vitamin A carotenoid content |
| 15 | Ndiringwe, Jean | Relationship among yield components of eight introduced yellow and orange fleshed sweetpotato in Rwanda |
| 16 | Ndolo, P.J. | Agronomic performance of regional popular orange-fleshed sweetpotato (*Ipomoea batatas* (L.) Lam) cultivars in Kenya |
| 17 | Ssemakula, Gorrettie | Release and diffusion orange sweetpotato cultivars, 'NASPOT 9 O', 'NASPOT 10 O' in Uganda |
| 18 | Habib, Natalia | Endogenous glucogon-like peptide-1 (GLP-1) on lipid-lowering effect of yacon roots in diabetic rats |
| 19 | Ceballos, Hernan | Heritability estimates of carotenoid content in cassava roots |
| 20 | Ceballos, Hernan | Variation in carotenoid content in roots from the same plant and plants from the same cassava genotype. Colombia |
| 21 | Ceballos, Hernan | Progress in developing a system for direct and simple measurement of protein content in cassava roots |
| 22 | Ceballos, Hernan | Effect of age of the plant in total carotenoids content in cassava roots |
| 23 | Ceballos, Hernan | Agronomic biofortification to improve nutritional quality of cassava roots |
| 24 | Honore, Stella M. | Protective effect of yacon leaves extracts against nephropathy induced by experimental diabetes in rats |
| 25 | Mukantwali,C.hristine | Development of quality cereal based composite flour for nutritionally vulnerable children using locally available raw material |

# Consumers preferences for potatoes with quality attributes in Argentina

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## Introduction

When purchasing food, consumers make their choices by comparing prices and qualities. Such choices are definitely conditioned by the uncertainty they perceive in relation to the different qualities offered and by the information available to them.

The concept of quality has become crucial in the new approaches of Demand Theory (Lancaster, 1966), who affirms that consumers derive utility from goods´ attributes, not directly from goods. Consumers´ choices are definitely conditioned by the uncertainty they perceive with regard to different qualities offered. Consequently, quality has started to be incorporated as an additional variable in food demand functions (Antle, 1999). As a wide and subjective notion, it deals with different kinds of attributes which could either be verified by consumers or not, before or after purchasing food e.g., colour, flavor, nutritional facts, added substances during the productive processes and risks perceptions, retail channel preferences, knowledge about varieties, and opinions regarding private or public regulation systems. Govindasamy and Italia (1999) reported that higher income earners and younger people were more willing to purchase integrated pest management produce than lower income earners and older people.

The aim of this research is twofold: to examine consumers' preferences for potatoes quality attributes and also to identify those factors associated to purchase of potato quality. For these purposes we have analysed socio-demographic variables, potato purchasing habits, perceptions and attitudes towards potato quality attributes. The importance of prices in potato buying decisions and also consumers´ willingness-to-buy high quality potatoes.

## Theoretical background

### *Perception and evaluation of food quality*

Consumers' evaluation of quality plays a major role when selecting and consuming fresh foods. In the case of unprocessed food, lacking brands, other factors are influencing purchasing decisions. Consumers use various intrinsic and extrinsic cues to infer food quality (Alfnes, 2004). Beside intrinsic cues such as fat content and appearance, extrinsic cues, such as price, labels or packaging are becoming increasingly important to consumers. Thus, in order to meet consumers' expectations and preferences, it becomes important for producers to know which quality cues and attributes are relevant and available to consumers. And, from a consumers' perspective, certain qualities have to be visible and understandable in order to reduce uncertainty about the product and consumer dissatisfaction. Thus, any effort to differentiate products and promote food quality will only be successful if new or advanced attributes can be communicated to consumers (von Alvensleben and Scheper, 1997).

Steenkamp (1990) developed a model of the quality perceptions process that describes the way in which consumers form perceptions about the quality of a product in purchase decisions. It offers a useful framework for uncovering the effects of quality cues and attributes on perceived quality. Quality characteristics are identified as intrinsic and extrinsic quality cues and experience and credence quality attributes. Quality cues are used in the development of perceived quality by the individual. This quality perception involves three processes: 1. Cue adquisitions and categorization 2. Quality attributes belief formation, and 3. Integration of quality attributes beliefs. This process is influenced by personal and situational variables. Caswell *et al.* (2000) indicate that food quality attributes can be analyzed along a Unified Quality Framework as it is used as the basis of our empirical work (Figure 1)

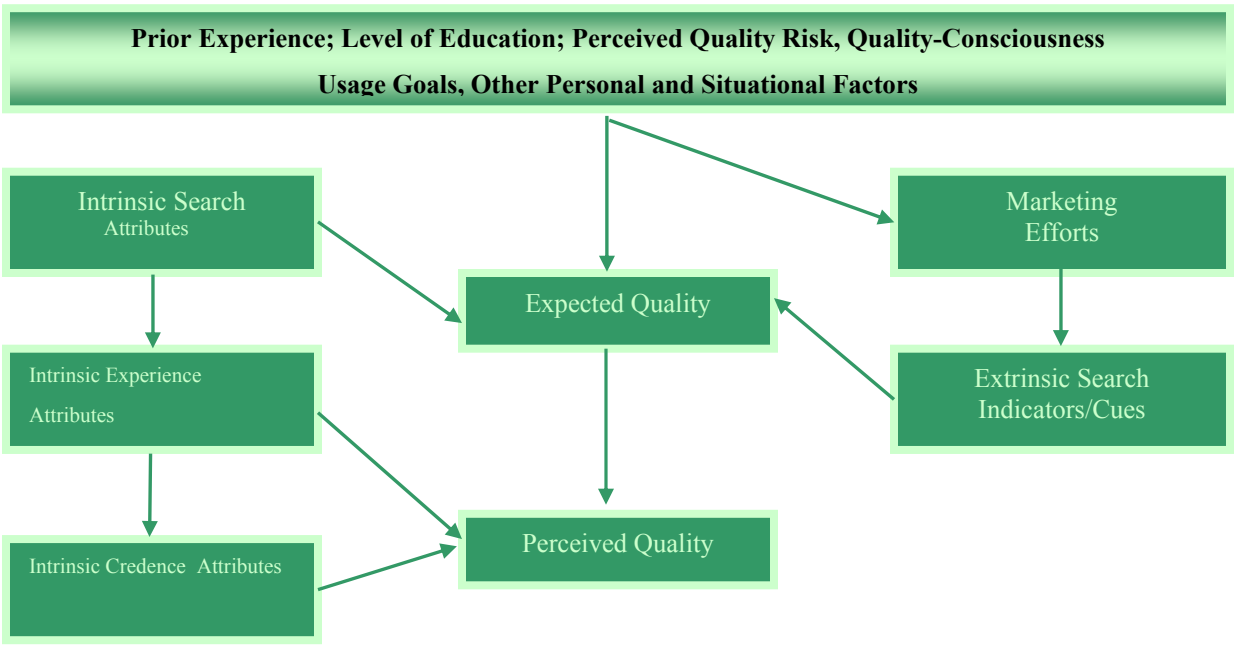


**Figure 1. A Unified Quality Framework**

Source: Caswell *et al.* (2002)

In our application, the following quality characteristics related to the purchase of potatoes were analyzed:

1. Food safety:
   - Pesticide or Drug Residues — Intrinsic Quality attributes
   - Food safety — Credence Quality Attributes
   - Health — Credence Quality Attributes
2. Nutrition:
   - Calories — Intrinsic Quality Cues
   - Fat content — Intrinsic Quality Cues
   - Carbohydrates and Fiber content — Intrinsic Quality Cues
   - Protein content and Vitamins — Intrinsic Quality Cues
3. Sensory:
   - Colour
   - Appearance — Extrinsic Quality Cues
   - Softness — Intrinsic Quality Cues
   - Smell — Intrinsic Quality Cues
   - Freshness — Experience Quality Attributes
   - Kind variety — Intrinsic Quality Cues Sensory
   - Taste/flavor — Experience Quality
4. Value/Function Attributes:
   - Size, Preparation/convenience, Packaging
5. Image:
   - Brand — Extrinsic Quality Cues
   - Price — Extrinsic Quality Cues
   - Labels — Extrinsic Quality Cues
6. Process:
   - Local — Credence Quality Attributes
   - Integrated pest management potato — Credence Quality Attributes
   - Origin — Credence Quality Attributes

## Data

Data come from a household survey we conducted in Mar del Plata city, Argentina, in June 2009 using a questionnaire - based face to face interviews. A representative sample of the population in this city included 500 randomly selected households. The survey included questions concerning different socio-economic and demographic factors such as household income (Respondents were asked to choose categories of income due to reluctance to give specific income values), household size, employment status, education level and age. Respondents were also asked about their shopping habits and attitudes. These questions were related to the frequency of potato shopping and consumption, attitudes toward food safety, perceptions of good and also bad potato quality. Willingness- to-purchase and to pay a higher price for an integrated pest management potato was also included in the questionnaire.

## Results

### *Consumers' perception about potatoes quality attributes*

Some factors related to consumer attitudes and perceptions of potato quality attributes included in this study were selected from discussions with consumers, producers and retailers' focus groups (Rodríguez *et al,* 2008).

Consumers with high education level are more likely to be worry about health, food nutritional content and pesticide usage in the production process. By contrast, price is not relevant for them. Potatoes were consumed at least 1-2 times a week by nearly 35% of the interviewers. The main reason to purchase potatoes regardless education is the appearance (66 %), size (62 %) and skin colour (34 %). Consumers mainly prioritize taste/flavor (48 %) and smell (15 %).

In this sample the household size is between two and four members *per* household. Respondents who have reached the lowest educational level belong to the largest households' size. The higher the educational level, the higher the household monthly income. 45% of respondents have declared a monthly income not higher than $ 2,000 Argentinean pesos (1 US dollar = 3.8 Argentinean Pesos, Exchange rate June 2009).

Respondents have declared health care, nutritional content and lack of agrichemicals content in food as the most important reasons they take into account when purchasing food products. The average score given by consumers to risk in consuming potatoes with pesticide and fertilize content is high (8 points).

Motives for buying potatoes. Respondents have considered the visual appearance (e.g., no scratches or bruises) and also the size, as the most important extrinsic attributes when selecting potatoes and the marketplace. These results have been verified for respondents within all the educational levels. Among the higher educational level respondents, potato price is not an emphasized attribute. After purchasing potatoes and when they cook and prepare a wide range of meals, all the respondents have highlighted the flavour and the softness as the most relevant intrinsic potato attributes.

**Sale channel.** All the respondents, regardless their educational level, have declared their preferences for buying potatoes at greengroceries and supermarkets shops.

**Weekly potato purchases.** Respondents who have reached the lowest educational level usually buy fewer kilograms of fresh potatoes per week (3.15 kgs) than respondents who have reached the highest educational level (4.56 kgs.)

**Product quality and price potato association.** As the educational level increases, the number of respondents who declared that the price of product is a trustful sign of its quality falls. In fact, 96% of those who have the lower educational levels uphold this opinion. This figure decreases to 49% in the case of respondents with a higher educational level. Respondents associate a bad quality with scratches, bruises, sprouted and gummy potato. Respondents who have reached an upper education level also consider that a bad quality potato is dirty or sprouted.

When asked about willingness-to-pay for fresh potatoes of better quality, a high *per* percentage of households (34%), were willing to pay a price premium of $ 0.50 peso *per* kilo and only 19 % were willing to pay a price

premium of $ 1 . A great proportion of respondents, who have reached a lower educational level consider that food quality controls are satisfactory.

### *Empirical analysis based on the Ordered Logit Model*

An Ordered Logit Model was applied to identify the quality attributes that are influencing consumers´ evaluation of potatoes quality and to estimate the probability of consumers´ frequency and making purchase. Consumers´ willingness-to-buy potatoes is expressed in frequency of consumption, such 1-2 times a week, 3-4 times a week and 5 or more times a week. And the attributes are included in the Ordered Logit Model to evaluate their impact on consumers´ consumption and purchasing patterns (McCullagh, 1980; Agresti, 2002; Norusis, 2005).

The random sample consisted of 471 households (94% of total sample survey of 500 households).

The results of the estimated model are presented in Table 2:

**Table 2. Estimation results for Ordered Logit Model**

| Variables | | Coefficient Signs | Std. Error | Significance |
|---|---|---|---|---|
| **Threshold** | **FREQUENCY (= 0)*** | + | 0.690 | 0.059 |
| | **FREQUENCY (= 1)***** | + | 0.713 | 0.000 |
| **Location** | **HOUSEHOLD SIZE***** | + | 0.060 | 0.000 |
| | **AGE***** | + | 0.006 | 0.010 |
| | **BALANCED DIET***** | + | 0.036 | 0.009 |
| | **POTATO FATTENING*** | - | 0.026 | 0.060 |
| | **PREPARATION / CONVENIENCE**** | + | 0.040 | 0.034 |
| | **PRICE*** | - | 0.175 | 0.003 |
| | **EDUCATION (= 0)**** | + | 0.217 | 0.017 |
| | **EDUCATION (= 1)** | 0[a] | | |
| | **SIZE (= 0)**** | - | 0.190 | 0.017 |
| | **SIZE (= 1)** | 0[a] | | |
| | **SKIN COLOUR (= 0)**** | - | 0.195 | 0.030 |
| | **SKIN COLOUR (= 1)** | 0[a] | | |

Level of significance: *** p< 0.01, **p<0.05,* p<0.10
a = This parameter is redundant
n = 471; Link function: logit

Source: Potato Consumption Survey, Mar del Plata-Argentina, June 2009

## Definition of variables

### *Dependent variable:*

FRECUENCY: Ordinal variable. The times a week potato is consumed in the household. Categories: 0 = less than once a week-2 times a week , 1 = 3-4 times a week, 2 = 5 and more times a week .

### *Independent variables*

Quantitative explanatory variables:

HOUSEHOLD SIZE: members in the household. Average = 3.3 persons in the household

AGE: Age of respondent. Average Age: 50 years old

BALANCED DIET: If to eat potato is important to have a balanced diet. Average score = 7.18 points.

POTATO FATTENING: If potato contributes to gain weight / get fat. Average score = 5.44 points.

PREPARATION / CONVENIENCE: If potatoes are easy to clean and good to prepare recipes and dishes. Average score = 8.29 points.

PRICE: average price of fresh potato paid *per* kilogram. Average price = US dollar 0.46 (exchange rate, June 2009, 1 US dollar = 3.8 Argentinean Pesos)

Categorical explanatory variables:

EDUCATION: Respondents´ education level. Categorical variable: 0 = modest education, 1 = high education

SIZE: Potato size is an important attribute. Categorical variable: 0 = No, 1 = Yes

SKIN: If Potato skin colour is an important attribute. Categorical variable: 0 = No, 1 = Yes

These measures indicate that the model fits adequately. The model performance results are depicted in Table 3 below:

**Table 3. Model performance evaluation**

| **Goodness-of-fit statistics** | **Significance** |
|---|---|
| Pearson | 0.356 |
| Deviance | 0.965 |
| **Model fitting information** | **Significance** |
| Intercept only | |
| Final | 0.000 |
| **Test of Parallelism** | **Significance** |
| Null Hypothesis | |
| General | 0.914 |
| **Pseudo R-square** | |
| Cox and Snell | 0.18 |
| Nagelkerke | 0.21 |
| McFadden | 0.10 |

Source: Potato Consumption Survey, Mar del Plata-Argentina, June 2009

The signs are all as we expected, and they are suggesting that:

- ⇨Households with high number of members have a higher probability to consume fresh potato more frequently. **(HOUSEHOLD SIZE)**
- ⇨Older respondents consume more frequently fresh potatoes than younger respondents. **(AGE)**
- ⇨Households considering potato as a relevant food for a balanced diet are likely to consume more frequently fresh potato. **(BALANCED DIET)**
- ⇨There is an inverse relationship between frequency of consumption and the belief that potato helps to get fat. **(POTATO FATTENING)**
- ⇨Those consumers considering potato as *´a food easy to prepare meals and also easy to clean´* have a higher probability of consuming this good more frequently. **(PREPARATION / CONVENIENCE)**
- ⇨Households paying higher average potatoes prices are likely to consume fresh potato less frequently. **(PRICE)**
- ⇨Low educated consumers have a higher probability to buy fresh potatoes more frequently. **(EDUCATION)**
- ⇨Those who do not care about potato size and skin colour have a low probability to consume fresh potatoes more frequently. **(SIZE** and **SKIN COLOUR)**

## Final remarks

According to our research, health care, nutritional content and lack of agrichemicals content in food are the most important reasons that consumers take into account when purchasing food products. The average score given by consumers to risks in consuming fresh potatoes with pesticide and fertilize content is high. In Argentina, there is a little consumer recognition of potato varieties and their uses. This lack of information creates an excellent opportunity for market niche developing. The information provided in food labels could be considered as an instrument to improve consumers´ perception of potato quality. It also makes it easier for consumers to choose products based on their preferences and finally they would be informed about varieties and cooking preparation methods.

Consumers want to assurance that what their purchases meet their expectation for size, colour, texture, and nutritional value. Producers and stakeholders should give to consumers something to look for and tell them they have made the right decisions. A quality label would also benefit the producer striving to maintain a quality product and also inform to those consumers that are willing to buy and pay a price premium for this product.

## Acknowledgements

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# The effect of process and environment on the nutritional value of *chuño*

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## Abstract

The potato in its Andean center of origin is commonly freeze-dried to assure long-term storability and consequent availability of food during periods of scarcity. The final product is known as *chuño*. Depending on the process and cultivars used, different kinds of *chuño* are prepared: white *chuño* (*moraya*, *tunta*) and black *chuño*. This paper explores the nutritional value of *chuño* using data from research in the Peruvian Andes. The paper specifically investigates the effect of regionally different processes on the mineral content of *chuño*: Zn, Fe, Ca, K, P, Mg and Na. First, the effect of 4 processes (P), resulting in 2 types of white and black *chuño* respectively, for 4 cultivars (C) belonging to distinct botanical species (P*C interaction). Second, the influence of locality, cultivar and process on nutrient concentrations (L*C*P interaction). Specifically, the effect of 3 contrasting growing environments on the mineral content of 4 cultivars processed into 2 types of white *chuño*. Results of the first experiment show that the mineral content of *chuño*, independent of the mineral analyzed, is significantly influenced by P*C interaction. Results of the second experiment show that particularly the dry matter, Ca, Mg and Na content of white *chuño* is significantly affected by L*C*P interaction. The zinc, potassium, phosphorus and magnesium content of all 'types' of *chuño* decreases in comparison with boiled (unprocessed) tubers. White *chuño* generally contains stable to high iron and high calcium concentrations.

**Keywords:** potato, micro and macronutrient content, traditional freeze-drying.

## Introduction

The cultivated potato in its Andean center of origin is commonly freeze-dried to assure long-term storability and consequent availability of food during periods of scarcity. The final product is known as *chuño* (López Linage, 1991; Towle, 1961). Depending on the process followed and cultivars used, different kinds of *chuño* are recognized (Condori Cruz, 1992). So-called black and white *chuño* are the result of different steps involved in the processing pipeline. The elaboration of either 'type' takes advantage of severe frosts at night alternated with high daytime levels of solar radiation and low levels of relative humidity during the months of June and July (Woolfe, 1987). White *chuño*, also commonly known as *moraya* or *tunta* in the Quechua and Aymara languages respectively (Gianella, 2004; Yamamoto, 1988), is frequently commercialized at markets while the use of black *chuño* is generally restricted to home consumption.

A main difference between the process of preparing black or white *chuño* relates to the prolonged exposure of tubers to (running) water. White *chuño* is always washed or soaked, in part to remove glycolalkaloids. Black *chuño*, on the other hand, is not exposed to water and its elaboration is generally simpler, basically consisting of tending, treading, freezing and drying (Mamani, 1981). The elaboration of white *chuño* has several regional variants. It generally involves all of the following steps: tending, treading, freezing, washing and drying (Werge, 1979). Aside from the process of preparing chuño, the particular potato cultivar involved influences the final quality. Cultivars belonging to the bitter species *Solanum curtilobum*, *S. juzepczukii* and *S. ajanhuiri* are almost exclusively used for traditional freeze-drying (Christiansen, 1977). Their high glycoalkaloid content restricts their use for fresh consumption. Native-floury cultivars of non-bitter cultivated species and even improved cultivars with *S. tuberosum* subsp. *tuberosum* within their pedigree are also commonly used to prepare *chuño* (De Haan *et al.*, 2009).

Woolfe (1987), quoting Collazos (1974), reports high energy contents for raw (non-boiled) white and black *chuño* of 323 and 333 kcal / 100 g on a fresh weight basis (FWB) compared to 80 kcal / 100 g for raw (non-boiled)

potatoes. De Haan *et al.* (2009) report slightly higher values in the case of boiled white *chuño* ranging from 390 to 394 kcal / 100 g on a dry weight basis (DWB). According to Christiansen (1978), between 67 to 83% and 18 to 30% of protein is lost during the elaboration of white and black *chuño* respectively. Other authors also report the protein content of raw (non-boiled) black *chuño* to be higher compared to white *chuño* (Paredes and Gomez, 1987; Woolfe, 1987). Zavaleta *et al.* (1996) list the average energy, protein, iron and calcium content of 100 g of raw (non-boiled) white *chuño* to be 323 kcal, 1.9 g, 3 mg and 92 mg and that of black *chuño* 333 kcal, 4.0 g, 0.9 mg and 44 mg (FWB). These values are the same as those reported by Collazos (1974). Burgos *et al.* (2008) show the protein, iron, zinc and calcium concentration of boiled white *chuño* of 9 native cultivars to range from 0.49 to 1.15 g, 0.29 to 0.65 mg, 0.04 to 0.14 mg and 18.9 to 31.0 mg respectively per 100 g (FWB). With the exception of carbohydrate, calcium and iron, the nutrient content of white *chuño* is greatly reduced in comparison with fresh potato (Woolfe, 1987). This is confirmed by recent research from Burgos *et al.* (2008) and De Haan *et al.* (2009) which shows that the transformation of potato into white *chuño* does not significantly affect iron concentrations, yet results in a decrease of the protein and zinc content, and an increase of calcium. Woolfe (1987) points out that the nutrient content of black *chuño* is also reduced, but not to such a great extent as in white *chuño*.

Highland farmers in central and southern Peru typically consume black and white *chuño* of diverse freeze-dried potato cultivars rather than *chuño* from a single cultivar. However, little is known about the nutritional content of diverse native cultivars (cultivars; C), the effect of regionally distinct 'traditional' processes (P), and the influence of the environment (locality; L) on the macro- and micronutrient content of the black and white *chuño* variants. The research presented in this article explores the effect of 2 variants of both black and white *chuño* processing following standard 'traditional' procedures common to the departments of Huancavelica (central Peru) and Puno (southern Peru) on the mineral content of 4 frequently used native potato cultivars grown in a uniform growing environment. Additionally, it investigates the influence of 3 different growing environments (localities; departments of Junín, Huancavelica and Puno) on the mineral content of 4 cultivars processed into 2 'types' of white *chuño*.

## Materials and methods

### *Process by cultivar experiment (P*C)*

Seed tubers of 4 cultivars were collected in Huancavelica and Puno. A native-floury and a native-bitter cultivar were obtained from each department (table 1). Seed from the cultivars collected in Huancavelica were shipped to Puno where a uniform trial site was located in the community of Salcedo at an altitude of 3,820 m. All cultivars were planted on November the 12th 2007 in a field trial following a completely randomized block design (CRBD) with 3 repetitions. Crop management was uniform and tubers were harvested on June the 5th 2008.

After harvest, fresh medium-sized and undamaged tubers from each locality, cultivar and repetition were dispatched to the CIP's nutrition laboratory for preparation and subsequent mineral analysis of unprocessed tubers. Simultaneously, tubers of the same quality were sent to Huancavelica and Puno to process black and white *chuño* following standard 'traditional' procedures. Processing of the 4 'types' of *chuño* was done by Andean farmers: black and white *chuño* of the 'Huancavelica-type', black and white *chuño* of the 'Puno-type'. Each of the different 'types' of *chuño* was processed at a different location and, depending on the specific steps involved, took between 12 to 38 days to complete. Samples of all cultivars, repetitions and 'types' of *chuño* were used for mineral analysis.

**Table 1. Native potato cultivars cultivated in a field trial at a uniform location (Salcedo, Puno)**

| Cultivar | Cultivar category | Species | Ploidy | Seed source |
|---|---|---|---|---|
| *Azul Qanchillu* | Bitter | *S. juzepczukii* | 2*n*=3*x*=36 | Huancavelica |
| *Puqya* | Floury | *S. stenotomum* | 2*n*=2*x*=24 | Huancavelica |
| *Piñaza* | Bitter | *S. juzepczukii* | 2*n*=3*x*=36 | Puno |
| *Ccompis* | Floury | *S. tuberosum* subsp. *andigena* | 2*n*=4*x*=48 | Puno |

### *Locality by cultivar by process experiment (L*C*P)*

Seed tubers of 4 native-bitter cultivars were collected in Huancavelica and Puno (table 2). Seed of each cultivar was shipped to locations in Junín, Huancavelica and Puno where field trials were installed following a completely randomized block design (CRBD) with 3 to 4 repetitions (table 3). Crop management was uniform for each locality with no agrochemicals applied and a single application of organic manure at 8 tons / ha.

After harvest, fresh medium-sized and undamaged tubers from each locality, cultivar and repetition were dispatched to CIP's nutrition laboratory for preparation and subsequent mineral analysis of unprocessed tubers. Simultaneously, tubers of the same quality were sent to Huancavelica and Puno to process white *chuño* following standard 'traditional' procedures. Two 'types' of *chuño* were prepared by Andean farmers from both departments: white *chuño* of the 'Huancavelica-type' and the 'Puno-type'. Samples from all localities, cultivars, repetitions and 'types' of *chuño* were used for mineral analysis.

**Table 2. Native potato cultivars cultivated in a field trial at a single location (Salcedo, Puno)**

| Cultivar | Cultivar category | Species | Ploidy | Seed source |
|---|---|---|---|---|
| *Azul Qanchillu* | Bitter | *S. juzepczukii* | 2*n*=3*x*=36 | Huancavelica |
| *Suytu Siri* | Bitter | *S. curtilobum* | 2*n*=5*x*=60 | Huancavelica |
| *Locka* | Bitter | *S. juzepczukii* | 2*n*=3*x*=36 | Puno |
| *Piñaza* | Bitter | *S. juzepczukii* | 2*n*=3*x*=36 | Puno |

**Table 3. Basis data for each of 3 different trial sites (localities; L)**

| Location | Community | District | Province | Altitude | Planting | Harvesting |
|---|---|---|---|---|---|---|
| Junín | Quilcas | Quilcas | Huancayo | 3,987 m | 12-11-2007 | 10-06-2008 |
| Huancavelica | Dos de Mayo | Yauli | Huancavelica | 4,357 m | 29-10-2007 | 04-06-2008 |
| Puno | Salcedo | Puno | Puno | 3,820 m | 12-11-2007 | 05-06-2008 |

### *Preparation of analytical samples*

Unprocessed tubers: a sample of 10 fresh tubers was prepared for each locality, cultivar and repetition. Tubers were washed with tap water, rinsed with deionized, distilled water and subsequently boiled. The boiled tubers were peeled and cut longitudinally into 4 sections (stem to bud end). Two opposite sections of each of the 10 tubers were combined to prepare each sample for mineral analysis. Two to 3 slices were taken from each section to obtain a 50 g sample; these were placed in a glass petri dish and oven-dried for 24 hours at 80ºC. The dried samples of approximately 12 to 16 g each were subsequently weighed and ground in an IKA A11 stainless steel mill and stored at -20ºC in hermetically sealed plastic bags.

Processed tubers: a sample of 10 freeze-dried tubers was prepared for each locality, cultivar, repetition and 'type' of *chuño*. *Chuño* tubers were washed, boiled, peeled and prepared to obtain samples for mineral analysis applying the same procedures as detailed above for unprocessed tubers.

### *Mineral determination*

Analytical sub-samples of 0.6 g each were taken after boiling from each of the repetitions of each cultivar and for all treatments and digested at 140ºC in 70% (v/v) HNO3/HClO4. Samples were analyzed for iron (Fe), zinc (Zn), calcium (Ca), potassium (K), phosphorus (P), magnesium (Mg), sodium (Na) and aluminum (Al) by inductively coupled plasma-optical emission spectrophotometry (ICP-OES) using and ARL 3580 ICP. Aluminum (Al) was included to provide an indication of possible iron contamination from soil particles (Darrell and Glanh, 1999). Mineral determination was done on boiled samples because this is how potato tubers and traditionally freeze-dried *chuño* are consumed and therefore the results are more appropriate for estimation of the contribution of native potato cultivars and *chuño* to the human diet.

### *Statistical analysis*

All the statistical tests were performed using SAS/STAT (version 8.2) software (SAS Institute 1999). Prior to the analysis of variance (ANOVA), the data sets were tested for normality using the Kolmogorov-Smirnov test and as not all the data were normally distributed, they were $\log^{10}$ transformed. When the combined ANOVA showed significant differences for the interactions, simple effect analysis on the GLM procedure was conducted considering the localities, cultivars and processes as fixed effects.

## Results

### *The effect of process by cultivar*

The mineral content of boiled *chuño*, independent of the mineral analyzed (Fe, Zn, Ca, K, P, Mg and Na), is significantly influenced by the process (P), cultivar (C), and P*C interaction. Tables 4 and 5 show the general results of the overall ANOVA for each of the 7 minerals analyzed. As an exception, only the dry matter content of boiled *chuño* is not significantly influenced by the interaction between process and cultivar (P*C). Content values for all cultivars and 'types' of *chuño* are shown in annex I. Findings described below are based on these values.

Dry matter (DM). Independently of the cultivar employed, black *chuño* of the 'Huancavelica-type' retains significantly higher levels of dry matter after boiling compared to the other 'types' of *chuño*. On average, the cultivar *Azul Qanchillu* maintained a higher dry matter content compared to the other cultivars in boiled tubers, both 'types' of boiled black *chuño* and boiled white *chuño* of the 'Huancavelica-type'. To the contrary, the cultivar *Piñaza* consistently had much lower dry matter contents compared to the other cultivars.

Iron (Fe). Only in the case of white *chuño* from Puno the influence of contamination was minimal (soil, dust). Results for this particular 'type' of *chuño* show that its iron content is significantly influenced by the cultivar employed. Interestingly, the iron content of boiled white *chuño* of the 'Puno-type' originating from native-bitter cultivars was higher while that of native-floury cultivars was lower compared to content values of boiled tubers of the same cultivars.

Zinc (Zn). Without exception, processing of *chuño* significantly reduces the tuber zinc concentration of all cultivars analyzed with an average loss of 71.3% for white *chuño* of the 'Huancavelica-type', 65.7% for white *chuño* of the 'Puno-type', 49.6% for black *chuño* of the 'Huancavelica-type' and 51.0% for black *chuño* of the 'Puno-type'. Results show that black *chuño*, independent of the specific 'type', retains higher levels of zinc compared to white *chuño*. The cultivar *Puqya* contained the highest concentration of zinc in boiled tubers while the cultivar *Piñaza* contained the highest concentration in boiled *chuño* for 3 out of 4 'types' analyzed.

Calcium (Ca). Both 'types' of white *chuño* contained significantly higher concentrations of calcium compared to boiled tubers while the content of both 'types' of black *chuño* generally tended to be lower. The only exception to the latter is boiled black *chuño* of the 'Huancavelica-type' from the cultivar *Piñaza*. The average calcium content of boiled white *chuño* of the 'Huancavelica-type' and the 'Puno-type' was 75.6% and 103.2% higher compared to the concentration of boiled tubers. On the other hand, the average calcium content of boiled black *chuño* of the 'Huancavelica-type' and the 'Puno-type' was 16.5% and 35.0% lower compared to boiled tubers. The cultivar *Piñaza* contained considerably higher levels of calcium in boiled tubers, both 'types' of white *chuño* and black *chuño* of the 'Huancavelica-type' compared to the other cultivars.

Potassium (K). The content of this mineral in boiled white and black *chuño* is affected negatively by freeze-drying. Both 'types' of boiled black *chuño* show an average 2.6-fold decrease in their potassium concentration compared to boiled tubers. White *chuño* is particularly subject to sizable losses with the 'Huancavelica-type' and 'Puno-type' respectively suffering an average 136-fold and 93-fold reduction of their potassium content compared to potato tubers. The potassium content of both 'types' of boiled white *chuño* is not significantly influenced by the cultivar used while its concentration in boiled tubers and both 'types' of black *chuño* is significantly dependent on the cultivar.

Phosphorus (P). The phosphorus content of all 'types' of *chuño* is reduced significantly by traditional freeze-drying. The average phosphorus concentration of boiled black *chuño* as compared to boiled potato tubers reduced 45.2% and 45.8% for the 'Huancavelica-type' and 'Puno-type' respectively. Losses for both 'types' of

white *chuño*, the 'Huancavelica-type' and 'Puno-type' respectively, average 67.8% and 62.7%. Differences in the phosphorus content of the different cultivars were significant for boiled tubers and both 'types' of black *chuño* while differences in the content of the distinct cultivars was insignificant for both 'types' of white *chuño*.

Magnesium (Mg). Without exceptions, the magnesium concentration of all 'types' of boiled *chuño* was significantly lower compared to the content of boiled potato tubers. On average losses were higher for both 'types' of white *chuño*, 67.6% for white *chuño* of the 'Huancavelica-type' and 72.3% for white *chuño* of the 'Puno-type', compared to both 'types' of black *chuño*: 53.2% for black *chuño* of the 'Huancavelica-type' and 56.5% for black *chuño* of the 'Puno-type'. The cultivar *Piñaza* retained the highest concentration in (unprocessed) tubers, both 'types' of black *chuño* and white *chuño* of the 'Puno-type' when compared to the other cultivars while the cultivar *Azul Qanchillu* maintained the highest content in black *chuño* of the 'Huancavelica-type'. Both native-floury cultivars show higher average losses of magnesium compared to both native-bitter cultivars.

Sodium (Na). Both 'types' of black *chuño* show a decrease of sodium concentrations for all of the cultivars analyzed. Depending on the specific cultivar, levels of decrease range from 4.9 to 45.8% for black *chuño* of the 'Huancavelica-type' and 5.3 to 31.8% for black *chuño* of the 'Puno-type'. With the exception of the cultivar *Ccompis*, the sodium content of boiled white *chuño* of the 'Huancavelica-type' was 18.7 to 88.0% lower compared to the content of boiled tubers. Interestingly, the sodium content of boiled white *chuño* of the 'Puno-type' was significantly higher compared to the content of boiled tubers. Depending on the cultivar, the average sodium content of white *chuño* of the 'Puno-type' increases by 53.7 to 811.4%. No significant differences between cultivars were encountered concerning the sodium concentration of white *chuño* of the 'Huancavelica-type' and black *chuño* of the 'Puno-type'. However, the sodium content of boiled tubers, black *chuño* of the 'Huancavelica-type' and white *chuño* of the 'Puno-type' depended significantly on the specific cultivar employed.

**Table 4. Analysis of variance for the dry matter, iron, zinc and calcium content of boiled *chuño***

| Source | DF | Dry Matter (%) | | | Fe (mg / kg)[a] §, DWB | | | Zn (mg / kg)[a], DWB | | | Ca (mg / kg), DWB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F |
| Repetition (proc) | 10 | 6,932 | 1,830 | | 0,006 | 1,400 | | 0,002 | 0,940 | | 1709,013 | 0,380 | |
| Cultivar (C) | 3 | 133,961 | 35,350 | ** | 0,120 | 26,700 | ** | 0,071 | 31,590 | ** | 516688,064 | 114,020 | ** |
| Process (P) | 4 | 126,482 | 33,370 | ** | 0,171 | 37,990 | ** | 0,538 | 238,320 | ** | 658781,303 | 145,380 | ** |
| Process*Cultivar | 12 | 5,527 | 1,460 | | 0,017 | 3,830 | ** | 0,018 | 7,930 | ** | 50374,516 | 11,120 | ** |
| Error | 30 | 3,790 | | | 0,004 | | | | | | 4531,569 | | |
| Corrected total | 59 | 1157,156 | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Mean | | 30,402 | | | 27,260 | | | 5,924 | | | 473,014 | | |
| CV | | 6,403 | | | 4,767 | | | 6,608 | | | 14,231 | | |
| $R^2$ | | 0,902 | | | 0,907 | | | 0,975 | | | 0,972 | | |

[a] = data transformed to $\log^{10}$; ** p>0,01; § = values likely influenced by contamination

**Table 5. Analysis of variance for the potassium, phosphorus, magnesium and sodium content of boiled *chuño***

| Source | DF | K (mg / kg), DWB | | | P (mg / kg), DWB | | | Mg (mg / kg)[a], DWB | | | Na (mg / kg), DWB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F |
| Repetition (proc) | 10 | 338333,000 | 0,660 | | 10310,000 | 0,430 | | 0,001 | 0,540 | | 177,948 | 0,420 | |
| Cultivar (C) | 3 | 4104863,000 | 7,990 | ** | 822215,560 | 34,550 | ** | 0,177 | 97,060 | ** | 6185,000 | 14,530 | ** |
| Process (P) | 4 | 431689321,000 | 840,150 | ** | 5568310,830 | 234,000 | ** | 0,575 | 316,070 | ** | 33408,032 | 78,460 | ** |
| Process*Cultivar | 12 | 3071236,000 | 5,980 | ** | 167541,940 | 7,040 | ** | 0,015 | 7,990 | ** | 1909,905 | 4,490 | ** |
| Error | 30 | 513826,000 | | | 23796,670 | | | 0,002 | | | 425,778 | | |
| Corrected total | 59 | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Mean | | 5441,186 | | | 1386,333 | | | 417,594 | | | 51,702 | | |
| CV | | 13,174 | | | 11,127 | | | 1,667 | | | 39,910 | | |
| $R^2$ | | 0,991 | | | 0,974 | | | 0,982 | | | 0,933 | | |

[a] = data transformed to $\log^{10}$; ** p>0,01

### *The effect of locality by cultivar by process*

The overall ANOVA indicates that the dry matter, Fe, Ca, Mg and Na content of boiled white *chuño* is significantly dependent on the locality (L), cultivar (C), process (P), and L*C*P interaction effect (tables 6 and 7). However, iron content levels, particularly of white *chuño* of the 'Huancavelica-type', were influenced by contamination. The Zn content of boiled white *chuño* is significantly influenced by the locality (L), cultivar (C), process (P) and L*P interaction while the K content is significantly influenced by the locality (L), process (P) and L*P interaction. Both Zn and K are not significantly dependent on L*C or L*C*P interaction effects. The P content of boiled white *chuño* is significantly influenced by the locality (L), cultivar (C), process (P), L*C and L*P interaction, but not by the L*C*P interaction effect. Annex II shows the dry matter, Fe, Ca, Mg and Na content values for all localities, cultivars and 'types' of *chuño*. In the case of Zn, K and P the same annex shows average content values by locality (L) and process (P), but not by cultivar (C), as no significant L*C*P interaction effects were found. Findings described below are based on results shown in annex II.

Dry matter (DM). Without exception the dry matter content of boiled (unprocessed) tubers and both 'types' of white *chuño* of all cultivars is significantly influenced by the locality where the potato has been grown. Interestingly, for all localities and cultivars, the dry matter content of white *chuño* of the 'Huancavelica-type' was always higher while that of white *chuño* of the 'Puno-type' was always lower compared to content values of boiled (unprocessed) tubers. The average dry matter content of boiled (unprocessed) tubers and both 'types' of white *chuño* from tubers grown in Huancavelica was always lower compared to materials from the other localities. The only exception to the former concerns white *chuño* of the 'Puno-type' from the cultivar *Azul Qanchillu*. The dry matter content of *chuño* from all localities and cultivars, with the exception the cultivar *Locka* produced in Puno and Junín, was significantly influenced by the process.

Iron (Fe). High aluminum concentrations indicate likely soil contamination of white *chuño* of the 'Huancavelica-type'. Therefore only the results concerning iron content values for boiled (unprocessed) tubers and white *chuño* of the 'Puno-type' are considered for detailed interpretation. Results for unprocessed tubers and white *chuño* of the 'Puno-type' indicate that the influence of the locality on iron content values is non-significant for both processes and all cultivars with the single exception of boiled (unprocessed) tubers from the cultivar *Suytu Siri*. Depending on the locality and cultivar, average iron concentrations of white *chuño* of the 'Puno-type' were between 11.2 to 45.6% higher compared to boiled (unprocessed) tubers.

Zinc (Zn). The average zinc content of boiled (unprocessed) tubers and white *chuño* of both the 'Huancavelica-type' and 'Puno-type' is significantly influenced by the locality where the potato has been produced (L*P interaction effect). The zinc content of white *chuño* is not significantly influenced by L*C or L*C*P interaction effects. The zinc content of both 'types' of white *chuño* is always significantly lower compared to boiled tubers. Depending on the locality, average losses fluctuated between 70.0 to 80.5% for white *chuño* of the 'Huancavelica-type' and 48.3 to 81.5% for white *chuño* of the 'Puno-type'.

Calcium (Ca). Without exception the calcium content of boiled (unprocessed) tubers and both 'types' of white *chuño* of all cultivars is significantly influenced by the locality where the potato has been grown. The calcium concentration of both types of white *chuño*, independent of the locality and cultivar, was always higher compared to boiled (unprocessed) tubers. In the case of white *chuño* of the 'Huancavelica-type' 1.7 to 5.6-fold and in the case of white *chuño* of the 'Puno-type' 2.1 to 8.1-fold higher. Independently of the cultivar employed, the calcium concentration of both types of *chuño* processed from tubers produced in Huancavelica always tended to be considerably higher compared to the same *chuño* elaborated from tubers produced in Puno or Junín. The calcium content of *chuño* from all localities and cultivars was also significantly influenced by the process.

Potassium (K). The potassium content of boiled (unprocessed) tubers is significantly influenced by the locality where potatoes have been produced (L*P interaction effect). Yet, no significant effect of locality on the potassium concentration of both 'types' of white *chuño* was found. The potassium content of white *chuño* is not significantly influenced by L*C, C*P or L*C*P interaction effects. The potassium content of both 'types' of white *chuño* was always significantly lower compared to boiled tubers. Average losses above 99% of the original content are normal.

Phosphorus (P). The phosphorus content of boiled (unprocessed) tubers and white *chuño* of the 'Huancavelica-type' is significantly influenced by the locality where potatoes have been produced (L*P interaction effect). No significant effect of locality on the phosphorus concentration of white *chuño* of the 'Puno-type' was found. The phosphorus content of white *chuño* is also significantly influenced by L*C and C*P interaction effects. The phosphorus content of both 'types' of white *chuño* was always significantly lower compared to boiled tubers.

Depending on the locality, average losses fluctuated between 62.3 to 73.0% for white *chuño* of the 'Huancavelica-type' and 61.2 to 71.4% for white *chuño* of the 'Puno-type'.

Magnesium (Mg). Without exception the magnesium concentration of boiled (unprocessed) tubers and white *chuño* of the 'Huancavelica-type' of all cultivars is significantly influenced by the locality where the potato has been grown. With the exception of the cultivar *Piñaza*, the magnesium concentration of white *chuño* of the 'Puno-type' was generally not significantly influenced by locality. The magnesium concentration of both 'types' of *chuño* was always significantly lower compared to boiled tubers. Depending on the locality and cultivar, average losses fluctuated between 69.7 to 81.9% for white *chuño* of the 'Huancavelica-type' and 62.0 to 89.7% for white *chuño* of the 'Puno-type'.

Sodium (Na). The sodium content of boiled (unprocessed) tubers of all cultivars is significantly influenced by the locality where the potato has been grown. The content of both 'types' of white *chuño*, on the other hand, is not significantly influenced by the locality. Indepent of the cultivar, both 'types' of *chuño* elaborated with tubers from the locality Huancavelica increased its sodium content compared to boiled tubers. White *chuño* of the 'Huancavelica-type' elaborated from tubers produced in Puno and Junín generally had lower sodium concentrations compared to content values of boiled tubers. To the contrary, white *chuño* of the 'Puno-type' elaborated from tubers produced in Puno and Junín generally had higher sodium concentrations compared to content values of boiled tubers.

**Table 6. Analysis of variance for the dry matter, iron, zinc and calcium content of boiled white *chuño***

| Source | DF | Dry Matter (%) | | | Fe (mg / kg)[a] §, DWB | | | Zn (mg / kg), DWB | | | Ca (mg / kg), DWB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F |
| Locality (L) | 2 | 305,24 | 72,51 | ** | 0,24 | 29,89 | ** | 126,14 | 402,31 | ** | 2229788,71 | 72,78 | ** |
| Repetition (Loc.) | 8 | 4,24 | 2,39 | * | 0,01 | 0,76 | | 0,30 | 0,20 | | 30882,78 | 3,76 | ** |
| Cultivar (C) | 3 | 29,91 | 16,86 | ** | 0,07 | 6,72 | ** | 12,66 | 8,25 | ** | 52286,49 | 6,37 | ** |
| Locality*Cultivar | 6 | 10,74 | 6,05 | ** | 0,02 | 1,99 | | 2,28 | 1,49 | | 20988,01 | 2,56 | * |
| Process (P) | 2 | 372,54 | 209,96 | ** | 1,50 | 140,77 | ** | 2064,51 | 1345,99 | ** | 7172493,15 | 874,13 | ** |
| Locality*Process | 4 | 17,48 | 9,85 | ** | 0,00 | 0,16 | | 137,98 | 89,96 | ** | 156551,50 | 19,08 | ** |
| Cultivar*Process | 6 | 41,89 | 23,61 | ** | 0,01 | 0,63 | | 2,38 | 1,55 | | 33953,48 | 4,14 | ** |
| L*C*P | 12 | 13,45 | 7,58 | ** | 0,03 | 2,58 | ** | 2,32 | 1,51 | | 20545,42 | 2,50 | ** |
| Error | 80 | 1,77 | | | 0,01 | | | 1,53 | | | 8205,25 | | |
| Corrected total | 123 | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Mean | | 26,90 | | | 31,35 | | | 8,86 | | | 811,88 | | |
| CV | | 4,95 | | | 7,18 | | | 13,97 | | | 11,16 | | |
| $R^2$ | | 0,94 | | | 0,84 | | | 0,98 | | | 0,97 | | |

[a] = data transformed to $\log^{10}$; ** p>0.01; * p>0.05; § = values likely influenced by contamination

**Table 7. Analysis of variance for the potassium, phosphorus, magnesium and sodium content of boiled white *chuño***

| Source | DF | K (mg / kg), DWB | | | P (mg / kg), DWB | | | Mg (mg / kg), DWB | | | Na (mg / kg), DWB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F | Mean Square | F-value | Pr > F |
| Locality (L) | 2 | 75184365,00 | 195,77 | ** | 4263259,30 | 35,18 | ** | 549813,04 | 417,82 | ** | 3,62 | 94,86 | ** |
| Repetition (Loc.) | 8 | 382292,00 | 0,70 | | 122161,40 | 3,93 | ** | 1302,08 | 0,50 | | 0,04 | 0,65 | |
| Cultivar (C) | 3 | 807321,00 | 1,48 | | 212787,00 | 6,85 | ** | 36373,09 | 14,04 | ** | 0,18 | 3,02 | * |
| Locality*Cultivar | 6 | 507969,00 | 0,93 | | 86016,90 | 2,77 | * | 2557,91 | 0,99 | | 0,15 | 2,51 | * |
| Process (P) | 2 | 4772247574,00 | 8732,49 | ** | 59663754,60 | 1921,50 | ** | 9966966,67 | 3847,63 | ** | 12,20 | 207,57 | ** |
| Locality*Process | 4 | 83968718,00 | 153,65 | ** | 2542023,30 | 81,87 | ** | 323775,76 | 124,99 | ** | 2,49 | 42,31 | ** |
| Cultivar*Process | 6 | 681194,00 | 1,25 | | 30123,50 | 0,97 | | 11968,91 | 4,62 | ** | 0,13 | 2,18 | |
| L*C*P | 12 | 549756,00 | 1,01 | | 41521,30 | 1,34 | | 4867,04 | 1,88 | * | 0,11 | 1,92 | * |
| Error | 80 | 546494,00 | | | 31050,60 | | | 2590,42 | | | | | |
| Corrected total | 123 | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Mean | | 6835,89 | | | 1680,24 | | | 650,89 | | | 60,59 | | |
| CV | | 10,81 | | | 10,49 | | | 7,82 | | | 10,04 | | |
| $R^2$ | | 1,00 | | | 0,98 | | | 0,99 | | | 0,91 | | |

[a] = data transformed to $\log^{10}$; ** p>0.01; * p>0.05

## Conclusions

### *Process by cultivar*

The zinc, potassium, phosphorus and magnesium contents of all 'types' of boiled *chuño* are low in comparison with those of boiled (unprocessed) tubers. The process of traditional freeze-drying, without exception, negatively affects the nutritional value of *chuño* for these 4 minerals. In addition, the content of these minerals is reduced more drastically in both 'types' of white *chuño* as compared to both 'types' of black *chuño*. It seems likely that the higher loss of these minerals in white compared to black *chuño* originates from the exposure of tubers to (running) water during the process of freeze-drying.

The influence of the 4 different regional variants of freeze-drying on the dry matter, iron, calcium and sodium content of *chuño* was not as linear as for the minerals discussed above. Differences in the dry matter content of boiled tubers versus *chuño* were fairly modest for all 'types' of *chuño*, except black *chuño* of the 'Huancavelica-type' which had a considerably higher dry matter content compared to boiled tubers. Iron content values for white *chuño* of the 'Puno-type' clearly indicate a strong influence of the cultivar. The calcium concentration of boiled *chuño* is strongly influenced by the actual process of freeze-drying. Both 'types' of white *chuño* contained significantly higher concentrations of calcium compared to boiled (unprocessed) tubers. Both 'types' of black *chuño*, on the other hand, on average contained lower concentrations of calcium compared to boiled tubers. The fact that the calcium content of white *chuño* is nearly double compared to (unprocessed) potato tubers and black *chuño* suggests that that this particular mineral might be absorbed from the water. A similar phenomenon may be occurring in the case of sodium as average concentrations of this mineral in white *chuño* of the 'Puno-type' were generally much higher compared to those of boiled tubers. Sodium concentrations in all other 'types' of *chuño* tended to be significantly lower compared to content values of boiled tubers.

### *Locality by cultivar by process*

Independent of the locality where potatoes are produced, the zinc, potassium, phosphorus and magnesium concentrations of *chuño* always decrease in comparison with mineral content values of boiled tubers of the same treatment. The dry matter, calcium, magnesium and sodium content of boiled white *chuño* is significantly dependent on the L*C*P interaction effect. Without exception the dry matter and calcium content of boiled (unprocessed) tubers and both 'types' of white *chuño* of all cultivars is significantly influenced by the locality where the potato has been grown. Results confirm that the calcium content of white *chuño* from all localities and cultivars increases considerably in comparison with concentrations in boiled tubers.

The magnesium concentration of boiled (unprocessed) tubers and white *chuño* of the 'Huancavelica-type' of all cultivars is significantly influenced by the locality where the potato has been produced while it's content in white *chuño* of the 'Puno-type' is generally not significantly affected by locality. The sodium content of boiled (unprocessed) tubers of all cultivars is, whereas content vales of both 'types' of *chuño* are not, significantly influenced by the locality. Results confirm that the sodium content of white *chuño* of the 'Puno-type' is always higher in comparison with concentrations in boiled tubers. Content levels of sodium in white *chuño* of the 'Huancavelica-type' may either increase or decrease in comparison with boiled (unprocessed) tubers, depending on the locality where the potato was produced.

The concentrations of some minerals is significantly influenced by the locality, but not by L*C*P interaction effects. Such is the case for zinc and phosphorus. The zinc content of boiled (unprocessed) tubers and white *chuño* of both the 'Huancavelica-type' and 'Puno-type' is significantly influenced by the locality where the potato has been produced. Further, the phosphorus content of boiled (unprocessed) tubers and white *chuño* of the 'Huancavelica-type' is significantly influenced by locality whereas concentrations in white *chuño* of the 'Puno-type' are not significant affected.

The locality of potato production has little influence on the iron and potassium content of white *chuño*. Results for white *chuño* of the 'Puno-type' indicate that the influence of the locality on iron content values is non-significant. Average iron concentrations of white *chuño* of the 'Puno-type' were always higher compared to boiled (unprocessed) tubers. While the potassium content of boiled (unprocessed) tubers is significantly influenced by the locality where potatoes have been produced, the same is not true for potassium concentrations of both 'types' of white *chuño*. The main cause is the enormous reduction of potassium caused by traditional freeze-drying, amounting to losses above 99% of the original content.

### *Chuño and human nutrition*

In general terms, both white and black *chuño* are relatively poor sources of macro- and micronutrients. Interventions aimed at combating child malnutrition in the Andean highlands will probably have the highest possible impact when levels of consumption of meat, milk products, fruit and (leafy) vegetables can be increased. Nevertheless, these products are generally scarce in Andean communities located above 3.500 m of altitude. Potato, consumed as boiled tubers or *chuño* and often combined with grains such as barley, makes up the bulk of daily food intake. In an environment where harvests and food storage occur once a year, and where risks of crop failure and consequent temporal food shortages caused by frost, hail or drought are frequent, the preparation of *chuño* does contribute significantly to local food security. *Chuño*, just as other traditionally freeze-dried products (e.g. *kaya*), allow Andean households to overcome periods of relative food shortage. Additionally, the consumption of *chuño* is imbedded in the Andean culture and cuisine. From a human nutrition perspective the benefits of *chuño* consumption, beyond its long-term storability and year-round availability as an energy-rich food source, include the stable to high iron and high calcium content of white *chuño* as compared to unprocessed potato tubers and the comparatively high levels of retention of zinc, potassium, phosphorus and magnesium in black compared to white *chuño*. Additionally, the commercial value of high-quality white *chuño* may allow rural families to enrich their diets with foods obtained through monetary purchase.

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## Annex 1. Dry matter and mineral content values (process by cultivar experiment; P*C)

Dry matter content (%) of boiled potato tubers and four 'types' of boiled *chuño*

| | Potato tubers | | White *chuño* 'Hvca-type' | | Black *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | Black *chuño* 'Puno-type' | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) |
| *Qanchillu* | 33.4 | 1.3 | 32.7 | 3.4 | 39.8 | 6.9 | 28.8 | 0.7 | 32.7 | 1.1 |
| *Ccompis* | 29.0 | 1.0 | 32.0 | 1.1 | 37.6 | 1.1 | 29.8 | 1.5 | 29.0 | 1.8 |
| *Piñaza* | 24.3 | 1.8 | 27.7 | 1.9 | 31.0 | 1.9 | 22.3 | 1.8 | 26.7 | 2.0 |
| *Puqya* | 30.6 | 0.1 | 30.4 | 0.6 | 34.2 | 0.7 | 26.4 | 0.6 | 29.8 | 0.9 |

Iron content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

| | Potato tubers | | White *chuño* 'Hvca-type'[a] | | Black *chuño* 'Hvca-type'[a] | | White *chuño* 'Puno-type' | | Black *chuño* 'Puno-type'[a] | | P x G effect sliced by G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| *Qanchillu* | 21.9 | 2.8 | 62.1 | 15.8 | 38.1 | 6.4 | 25.0 | 0.7 | 31.0 | 1.7 | ** |
| *Ccompis* | 17.3 | 0.6 | 21.9 | 3.0 | 27.0 | 2.9 | 13.7 | 2.2 | 23.2 | 1.9 | ** |
| *Piñaza* | 18.6 | 2.8 | 32.4 | 12.0 | 28.2 | 2.3 | 24.0 | 3.7 | 27.6 | 4.6 | ** |
| *Puqya* | 21.5 | 2.9 | 41.1 | 10.6 | 27.3 | 4.5 | 15.7 | 1.6 | 27.3 | 3.9 | ** |
| P x G effect sliced by P | ns | | ** | | * | | ** | | ns | | |

[1] = Dry Weight Basis; [a] = values likely influenced by contamination; P = process; C = cultivar; ** p>0.01; * p>0.05

Zinc content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

| | Potato tubers | | White *chuño* 'Hvca-type' | | Black *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | Black *chuño* 'Puno-type' | | P x G effect sliced by G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| *Qanchillu* | 10.2 | 0.6 | 3.7 | 0.5 | 5.8 | 0.5 | 3.4 | 0.4 | 5.4 | 0.5 | ** |
| *Ccompis* | 10.6 | 0.5 | 3.0 | 0.4 | 4.8 | 0.3 | 2.9 | 0.2 | 4.2 | 0.1 | ** |
| *Piñaza* | 11.3 | 0.7 | 3.4 | 0.8 | 6.5 | 0.4 | 5.7 | 0.8 | 8.4 | 0.4 | ** |
| *Puqya* | 13.4 | 2.4 | 2.7 | 0.3 | 5.6 | 0.4 | 3.5 | 0.3 | 3.9 | 0.4 | ** |
| P x G effect sliced by P | * | | ** | | * | | ** | | ** | | |

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Calcium content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

| | Potato tubers | | White *chuño* 'Hvca-type' | | Black *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | Black *chuño* 'Puno-type' | | P x G effect sliced by G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| *Qanchillu* | 383.3 | 46.2 | 703.3 | 20.8 | 356.7 | 63.5 | 870.0 | 78.1 | 293.3 | 11.5 | ** |
| *Ccompis* | 270.0 | 10.0 | 490.0 | 60.8 | 199.0 | 28.1 | 463.3 | 25.2 | 191.4 | 25.2 | ** |
| *Piñaza* | 523.3 | 119.3 | 1030.0 | 26.5 | 533.3 | 37.9 | 1236.7 | 98.1 | 253.3 | 41.6 | ** |
| *Puqya* | 303.3 | 5.8 | 426.7 | 75.7 | 198.7 | 2.3 | 540.0 | 155.9 | 194.5 | 4.5 | ** |
| P x G effect sliced by P | ** | | ** | | ** | | ** | | ns | | |

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Potassium content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

| | Potato tubers | | White *chuño* 'Hvca-type' | | Black *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | Black *chuño* 'Puno-type' | | P x G effect sliced by G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| *Qanchillu* | 14000.0 | 1417.7 | 146.6 | 22.8 | 7233.3 | 472.6 | 98.1 | 13.3 | 6266.7 | 57.7 | ** |
| *Ccompis* | 14133.3 | 1159.0 | 165.4 | 100.4 | 5366.7 | 251.7 | 530.0 | 10.0 | 5033.3 | 152.8 | ** |
| *Piñaza* | 15766.7 | 1361.4 | 70.5 | 21.3 | 5966.7 | 208.2 | 119.7 | 30.4 | 8766.7 | 808.3 | ** |
| *Puqya* | 15366.7 | 1222.0 | 109.9 | 53.4 | 5066.7 | 873.7 | 216.9 | 24.8 | 4400.0 | 953.9 | ** |
| P x G effect sliced by P | ** | | ns | | ** | | ns | | ** | | |

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Phosphorus content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

| | Potato tubers | | White *chuño* 'Hvca-type' | | Black *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | Black *chuño* 'Puno-type' | | P x G effect sliced by G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| *Qanchillu* | 2866.7 | 321.5 | 810.0 | 45.8 | 1600.0 | 60.0 | 850.0 | 17.3 | 1463.3 | 72.3 | ** |
| *Ccompis* | 1986.7 | 196.3 | 893.3 | 104.1 | 1263.3 | 97.1 | 956.7 | 41.6 | 1153.3 | 125.8 | ** |
| *Piñaza* | 3033.3 | 208.2 | 750.0 | 17.3 | 1543.3 | 100.2 | 1023.3 | 15.3 | 1860.0 | 87.2 | ** |
| *Puqya* | 2150.0 | 229.1 | 666.7 | 96.1 | 1050.0 | 130.0 | 810.0 | 190.8 | 996.7 | 202.6 | ** |
| P x G eff. sliced by P | ** | | ns | | ** | | ns | | ** | | |

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Magnesium content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

| | Potato tubers | | White *chuño* 'Hvca-type' | | Black *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | Black *chuño* 'Puno-type' | | P x G effect sliced by G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| *Qanchillu* | 863.3 | 60.3 | 316.7 | 5.8 | 443.3 | 11.5 | 213.3 | 23.1 | 380.0 | 17.3 | ** |
| *Ccompis* | 706.7 | 60.3 | 256.7 | 20.8 | 290.0 | 10.0 | 183.5 | 10.2 | 253.3 | 15.3 | ** |
| *Piñaza* | 916.7 | 104.1 | 306.7 | 30.6 | 526.7 | 15.3 | 340.0 | 26.5 | 600.0 | 20.0 | ** |
| *Puqya* | 826.7 | 83.3 | 191.9 | 25.1 | 310.0 | 10.0 | 189.8 | 43.9 | 236.7 | 32.1 | ** |
| P x G eff. sliced by P | * | | ** | | ** | | ** | | ** | | |

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

Sodium content (mg/kg; DWB[1]) of boiled potato tubers and four 'types' of boiled *chuño*

| | Potato tubers | | White *chuño* 'Hvca-type' | | Black *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | Black *chuño* 'Puno-type' | | P x G effect sliced by G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| *Qanchillu* | 43.2 | 26.5 | 20.2 | 1.7 | 41.0 | 26.1 | 118.8 | 20.2 | 31.8 | 11.5 | ** |
| *Ccompis* | 16.2 | 13.5 | 18.8 | 2.1 | 13.6 | 12.5 | 147.9 | 12.9 | 12.6 | 7.7 | ** |
| *Piñaza* | 123.8 | 55.2 | 14.9 | 2.0 | 67.1 | 27.6 | 190.3 | 19.5 | 5.3 | 2.5 | ** |
| *Puqya* | 17.2 | 14.6 | 14.0 | 1.6 | 13.7 | 9.9 | 113.5 | 15.4 | 10.3 | 6.1 | ** |
| P x G eff. sliced by P | ** | | ns | | ** | | ** | | ns | | |

[1] = Dry Weight Basis; P = process; C = cultivar; ** p>0.01; * p>0.05

## Annex 2. Dry matter and mineral content values (locality by cultivar by process experiment; L*C*P)

Dry matter content (%) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

| Locality | Cultivar | Potato tubers | | White *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | L*C*P effect sl. by L*C |
|---|---|---|---|---|---|---|---|---|
| | | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| Huancavelica | *Azul Qanchillu* | 25.92 | 1.44 | 26.19 | 1.07 | 22.72 | 0.57 | ** |
| Puno | *Azul Qanchillu* | 33.36 | 1.33 | 34.36 | 2.29 | 19.21 | 0.91 | ** |
| Junin | *Azul Qanchillu* | 29.39 | 0.81 | 34.60 | 2.38 | 26.22 | 0.74 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ** | | |
| Huancavelica | *Locka* | 24.43 | 1.23 | 25.42 | 1.61 | 21.80 | 0.83 | ** |
| Puno | *Locka* | 26.87 | 1.53 | 27.35 | 1.42 | 25.50 | 0.54 | ns |
| Junin | *Locka* | 27.60 | 0.52 | 28.03 | 0.48 | 25.54 | 0.82 | ns |
| L*C*P effect sliced by C*P | | ** | | * | | ** | | |
| Huancavelica | *Piñaza* | 22.03 | 0.67 | 27.19 | 1.40 | 21.12 | 0.80 | ** |
| Puno | *Piñaza* | 24.27 | 1.79 | 32.04 | 1.24 | 23.62 | 0.96 | ** |
| Junin | *Piñaza* | 25.59 | 1.64 | 35.24 | 2.32 | 24.11 | 0.44 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | * | | |
| Huancavelica | *Suytu Siri* | 23.09 | 1.21 | 24.26 | 1.49 | 20.26 | 0.68 | ** |
| Puno | *Suytu Siri* | 28.27 | 1.28 | 31.45 | 2.07 | 27.49 | 0.83 | ** |
| Junin | *Suytu Siri* | 28.82 | 1.00 | 34.31 | 3.16 | 26.68 | 0.84 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ** | | |

L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

Iron content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

| Locality | Cultivar | Potato tubers | | White *chuño* 'Hvca-type'[a] | | White *chuño* 'Puno-type' | | L*C*P effect sl. by L*C |
|---|---|---|---|---|---|---|---|---|
| | | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| Huancavelica | *Azul Qanchillu* | 28.19 | 3.02 | 80.94 | 34.38 | 35.22 | 1.11 | ** |
| Puno | *Azul Qanchillu* | 21.94 | 2.85 | 45.56 | 15.96 | 31.94 | 4.27 | ** |
| Junin | *Azul Qanchillu* | 18.92 | 2.69 | 35.62 | 8.20 | 24.97 | 2.42 | ** |
| L*C*P effect sliced by C*P | | ns | | ** | | ns | | |
| Huancavelica | *Locka* | 20.03 | 2.84 | 34.91 | 3.40 | 25.82 | 1.34 | ** |
| Puno | *Locka* | 18.09 | 1.98 | 38.29 | 12.98 | 25.90 | 1.63 | ** |
| Junin | *Locka* | 14.85 | 0.97 | 48.76 | 20.35 | 17.93 | 0.74 | ** |
| L*C*P effect sliced by C*P | | ns | | ns | | ns | | |
| Huancavelica | *Piñaza* | 22.00 | 1.06 | 79.95 | 38.64 | 24.46 | 0.91 | ** |
| Puno | *Piñaza* | 18.64 | 2.75 | 44.50 | 12.29 | 25.01 | 0.42 | ** |
| Junin | *Piñaza* | 16.08 | 0.92 | 32.97 | 13.04 | 19.39 | 0.26 | ** |
| L*C*P effect sliced by C*P | | ns | | ** | | ns | | |
| Huancavelica | *Suytu Siri* | 22.44 | 1.77 | 37.94 | 7.64 | 26.81 | 2.19 | ** |
| Puno | *Suytu Siri* | 19.14 | 0.47 | 64.18 | 18.24 | 21.95 | 1.26 | ** |
| Junin | *Suytu Siri* | 14.19 | 1.95 | 38.62 | 15.49 | 17.41 | 0.57 | ** |
| L*C*P effect sliced by C*P | | * | | ** | | ns | | |

[1] = Dry Weight Basis; [a] = values likely influenced by soil contamination; L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

Zinc content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x process)

| Locality | Potato tubers | | White *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | L*P effect sl. by L |
|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| Huancavelica | 21.05 | 2.24 | 4.11 | 1.24 | 3.89 | 0.76 | ** |
| Puno | 10.40 | 0.95 | 3.12 | 0.66 | 5.38 | 1.60 | ** |
| Junin | 18.11 | 1.94 | 4.82 | 0.89 | 4.68 | 0.82 | ** |
| L*P effect sl. by P | ** | | ** | | * | | |

Calcium content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

| Locality | Cultivar | Potato tubers | | White *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | L*C*P effect sl. by L*C |
|---|---|---|---|---|---|---|---|---|
| | | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| Huancavelica | *Azul Qanchillu* | 427.50 | 56.79 | 1255.00 | 165.83 | 1446.67 | 64.29 | ** |
| Puno | *Azul Qanchillu* | 383.33 | 46.19 | 773.33 | 55.08 | 1226.67 | 49.33 | ** |
| Junín | *Azul Qanchillu* | 155.34 | 22.93 | 700.00 | 91.29 | 790.00 | 26.46 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ** | | |
| Huancavelica | *Locka* | 485.00 | 57.45 | 1392.50 | 84.61 | 1480.00 | 62.45 | ** |
| Puno | *Locka* | 543.33 | 70.24 | 1143.33 | 90.74 | 1123.33 | 58.59 | ** |
| Junín | *Locka* | 220.34 | 62.56 | 700.00 | 42.43 | 920.00 | 69.28 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ** | | |
| Huancavelica | *Piñaza* | 432.50 | 130.74 | 1095.00 | 203.06 | 1436.67 | 15.28 | ** |
| Puno | *Piñaza* | 523.33 | 119.30 | 913.33 | 75.72 | 1146.67 | 61.10 | ** |
| Junín | *Piñaza* | 129.53 | 48.45 | 652.50 | 136.72 | 1010.00 | 85.44 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ** | | |
| Huancavelica | *Suytu Siri* | 457.50 | 179.14 | 1277.50 | 219.15 | 1656.67 | 159.48 | ** |
| Puno | *Suytu Siri* | 460.00 | 98.49 | 813.33 | 111.50 | 1173.33 | 64.29 | ** |
| Junín | *Suytu Siri* | 123.13 | 50.23 | 690.00 | 34.64 | 1003.33 | 51.32 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ** | | |

L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

Potassium content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x process)

| Locality | Potato tubers | | White *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | L*P effect sl. by L |
|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| Huancavelica | 23062.50 | 1388.94 | 90.97 | 58.38 | 69.70 | 22.46 | ** |
| Puno | 14500.00 | 1231.41 | 96.50 | 45.91 | 113.04 | 43.90 | ** |
| Junin | 18500.00 | 1067.08 | 152.24 | 69.49 | 117.33 | 33.14 | ** |
| L*P effect sl. by P | ** | | ns | | ns | | |

Phosphorus content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x process)

| Locality | Potato tubers | | White *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | L*P effect sl. by L |
|---|---|---|---|---|---|---|---|
| | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| Huancavelica | 3862.50 | 452.95 | 1066.25 | 56.08 | 1105.00 | 65.30 | ** |
| Puno | 2858.33 | 264.43 | 772.50 | 38.41 | 957.50 | 114.58 | ** |
| Junin | 2291.88 | 276.63 | 865.00 | 75.10 | 888.33 | 88.51 | ** |
| L*P effect sl. by P | ** | | ** | | ns | | |

Magnesium content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

| Locality | Cultivar | Potato tubers | | White *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | L*C*P effect sl. by L*C |
|---|---|---|---|---|---|---|---|---|
| | | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| Huancavelica | *Azul Qanchillu* | 1360.00 | 65.83 | 407.50 | 34.03 | 263.33 | 15.28 | ** |
| Puno | *Azul Qanchillu* | 863.33 | 60.28 | 300.00 | 10.00 | 256.67 | 25.17 | ** |
| Junín | *Azul Qanchillu* | 1247.50 | 86.17 | 420.00 | 25.82 | 293.33 | 30.55 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ns | | |
| Huancavelica | *Locka* | 1450.00 | 102.31 | 370.00 | 34.64 | 270.00 | 43.59 | ** |
| Puno | *Locka* | 856.67 | 56.86 | 263.33 | 15.28 | 293.33 | 15.28 | ** |
| Junín | *Locka* | 1292.50 | 20.62 | 420.00 | 21.60 | 310.00 | 26.46 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ns | | |
| Huancavelica | *Piñaza* | 1587.50 | 53.15 | 430.00 | 58.31 | 293.33 | 66.58 | ** |
| Puno | *Piñaza* | 916.67 | 104.08 | 286.67 | 20.82 | 400.00 | 17.32 | ** |
| Junín | *Piñaza* | 1305.00 | 79.37 | 450.00 | 35.59 | 320.00 | 17.32 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | * | | |
| Huancavelica | *Suytu Siri* | 1357.50 | 60.76 | 417.50 | 65.00 | 270.00 | 26.46 | ** |
| Puno | *Suytu Siri* | 800.00 | 26.46 | 293.33 | 28.87 | 216.67 | 5.77 | ** |
| Junín | *Suytu Siri* | 1180.00 | 14.14 | 425.00 | 36.97 | 310.00 | 65.57 | ** |
| L*C*P effect sliced by C*P | | ** | | ** | | ns | | |

L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

Sodium content (mg/kg; DWB[1]) of boiled potato tubers and two 'types' of boiled *chuño* (locality x cultivar x process)

| Locality | Cultivar | Potato tubers | | White *chuño* 'Hvca-type' | | White *chuño* 'Puno-type' | | L*C*P effect sl. by L*C |
|---|---|---|---|---|---|---|---|---|
| | | Av. | SD (±) | Av. | SD (±) | Av. | SD (±) | |
| Huancavelica | *Azul Qanchillu* | 0.93 | 0.77 | 15.56 | 2.44 | 86.38 | 3.95 | ** |
| Puno | *Azul Qanchillu* | 43.15 | 26.48 | 16.23 | 1.16 | 163.77 | 20.24 | ** |
| Junín | *Azul Qanchillu* | 17.38 | 6.57 | 17.85 | 2.57 | 146.96 | 4.13 | ** |
| L*C*P effect sliced by C*P | | ** | | ns | | ns | | |
| Huancavelica | *Locka* | 2.19 | 2.48 | 10.73 | 0.48 | 112.32 | 3.38 | ** |
| Puno | *Locka* | 196.54 | 78.38 | 13.87 | 1.32 | 159.51 | 8.11 | ** |
| Junín | *Locka* | 31.53 | 31.60 | 15.81 | 1.89 | 141.38 | 12.87 | ** |
| L*C*P effect sliced by C*P | | ** | | ns | | ns | | |
| Huancavelica | *Piñaza* | 6.24 | 3.78 | 15.52 | 3.74 | 129.78 | 9.12 | ** |
| Puno | *Piñaza* | 123.80 | 55.19 | 13.48 | 0.40 | 199.23 | 17.99 | ** |
| Junín | *Piñaza* | 21.13 | 18.15 | 19.73 | 1.90 | 176.20 | 16.52 | ** |
| L*C*P effect sliced by C*P | | ** | | ns | | ns | | |
| Huancavelica | *Suytu Siri* | 4.25 | 2.86 | 13.70 | 2.54 | 120.07 | 11.80 | ** |
| Puno | *Suytu Siri* | 35.37 | 13.58 | 13.54 | 1.72 | 131.08 | 7.55 | ** |
| Junín | *Suytu Siri* | 22.85 | 21.74 | 17.64 | 2.82 | 171.11 | 50.65 | ** |
| L*C*P effect sliced by C*P | | ** | | ns | | ns | | |

L = locality; P = process; C = cultivar; ** p>0.01; * p>0.05

# Carotenoid retention in yellow – fleshed cassava during processing

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## Abstract

Cassava (*Manihot esculenta* Crantz) is a staple food for many people in the tropical and sub-tropical regions of the world. The tuber flesh colours of most of the edible varieties are cream or white which contains traces of carotene or devoid of any carotene. In the yellow- fleshed cassava the major carotenoid present in the tuber is β – carotene which is a precursor of vitamin A. In India, cassava tubers are consumed after boiling, baking or making it into dried chips. Hence the retention of carotenoids was studied in one local yellow- fleshed and three high carotene clones in four different processing methods. The results indicated that the highest retention of total carotenoids (79-84%) and β- carotene (83 -97%) was observed in oven drying followed by boiling *ie* 71–84 % of total carotenoids and 74 – 84 % of β – carotene. In the fried chips the retention of total carotenoids was 68 - 75 % and β – carotene was 45 – 75 % and the least retention of total carotenoids (22 -51 %) and β – carotene (37 -43 %) was recorded in the sun drying method. All the high carotene clones possessed low dry matter content. The tubers had poor cooking quality and are not suitable for consumption after boiling. However these clones are very good for making golden coloured, crispy fried chips. The high carotenoid retention in yellow- fleshed tubers in different processing methods indicates the possibility of significantly improving the nutritive value for making more acceptable products.

**Keywords:** Retention, carotenoids, yellow-fleshed cassava, processing.

## Introduction

Cassava (*Manihot esculenta* Crantz) tubers are mainly used for human consumption, animal feed and raw material for the industries. Tuber flesh colour and cooking quality are the important traits for human consumption. In most of the edible cassava, the tuber flesh colour is cream or white which contains traces of carotene or devoid of any carotene (Bradbury and Hollow,1988).The yellow-fleshed cassava contains higher amount of β-carotene (McDowell and Oduro,1983). The yellow pigmented cassava is under cultivation in a limited way in Colombia, Philippines, Jamaica and some African countries (Oduro,1981). Vitamin-A deficiency is a common dietary deficiency disease in many developing countries. In the yellow-fleshed cassava the major carotenoid pigment present is β- carotene. It has an important role as a principal pre-cursor of pro-vitamin-A which is involved in vision, cell differentiation, synthesis of glycoprotein, reproduction and overall growth and development of bones (Woolfe, 1982). In the CIAT funded project "Identification and promotion of cassava clones with higher nutritional quality", several local yellow-fleshed cassava clones with good culinary quality has been collected. The high carotene clones developed through gene pool development programme are maintained in the cassava germplasm. The tubers of all high carotene clones possess low dry matter and poor culinary quality (Moorthy *et al.*,1990). In India, cassava tubers are consumed after processing like boiling, baking or stored it by making it into chips. To alleviate vitamin-A deficiency through dietary intake it is necessary to get information regarding the stability of total carotenoids and β-carotene after different processing methods. Hence the objective of the present study is to find out the effect of different methods of processing on the retention of total carotenoids and β-carotene on the cassava tubers.

## Materials and methods

The material included to study the retention of carotenoids were one yellow-fleshed local cassava clone with good culinary quality Narayanakappa and three high carotene accessions with poor culinary quality from the cassava germplasm. About five cassava tubers were randomly selected from each clone peeled and cut it into small pieces and used for the different processing.

***Oven-drying***- 100g tuber sample were kept in a hot air oven at 50C and dried till a constant weight was obtained.

***Boiling***-100g tuber sample was cut into pieces and put it in boiling water and cooked for 10 minutes.

***Sun-drying***-100g tuber sample was cut it into small pieces and dried in direct sunlight till a constant weight was obtained.

***Frying***- 100g tuber sample was cut it into thin slices, blanched it in hot water for one minute, kept overnight in a hot air oven at $50^0$C for drying and fried in vegetable oil.

Carotenoids were extracted and separated based on the procedure described in AOAC (1995) using Alumina as adsorbent. The concentration of total carotenoids and β-carotene in the fresh as well as in the processed samples were calculated by determining OD at 450nm. β- carotene standard was prepared and used for the calculation of carotenes in the test sample.

## Results and discussion

The flesh colour of the tubers included in the study ranged from yellow to orange. In the fresh cassava sample the total carotenoids ranged from 3.10-10.54µg and β- carotene varied from 2.30-7.22µg. The local clone Narayanakappa has yellow-fleshed tubers with good culinary quality, however, the total carotenoid (3.10µg/g) and β-carotene (2.3µg/g) was low. The other three germplasm accessions had different intensities of orange-flesh colour. These clones were developed through the recurrent selection programme of Central Tuber Crops Research Institute ( Jos, *et al,*1990). Compared to the local clone, the orange-fleshed germplasm accessions had high total carotenoids (6.06-10.54µg/g) and β- carotene (3.77-7.22µg/g. The flesh colour of the tuber is correlated with the carotenoid content. Iglesias, *et al* (1997) and Chavez, *et al* (2007) also observed that the flesh colour in cassava is positively correlated with the carotenoids. Although there is close association of flesh colour and carotenoids, variability was also observed in the clones with similar colour which resulted variation in the total carotenoids and β- carotene content.

The nutritive value of yellow-fleshed cassava depends on the retention of carotenoids present after processing prior to its consumption. The retention of carotenoids varied in different processing methods. Highest retention of total carotenoids (79-84%) and β- carotene (83-95%) was observed in the oven-drying method. In the boiling method, the retention of total carotenoids was 71-84% and β- carotene was 74-84%. During boiling the flesh colour changes to dark yellow and orange and this may be due to the gelatinization of starch. Even though the retention of carotenoids was higher in the oven-drying method there was not much difference in both the processing methods. In the fried chips the retention of total carotenoids ranged from 68-75% and β-carotene varied from 45-75%. The least retention of total carotenoids (37-43%) and β-carotene (22-51%) was found in the sun-dried chips. Similar results were observed by Nascimento, *et al* (2008) *ie* highest retention of β –carotene was in the oven-drying (91%) followed by boiling (80%) and frying (54%). The studies on the retention of β-carotene in the cassava products (Oliviera,*et al*.,2008) indicated that boiling was the best method (72-96%) for the retention of carotenoids and lowest was in the fried chips (26-43%).Variation in the retention of carotenoids may be due to the difference in the enzymatic oxidation during processing. Retention of carotenoids in boiling is more important since majority of common people consume cassava tubers after boiling. In the present study highest retention of total carotenoids and β- carotene was found in the oven-drying method, but it is not a common method of processing for human consumption. The high carotenoid retention may be beneficial for the production of animal and poultry feed. The three high carotene accessions had poor culinary quality and all of them possess low dry matter (20-22%) since negative correlation exits between dry matter and carotene content as reported by Jos *et al* (1990) and Murthy *et al* (1990). It is very interesting to note that all the high carotene clones are very good for making golden coloured crispy fried chips. There was reasonably good retention of total carotenoids (45 – 75%) as well as β- carotene (68 – 75%) in the fried chips. Compared to other methods, sun drying resulted in the lowest retention of total carotenoids (37 – 43%) and β- carotene (22 – 51%). Similar results were reported by Chavez et al (2007). Sun drying is the most traditional, cheapest and acceptable means of food preservation. Since cassava tubers are easily perishable the common and quick method of storage is by making it into sun dried chips. The drastic reduction of carotenoids in the sun drying process may be due to the detrimental effect of the sun light on the stability of carotenoid pigment.

The high carotenoid retention in the different processing methods indicates the possibility of significantly improving the nutritive value by making more acceptable products to the consumers. Vitamin A deficiency is a preventable problem occurring due to the unbalanced diet of the people and it can be successfully overcome by the supplementation and fortification of different food especially from yellow- fleshed cassava.

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# Screening for β-carotene, iron, zinc, starch, individual sugars and protein in sweetpotato germplasm by Near-Infrared Reflectance Spectroscopy (NIRS)

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## Abstract

Vitamins and minerals are often seriously lacking in human diets, especially vitamin A, iron and zinc. It is estimated that 25% of preschool age children have vitamin A deficiency; 37% and 49% of the total world population is affected by low iron and zinc intake, respectively. Impact assessment indicated that orange-fleshed sweetpotato (OFSP) can alleviate vitamin A malnutrition. Elevation of iron and zinc levels in sweetpotato can also result in an important contribution in the human diet. To support sweetpotato breeding programs, a high throughput technique was needed to simultaneously screen, in short time, several quality traits in thousands of genotypes of the sweetpotato germplasm at CIP.

NIRS calibrations, based on several hundred samples each, were developed and showed high prediction accuracy. Calibrations were applied to the screening of 1209 accessions of the sweetpotato germplasm in 2 locations: La Molina and San Ramon. Only 246 clones were considered as OFSP clones because they have more than 20mg β-carotene/100 g, DW in at least one location. The mean concentration and distribution of β-carotene, iron, zinc and protein was higher in La Molina than in San Ramon. A group of 13 clones with high β-carotene, a significant amount of iron, high dry matter and yield and a second group of 16 clones with high β-carotene a significant amount of zinc, high dry matter and yield were identified and are recommended for dissemination and evaluation in Africa.

**Keywords:** Sweetpotato, β-carotene, Minerals, Near-Infrared Reflectance Spectroscopy, Germplasm Evaluation.

## Introduction

Sweetpotato ranks as the world's seventh most important food crop - after wheat, rice, maize, potato, barley, and cassava. Sweetpotato is mainly produced in marginal soils in low-input subsistence farming systems of developing countries where it is a major food crop and it is consumed in large quantities (Woolfe, 1992; Grüneberg et al., 2005). CIP germplasm collection contains about 6000 sweetpotato genotypes/accessions. Sweetpotato is an important source of carbohydrates and the orange fleshed varieties are a rich source in β-carotene, a precursor of vitamin A (Kang and Priyadarshan, 2007). Socio-economists and nutritionists have estimated that breeding for enhancing β-carotene, iron and zinc concentrations in sweetpotato would have a major impact on public health (Welch and Graham, 2000; Nestel et al., 2006).

To support breeding programs for sweetpotato there is a need of high throughput techniques to screen the macro- and micronutrient concentrations of the sweetpotato germplasm and to estimate the concentrations in thousands of genotypes in relative short time. For accurate analysis of micronutrients spectrophotometer, HPLC and ICP are the methods of choice. However, these methods are time-consuming, involve low sample throughput, and are expensive if thousand of samples have to be screened.

Requiring only simple sample preparation methods (drying and milling for sweetpotato) NIRS is a rapid and relatively inexpensive technique that facilitates the analysis of several traits simultaneously, and is commonly used to estimate the main organic constituents like oil, protein and starch in various agricultural products and even in the complex matrices of processed foods (Shenk and Westerhaus, 1993; zum Felde et al., 2007). The advantages to use NIRS in screening and breeding programs are various. Application of NIRS in routine does not

need chemical reagents and avoids contamination with chemical waste! Fast analysis of several traits simultaneously in less than 2 minutes per sample are possible and several hundred samples can be analyzed per day.

The objectives of this study were:

1. To develop NIRS calibrations to estimate protein, β-carotene, iron, zinc, starch and individual sugars in sweetpotato.
2. To screen for high β-carotene, iron and zinc types in the sweetpotato germplasm of CIP.

## Material and methods

### *Development of NIRS calibrations*

Reference values for protein, β-carotene, iron, zinc, starch and individual sugars were obtained in a set of 216 (protein), 320 (β-carotene), 422 (iron and zinc), 268 (starch) and 266 (individual sugars) freeze dried and milled sweetpotato samples (Table 1). B-carotene and individual sugars were analyzed by HPLC, iron and zinc were analyzed by ICP, starch was analyzed polarimetric and protein by Kjeldahl.

Each freeze dried and milled sample was scanned by NIRS within the range of 400 to 2500 nm using a NIRS monochromator (model FOSS 6500; NIRSystems Inc., Silver Spring, MD, USA) and using small ring cups with a sample autochanger. Calibration equation for β-carotene were developed under WinISI II Project Manager 1.50, with spectral information from 400 to 2498 nm and using modified partial least squares (MPLS) regression and cross validation techniques. Calibration equation for protein, iron, zinc, starch and individual sugars were developed with reduced spectral information from 1100 to 2500nm. The derivative and mathematical treatments were 2, 5, 5 and 1 for β-carotene and 1, 4, 4 and 1 for protein, iron, zinc, starch and individual sugars. The first number is the derivative, the second the gap, and the third and fourth numbers are the smooth. The results of the calibration calculation were checked observing the t-outliers with t > 2.0, GH- and X-outliers >8. The number of outlier elimination passes was two. Samples with t > 2.0 were deleted from the sample file. A lower than usual t-outlier value of 2 was chosen because no extra care was taken during the reference analysis, e.g. duplicate analysis of the same samples.

### *Screening for high β-carotene, iron and zinc in sweetpotato germplasm*

The germplasm evaluation, 1209 clones in total, was carried out in two environments of Peru (La Molina and San Ramon) with two replications and ten plants per plot in 2006. The β-carotene, iron, zinc, starch, glucose, fructose and sucrose concentrations in storage roots were estimated by the developed calibrations in freeze dried and milled samples of 1209 germplasm accessions. Additional traits recorded were: Storage root yield, upper biomass yield and dry matter. Descriptive statistics of the mean concentration of all traits evaluated and multivariate analysis on both locations, San Ramon and La Molina, was done.

## Results and discussion

### *Development of NIRS calibrations*

Mean values, standard deviations and ranges of the reference values and the statistics of the NIRS calibration and of the cross-validation are shown in Table 1.

NIRS calibration equations developed on the basis of 216-422 selected samples showed high coefficients of determination for the calibrations ($R^2_c$) (0.81 to 0.98) with slightly lower coefficients of determination for cross-validations ($R^2_{cv}$) (0.80 to 0.97). The highest $R^2_c$ and $R^2_{cv}$ were found for β-carotene (0.98 and 0.97, respectively), starch (0.97 and 0.96, respectively), and for protein (0.97 and 0.95). The standard errors of calibration (SEC) and the standard errors in cross validation (SECV) were low for all traits (Table 1). Independent and external validations (Bonierbale et al., 2008) confirmed the values of cross validation (results not shown).

**Table 1. Variation of concentrations as measured by reference methods, NIRS-calibration and cross validation statistics for the content of protein, -carotene, iron, zinc, starch and individual sugars concentrations in sweetpotato in the calibration sets**

| Trait | Reference Values | | | Calibration | | Cross Validation | |
|---|---|---|---|---|---|---|---|
| | Range [a,b] | Mean [a,b] | SD [a,b] | $R^2_c$ | SEC [a,b] | $R^2_{cv}$ | SECV [a,b] |
| Protein (N=216) [b] | 1.7 – 9.1 | 4.1 | 1.7 | 0.97 | 0.30 | 0.95 | 0.36 |
| -carotene (N=320) [a] | 0.0 – 157.2 | 33.7 | 37.9 | 0.98 | 4.25 | 0.97 | 5.69 |
| Iron (N=422) [a] | 0.8 – 4.5 | 2.0 | 0.7 | 0.81 | 0.26 | 0.80 | 0.27 |
| Zinc (N=422) [a] | 0.5 – 3.1 | 1.3 | 0.5 | 0.91 | 0.14 | 0.89 | 0.15 |
| Starch (N=268) [b] | 22.3 – 73.7 | 58.0 | 9.3 | 0.97 | 1.41 | 0.96 | 1.58 |
| Fructose (N=266) [b] | 0.1 – 19.1 | 2.88 | 3.0 | 0.95 | 0.55 | 0.94 | 0.61 |
| Glucose (N=266) [b] | 0.0 – 28.3 | 3.9 | 4.4 | 0.95 | 0.67 | 0.94 | 0.72 |
| Sucrose (N=266) [b] | 3.0 – 44.1 | 13.8 | 6.7 | 0.82 | 2.60 | 0.80 | 2.76 |

SD = standard deviation, $R^2_c$ = coefficient of determination in calibration, SEC = standard error of calibration, $R^2_{cv}$ = coefficient of determination in cross validation, SECV = standard error of cross validation, [a] = mg 100 $g^{-1}$ in dry weight, [b] = % in dry weight.

Based on several hundred samples each, NIRS calibrations to estimate protein, β-carotene, iron, zinc, starch and individual sugars in freeze dried and milled sweetpotato root samples were developed. Applied calibrations are ongoing extended by including samples from different African and Peruvian environments.

The iron and zinc calibrations for freeze dried and milled sweetpotato material have high precision close to those for protein, β-carotene, starch and individual sugars. Extension of existing calibrations for freeze dried sweetpotato samples for protein, β-carotene, iron, zinc, starch and individual sugars is done every year with at least 50 samples, each. The available calibrations for freeze dried storage roots are ready to be used in a sweetpotato NIRS-network simultaneously and have been already installed on the NIRS equipment at NARO (National Agricultural Research Organization) in Namulonge, Uganda and are applied for routine analysis (Figure 1).

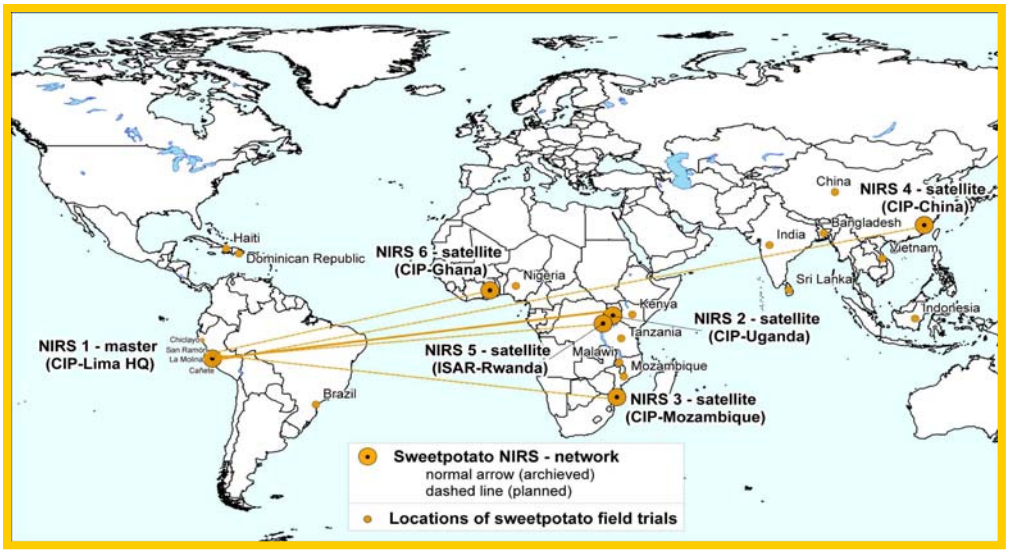


**Figure 1. Established and planned sweetpotato NIRS network**

Calibrations were applied for the documentation of descriptive and potentially beneficial characteristics of sweetpotato genebank accessions, the assessment of the food value of present farmers' varieties, and the selection of parents in breeding programs oriented to nutritional enhancement of sweetpotato.

### *Screening for high β-carotene, iron and zinc in sweetpotato germplasm*

The β-carotene concentration of the 1209 clones evaluated in this study ranges from 0 to 101.05 mg/100g DW in La Molina and from 0 to 63.48 mg/100g DW in San Ramon (Table 2). Since 12 µg of β-carotene to be equivalent to 1 µg of retinal (IOM, 2001) we consider that a variety with 20 mg/100g, DW (5 mg/100g, FW, considering 25% of dry matter) provide nearly 100% of the RDI of vitamin A for children under five years old (450 µg RE/ day; FAO/WHO, 2002) and hence defined it as a high β-carotene variety. Under this assumption only 246 clones out of 1209 were considered as OFSP clones because they have more than 20mg β-carotene/100 g, DW in at least one location.

The iron and zinc concentration ranges from 1.05 to 3.94 and from 0.63 to 2.78 mg/100g DW, respectively in La Molina and from 0.72 to 2.55 and from 0.36 to 1.54 mg/100g DW, respectively in San Ramon (Table 2). The mean concentration and distribution of β-carotene, iron, zinc and protein was higher in La Molina than in San Ramon (Figure 2, Table 2). We expect that this is associated with higher nitrogen supply in La Molina. B-carotene is slightly positive correlated with iron and zinc; however protein was closely correlated with iron and zinc (results not shown).

The dry matter percentage (DM) range from 15.58 to 44.02% and the starch concentration from 29.97 to 76.15 g/100g DW in La Molina and from 15.01 to 51.08% and 27.76 to 76.12 g/100g DW, respectively in San Ramon. The individual sugars range from 0 to 12.12 mg/100g DW in La Molina and from 0 to 18.85 g/100g, DW in San Ramon for fructose, from 0 to 17.53 g/100g DW in La Molina and from 0 to 25.57 g/100g DW in San Ramon for glucose and from 0 to 35.34g/100g DW in La Molina and from 0.02 to 30.64g/100g in San Ramon for sucrose (Table 2).

**Table 2. Variation of concentrations as measured by NIRS in 1209 germplasm accessions**

| Trait | La Molina | | | San Ramon | | |
|---|---|---|---|---|---|---|
| | Min.[a,b,c] | Max.[a,b,c] | Mean[a,b,c] | Min.[a,b,c] | Max.[a,b,c] | Mean[a,b,c] |
| Protein[b] | 2.97 | 15.46 | **8.72** | 1.05 | 6.14 | **2.63** |
| -carotene[a] | 0.00 | 101.05 | **16.58** | 0.00 | 63.48 | **12.17** |
| Iron[a] | 1.05 | 3.94 | **2.19** | 0.72 | 2.55 | **1.31** |
| Zinc[a] | 0.63 | 2.78 | **1.48** | 0.36 | 1.54 | **0.79** |
| Starch[b] | 29.97 | 76.15 | **61.47** | 27.76 | 76.12 | **65.51** |
| Fructose[b] | 0.00 | 12.12 | **1.71** | 0.00 | 18.85 | **1.87** |
| Glucose[b] | 0.00 | 17.53 | **2.05** | 0.00 | 25.57 | **2.49** |
| Sucrose[b] | 0.00 | 35.34 | **10.86** | 0.02 | 30.64 | **11.06** |
| DM[b] | 15.58 | 44.02 | **30.79** | 15.01 | 51.08 | **36.43** |
| FYLD[c] | 0.44 | 204.4 | **35.56** | 0.44 | 111.1 | **10.40** |
| RYLD[c] | 0.44 | 97.78 | **18.70** | 0.22 | 82.67 | **18.64** |

[a] = mg 100 $g^{-1}$ in dry weight, [b] = % in dry weight, [c] = t /ha

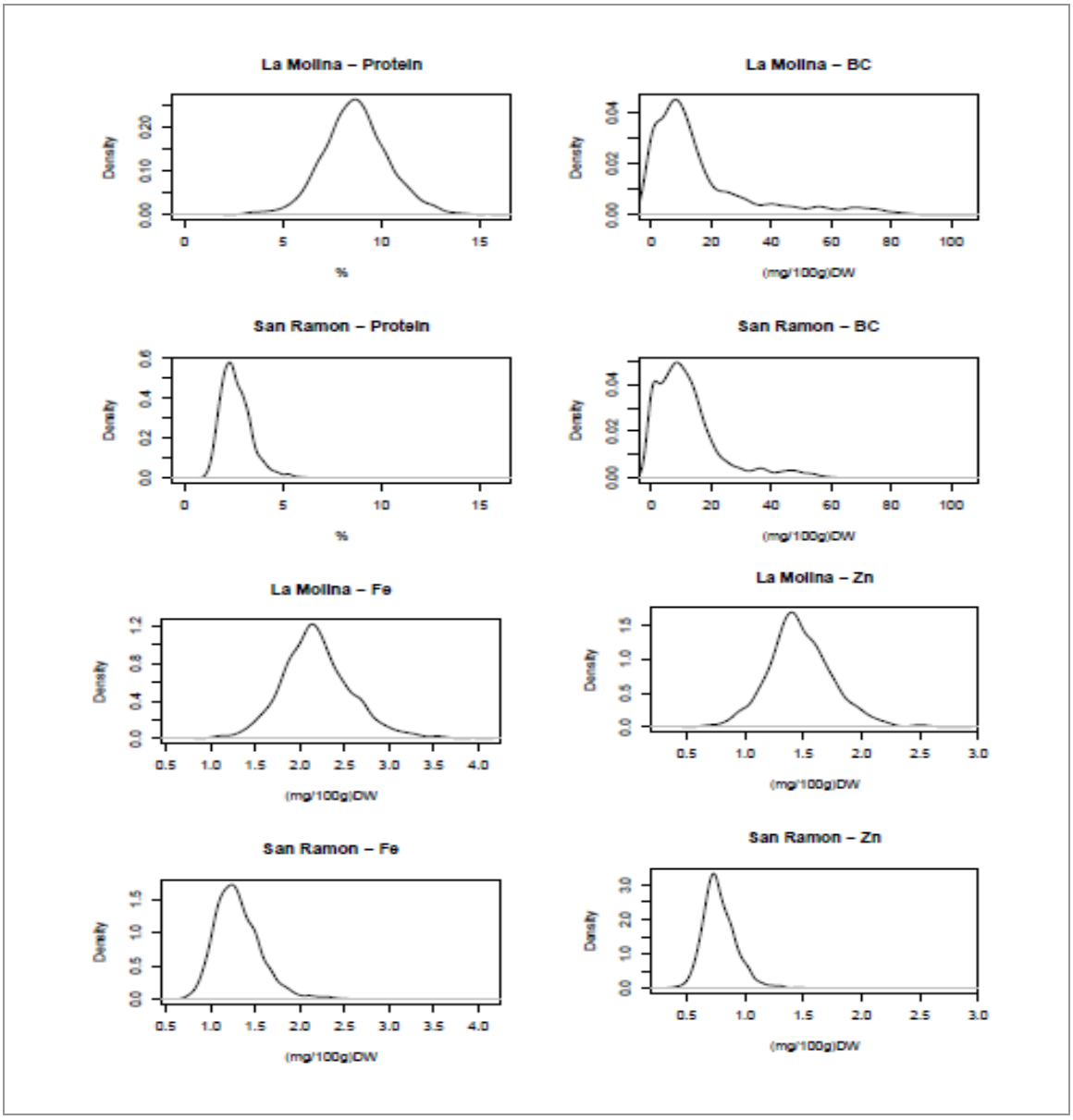


**Figure 2. Density plots for protein, -carotene (BC), iron (Fe) and zinc (Zn) in San Ramon and La Molina**

Multivariate analysis on each location was performed on the 1209 accessions and the 11 variables evaluated in this study. In La Molina, the 2 first principal components (PC) explain the 66% of the total variance, PC1 (41%) and PC2 (25%) (Figure 3a) while in San Ramon the 2 first principal components explain also 66%, PC1 (37%) and PC2 (29%) (Figure 3b).

In both locations, β-carotene showed similar vector directions to sucrose, iron, zinc and protein indicating positive relations between these compounds. However the β-carotene vector was opposite to the dry matter vector indicating a negative relation between β-carotene and dry matter (Figures 3a and 3b). This finding support what has been found in other studies for a reduced number of clones.

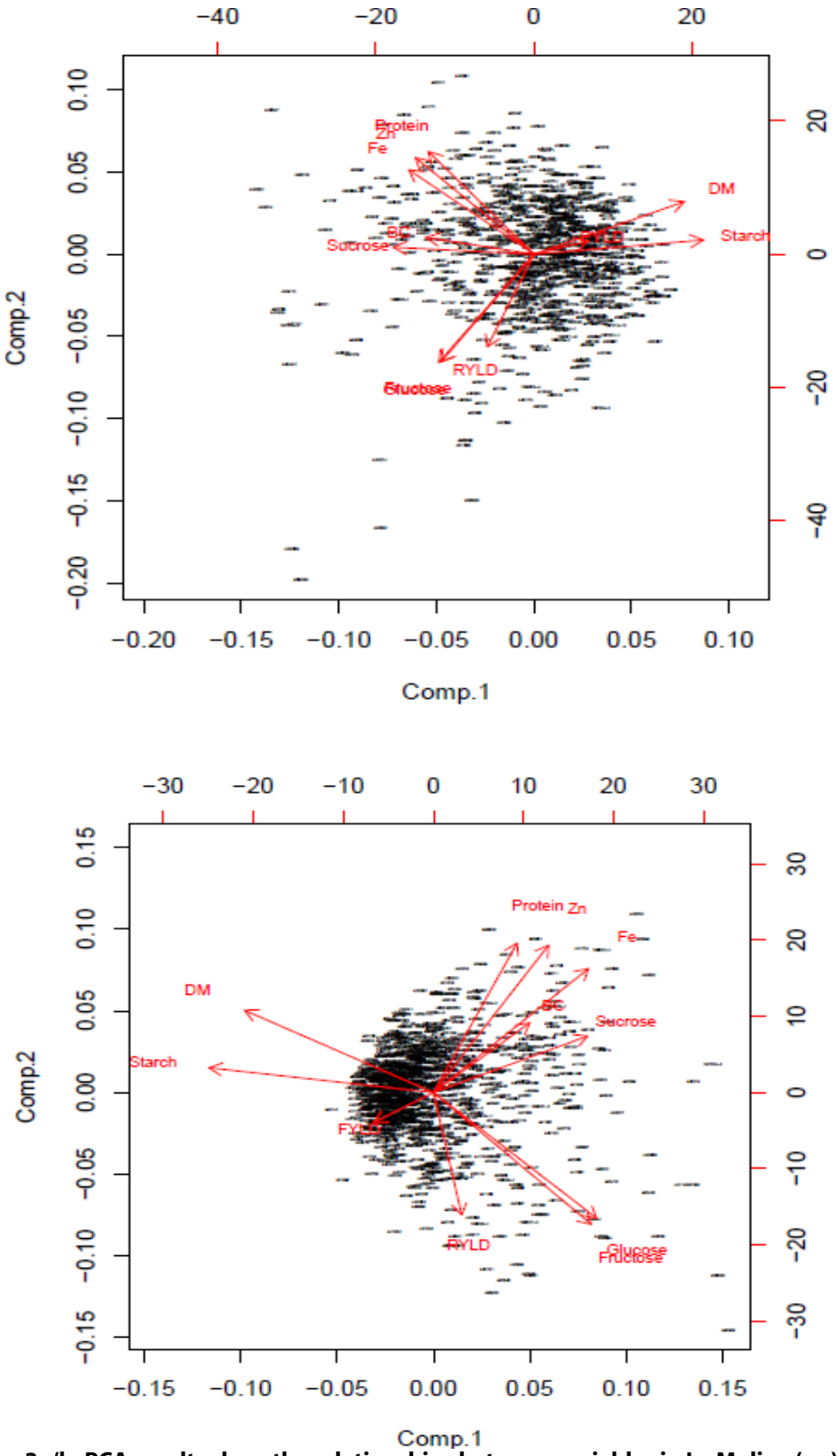


**Figure 3a/b. PCA results show the relationships between variables in La Molina (up) and San Ramon (down)**

A group of 13 clones with high β-carotene, a significant amount of iron, high dry matter and yield was identified. These clones were selected on the basis of single means estimations for storage root yield (>= 9 t /ha), β-carotene (>=20 mg / 100g), iron (>=1.8 mg/100g DM) concentrations and DM% (>25%) in storage roots. These clones have the following CIP-numbers: 401430, 440001, 440008, 440012, 440018, 440020, 440092, 440135, 440139, 440315, 440394, 441724, 441725.

A second group of 16 clones with high β-carotene a significant amount of zinc, high dry matter and yield was identified. These clones were selected on the basis of single means estimations for storage root yield (>= 9 t /ha), β-carotene (>=20 mg / 100g), zinc (>=1.8 mg/100g DM) concentrations and DM% (>25%) in storage roots. These clones have the following CIP-numbers: 420081, 440001, 440002, 440008, 440010, 440012, 440018, 440020, 440090, 440092, 440135, 440139, 440315, 440394, 441724, 441725.

These in total 17 different OFSP clones are recommended for dissemination and evaluation in Africa and for use in sweetpotato breeding programs.

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# The foods of *Rongo-marae-roa*; sustaining the Māori of New Zealand

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New Zealand lies to the southwest extreme of the Pacific Ocean. Māori, as the indigenous Polynesian people of New Zealand, relied upon just a handful of cultivated crops to support their subsistence lifestyle and the tutelage of *Rongo-marae-roa* as their deity aligned to cultivated foods. The *kūmara* (sweetpotato) and *taewa* (Māori potato) are among a suite of crop introductions that arrived either with the first Polynesians or later colonial contacts.

The ability of Māori to transpose sub-tropical crops to a temperate climate corroborates their horticultural skill. Kūmara are a marginal crop as they need summer heat to produce quality roots and do not flower in New Zealand. However, Māori taught themselves to propagate kūmara from cuttings taken from selected over-wintered parent material. Kūmara became the staple carbohydrate food source and a valuable commodity, especially in cooler southern regions.

The introduction of potatoes in the eighteenth century impacted immensely on Māori. Without any pests or diseases of note, New Zealand provided a seemingly unlimited and suitable land resource; potatoes thus succeeded kūmara as the primary carbohydrate crop. However, modern cultivars of both crops and many pests and diseases have since been introduced to New Zealand, impacting greatly on these traditional crops.

With the growing interest in indigenous and holistic systems applied to crop management, the skills Māori applied to root crops are becoming increasingly scrutinised. A bio-technology approach to kūmara and taewa drawing from plant and soil systems is being investigated, inclusive of traditional practices, and will contribute to future production. Outcomes are expected to also contribute to the wider horticultural sector.

**Keywords:** New Zealand, Māori, kūmara, taewa, indigenous, South Pacific.

## Introduction

New Zealand is an isolated country in the South Pacific with an often capricious climate and variable soil resource well suited to root and tuber crop production. Māori are the indigenous people of Aotearoa-New Zealand and as '*tangata whenua*' (literally 'the people of the land') they have created an enduring relationship with the landscape, including the flora and fauna which survives upon it. New Zealand is the southernmost landmass of the Pacific Ocean and of the Pacific cultures. As such it endures a relatively temperate climate with extremes from sub-tropical in the north to sub-Antarctic in the south. Coming from the tropical islands of the Pacific, Māori, on settling New Zealand had to adapt their horticultural practices to meet these climatic limitations. Much of their lifestyle was based on a subsistence approach including both cultivated and uncultivated plants and the seasonal harvesting of birds and fish. Among the plants which Māori had access to are two of the primary root and tuber crops, kūmara or sweetpotato (*Ipomoea batatas*) and taewa or Māori potato (*Solanum tuberosum* spp. andigena).

## Māori root and tuber crop production systems

Kūmara is the noun in the Māori language for the root crop known as sweetpotato. Buck (1954) noted the name *kumar* exists in the Quechua dialect of Northern Peru for the sweetpotato and has probably contributed to the generic name *kūmara* used around Polynesia. Kūmara is the only South American plant in the inventory of plants grown by pre-European Māori. Early visitors to New Zealand identified sweetpotato *(kūmara)* as the most prominent crop being grown by Māori in northern districts (Yen, 1963; Best, 1976; Jones, 1989) and the staple

carbohydrate in the diet. Kūmara production was adapted by Māori to be grown in the temperate climate. There were several cultivars of pre-European kūmara of which only a handful survive and are grown today. The modern cultivars are sports of earlier sweetpotato varieties (mostly American varieties introduced through early European contact) which have gained favour with consumers and producers alike (Coleman, 1972; Yen, 1974).

In New Zealand both the pre and post-European cultivars of kūmara are not known to flower, and in fact, efforts to induce flowering have not been successful (Yen, 1963). An exception is the testimony of an early botanical observer who ONCE saw a kūmara plant in flower in the far northern region in 1883, (Hammond, 1894). This means that all varieties are propagated vegetatively. The kūmara plant is tolerant of salt winds, drought and lower fertility in soils, thus making it quite suitable to the sand and silt loams of much of the coastal fringe in New Zealand. It was not very successful however in most of the South Island of New Zealand because of the cooler climate but was grown in some coastal pockets where a warmer micro-climate existed. It was however, also considered a difficult crop to grow in the central North Island because of the severity of seasonal frosts and short growing seasons experienced there – except of course in some microclimates on river terraces with alluvial soils (Williams & Walton, 2003).

Traditional production of kūmara is immersed in customs expressed as ritual, prayers and incantations, and sacred behaviour because of the tapu or sacredness accorded to the crop. This sacred aspect falls under the tutelage of a cultural deity known as *Rongo-marae-roa* who holds responsibility for cultivated crops. Considerable effort was given to preparing land to benefit kūmara production such as draining swampy soils (Barber, 1984) or amending soils with gravels to raise temperatures and improve drainage. Early production systems were based on 'pieces' of kūmara with shoots being cut and planted rather than the process of shoot production which is the procedure used today (Berridge, 1913 & 1914; Yen, 1961; Best, 1976). Plants were placed in ridges or mounds and tended to religiously throughout the growing period, generally from November to the following March.

Harvest, grading and storage of the kūmara crop were equally important activities, also steeped in cultural practices. In the tropical Pacific, sweetpotato is continuously harvested on demand year-round and there is no need for specific storage techniques. The temperate and seasonal climate of New Zealand required Māori to adapt their management of the crop to ensure it was accessible throughout the year. Yen (1961) noted that in no kūmara growing region within New Zealand had he encountered over-wintering of kūmara in the field or in propagating beds of previous seasons. This observation was supported by over-wintering trials at several sites around New Zealand where the kūmara failed to survive the winter season. Crops that were late harvested or left in-situ over the winter months generally succumbed to rot pathogens; even when harvested they failed to store well after being held in a damp soil environment which had affected the skin and tuber qualities.

The taewa or Māori potato is a tuber crop known by a number of generic names according to tribe and dialect around New Zealand and as the 'native potato' or *'la papa nativas'* in its centre of origin. The term taewa differentiates the Māori potato from the more recently introduced 'European' potato (*S. tuberosum* spp. *tuberosum*).

There are several different beliefs regarding the origin of the Māori potato in New Zealand and the route taken to get there. It is generally accepted that potatoes were not brought as cargo during the migrations of Māori to New Zealand but how they arrived remains an interesting point. Some believe that chance visits by unrecorded trading vessels which may have earlier visited South America are responsible for the introduction of taewa (Richards, 1993). Other tribes hold beliefs that taewa were sourced by their own people from the bush or through other obscure processes. South Taranaki tribes in the North Island of New Zealand claim a variety known to them as Tātairongo was obtained from the underworld by their ancestor Te Reke Tātairongo (Hammond, 1924).

Captain James Cook is credited with the earliest recorded introduction of potatoes to New Zealand. On his first voyage and contact in November 1769 he visited Mercury Bay in the Coromandel region of the North Island. A man, Te Horeta Te Taniwha was a child at the time and his recollections in old age included:

> *'Cook then gave two handfuls of potatoes to the old chief* [Toiawa], *a gift of profound importance to the M oris. By tradition these potatoes were planted at Hunua where, after cultivation for 3 years, a feast was held and a general distribution made.'* (Begg & Begg, 1969:36)

Lieutenant King, Governor of Norfolk Island is known to be a catalyst in the introduction of many exotic flora and fauna to the northern districts during a visit to New Zealand in 1793. King is credited with the introduction of the European or 'white' potato known to Māori as *riwai* which is said to have had an *'immediate influence on the food producing and dietary habits of the Māori's associated with these travellers'*. (Shawcross, 1967:142)

The Māori potato ultimately displaced traditional crops such as kūmara and fernroot (*Pteris* spp.) as the primary carbohydrate and subsistence crop produced by Māori for their own use (Best, 1976; Roskruge, 1999) some calling it the:

> '*… greatest gift of the European to the M ori agriculturist… which by 1835 was much more in use than any native vegetable'* (Hargreaves, 1963:103).

In comparison to many of the other crops grown by Māori, taewa had a high labour requirement which was able to be met by Māori communities at the time and yielded a plentiful return for the labour input (Firth, 1972). The potato production system copied that applied to the production of kūmara which Māori were very adept at and thus they became experts in production in a very short time. Local variations in cultivation such as the planting of crops by some inland tribes in light scrub as early as June (mid-winter) to shelter young growth from frosts (*ibid*) or site selection criteria on north facing slopes were common.

## Contemporary systems and and biotechnology

Today taewa are produced using much of the same processes and technology as the modern commercial potato crops. Kūmara are also produced commercially but under an entirely contemporary system in just one region of the country which draws significantly from the international systems applied to this crop. During the early colonisation period these root and tuber crops were important to Māori economic development and provided a marketable product which sold readily and was in continuous demand both in New Zealand and Australia. This intensification of horticultural demand contributed to the large areas brought into production during the rapid colonisation of the nineteenth century and the growing importance of these crops (Roskruge, 2007). Since colonisation however there has been a considerable change in the available land resource and biological pressures around these crops; new pest and disease pathogens, weed infestations and considerable postharvest management demands.

With the growing interest in indigenous and holistic systems applied to crop management, the skills Māori applied to root and tuber crops are becoming increasingly scrutinised. A bio-technology approach to kūmara and taewa drawing from both plant and soil systems is being investigated, inclusive of traditional practices, and will contribute to future production. Outcomes are expected to also contribute to the wider horticultural sector and include such things as rotation practices and the use of bio-fumigants in the soil to minimise fungal diseases through to the timely application of natural products such as plant extracts to assist in management of pests and diseases.

Taewa production systems are applied to approximately twenty taewa varieties with attributes ranging from yellow flesh & skin through variations of red, cream, blue and purple skin and flesh of several shapes and size. The retention of taewa in non-commercial systems has created considerable interest by the commercial sector. Future management will need to consider the preservation of the cultural factors contributing to their survival. Current production systems for these crops can include cultural aspects such as soil manipulation through biochar addition and crop rotation or plant physiological factors applied as harvest criteria. The restoration of this crop has included the need to define some primary agronomic factors such as timing and precocity of tuber-set by variety or nutritional demands aligned to the growth stages of the crops as well as submission of plant material to a seed certification programme thus eliminating generations of virus infection. Research associated with the agronomy of taewa continues but will take several more years to achieve commercial application due to the annual nature of the crop. Ultimately these factors help to better prepare producers for commercial demands: in the interim they will provide learning tools, some of them unique, for crop manipulation that producers of root and tuber crops can apply.

## Conclusion

Sweetpotato and native potatoes; kūmara and taewa respectively, are the primary root and tuber crops form part of the food production systems of Māori in New Zealand. Both crops have a considerable indigenous knowledge base applied to them under the tutelage of a local deity *Rongo-marae-roa.* The modern pressures on these crops, not least the introduction of new pathogens and weeds has prompted the interest in some of the indigenous system tools applied by Māori and how elements of these systems such as key rotation practices could be applied in a contemporary horticultural context. It is expected these elements will assist producers in managing their crops and provide some unique learning tools of use to root and tuber producers in general.

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# Seasonal variations of carotenoids in orange-fleshed sweetpotato (*Ipomoea batatas* (L.) Lam)

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## Abstract

Sweet potato (*Ipomoea batatas* (L.) Lam) is a hexaploid with 90 chromosomes. Due to the hexaploidy and heterozygous nature of the crop, wide range of variability was observed in the tuber yield, morphological and biochemical characters. The flesh colour of the tubers ranged from white to dark orange. In the orange- fleshed tubers, the major carotenoid present is the β – carotene which is a precursor of vitamin A. About 40 clones possessing different intensities of dark orange- flesh colour were selected and evaluated for total carotenoids, β – carotene and dry matter content during summer, kharif and rabi seasons to find out the variability of carotenoids at different seasons. The results indicated that the mean total carotenoid ranged from 8.5 – 15.0 mg/100g fresh weight and β – carotene varied from 6.8 – 13.7 mg/100g fresh weight. Out of 40 clones, stability in total carotenoid and β – carotene was observed in 13 clones. In 5 clones, the total carotenoid was stable and in 4 clones only β – carotene was stable for all the three seasons. Significant differences of total carotenoid and β – carotene content in different seasons was noticed in 18 clones. Majority of the clones possessed above 80% β – carotene and the dry matter was less than 25.0%. Vitamin A is produced in the human body in the presence of its precursor β – carotene. The variability in the carotenoids of orange – fleshed sweet potato can be exploited by selecting high β – carotene clones as a cheap source of vitamin A rich food.

**Keywords:** seasonal variations, carotenoids, orange-fleshed sweet potato.

## Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam) is an important vegetable cum food crop grown in the tropics, sub-tropics and warm temperate regions of the world for its edible tubers. The tubers are used as a source of carbohydrate and leaves are a potential source of proteins and minerals. In addition to its importance as human food, it is also used as an animal feed besides serving as a raw material for the production of alcohol. In India, it is grown throughout the country occupying an area of 1.06 ha with an annual production of 9.64 lakhs tones (FAO, 2000). The flesh colour of the tuber ranges from white to dark orange. In the orange-fleshed sweet potato the major carotenoid present is β-carotene which is a precursor of vitamin-A. The orange- fleshed sweet potato can provide twice the recommended daily requirement of vitamin-A and more than one third of vitamin-C. It is also a substantial source of dietary fibre. β -carotene protects the heart and cardiovascular system, boosts immune functions, speeds up the recovery from respiratory infections such as cold, flu and renders wound healing. As an anti-oxidant, β-carotene has been shown to inhibit oxidative damage due to cholesterol and protects against atherosclerotic plaque formation in human beings. One of the important health problems in India is the prevalence of vitamin- A deficiency in young children and adults. The objective of the present study is to estimate the total carotenoids and β- carotene of the selected orange- fleshed clones at different seasons in order to evaluate the Vitamin A potential.

## Materials and methods

The materials included for the study were 40 sweet potato clones possessing different intensities of dark orange-flesh colour which were selected from the polycross breeding programme of orange- fleshed sweet potato. The experiment was conducted in RBD in 3 replications during summer, kharif and rabi seasons following the recommended package practices of CTCRI. Each clone was planted on a 6.0 meter ridge. The spacing between and within the rows were 60.0 and 20.0 cm respectively accommodating 30 plants per clone per replication. The trials were harvested at 90 days after the planting. Biochemical analysis like dry matter, total carotenoids and β-

carotene content of all the clones were carried out for the 3 replications and 3 seasons following the method of AOAC (1995).

Carotenoids were extracted and separated using Alumina as adsorbent. The concentration of total carotenoids and β- carotene was calculated by determining OD at 450nm. β- carotene standard was prepared and used for the calculation of carotene in the test sample. Out of total carotenoids the percentage of β- carotene was calculated. In order to determine dry matter content about 100g of tuber sample was kept in a hot air oven at 50 $^{0}$C till a constant weight was obtained. From the weight of the dried sample, the percentage of dry matter was calculated. The data on dry matter, total carotenoids, β- carotene and percentage of β-carotene to total carotenoids of all the clones for the three seasons were analysed statistically as per the method given by Gomez & Gomez.(1984).

## Results and discussion

Sweet potato is a hexaploid and cross pollinated crop. Because of the hexaploidy and heterozygous nature of the crop a wide range of variability was observed in the seedling progenies for flesh colour, carotenoid and dry matter content. The biochemical analysis of the 40 clones showed that the total carotenoids in summer season ranged from 6.3 to 15.3 mg/ 100 g. fresh weight. In kharif season, it varied from 8.2- 15.5 mg/100g. fresh weight and in the rabi season the range was between 9.1 - 15.2 mg/100 g. fresh weight. The total carotenoid content and β-carotene was less than 10 mg / 100 m f.w. only in six clones.

The present studies showed that tuber carotenoid content was associated with the flesh colour as reported by Lin *et al* (1989). The β- carotene in 23 clones was 10.0 – 13.5 mg/100 g. f. w. in summer season and in the kharif and rabi season it varied from 10.1 – 13.8 and 10.0 – 14.5 mg / 100g f. w. respectively. The flesh colour of the tuber was positively correlated to the carotenoid content. Simonne *et al* (1993) reported that the carotenoids especially β- carotene was responsible for the orange flesh colour of sweet potato tubers and the depth of the orange flesh colour was mainly a function of the concentration of the β- carotene. The percentage of β- carotene to total carotenoids varied from 78 – 95 % which was higher than the value reported by Woolfe (1992).The clones ST 14- 6, KS-2, CO3 – 50 -33, CO3 – 50 -34 and ST 10 – 8 possessed above 90 % β- carotene in the summer season. In kharif season, 7 clones *viz,* ST- 14- 1, ST- 14-22, CO3- 50-33, ST 10 – 8, ST 10- 19, 108-2 and CIP- SWA-2 showed above 90% β- carotene. However, in rabi season only three clones ST 14-1, KS- 63, CO3- 50-33 possessed above 90 % β carotene.

The mean value of carotenoids in 3 seasons showed that out of 40 clones, significant difference of total carotenoids and β- carotene was noticed in 18 clones between different seasons. It may be due to the interaction of the genotype with the environmental factors. Thirteen clones (ST-14-22, ST-14-34, ST-14-39, KS - 37, CO3-50-23, CO3-50-39, CO3-50-43, ST- 10-4, ST-10-12, ST-10-19, SV3-17, 362-7, 108-14) possessed a stability in total carotenoids and β-carotene content at all the three seasons. However, five clones were stable only for total carotenoids contents (ST-14-1, ST-14-3, ST-14-47, ST-14-53, SV-3-8) and four clones (ST-14-16, ST-14-27, ST-10-8, CIP SWA 2 (2)) had a stable β- carotene content. Generally dry matter was less than 25 %. in all the high carotene clones. Only 6 - 7 clones possessed 25 – 27 % dry matter at different seasons. It has already been reported (Hernandez ,*et a*l.,1967; Jones, 1977; Zhang and Xie,1988) that negative correlation exists between dry matter content and carotenoids. The earlier studies of Vimala *et al* (2006) indicated that the highest total carotenoid of 14.0 mg /100g. f. w. was recorded in ST- 14. However in the present study it was observed that six clones possessed more than 14.0mg/100g.f.w. total carotenoids for all the three seasons .

Vitamin-A is produced by the human body when it has sufficient quantities of its pre-cursor β- carotene. The average daily requirement of β- carotene for children is 2.4 mg, adults is 3.5 mg and for lactating mother it is 5 mg (W.H.O 1995). It is estimated that 300-400µg equivalents of retinol per day satisfy the requirement for children upto 10 years of age which is equivalent to 2.1-2.4mg/100g.f.w. carotene. Usually a ratio of 4:1- 8:1 is used to convert β-carotene into retinol since the human body could not convert all the β-carotene. The major problem which results in vitamin-A deficiency in developing countries is due to the low dietary intake of vitamin A (Buycks,1996). One possible solution to control vitamin A deficiency in these areas is to increase the availability of a cheap source of vitamin rich food. A regular intake of 100g.of dark orange- fleshed sweet potato per day provides the recommended daily amount of vitamin A for children and adults which protects them from vitamin A deficiency (Tsou and Hong,1992). Sweet potato provides adequate amount of calories, vitamin C, vitamin D

and other micronutrients such as iron and zinc. Orange-fleshed sweet potatoes can play a significant role in the developing world as a viable, long term, cost effective, culturally acceptable, self- reliant, and sustainable food based approach to control vitamin A deficiency.

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# Concentration of ascorbic acid, carotenoids, total phenolics and total anthocyanins in cooked potatoes

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## Abstract

Potatoes are referred to as a good source of antioxidants like ascorbic acid (AA), carotenoids and polyphenols, however there is scarce information regarding the antioxidant concentration in cooked potatoes. In this study, the effect of cooking on the concentrations of ascorbic acid, carotenoids, total phenolic and total anthocyanins of diverse varieties were evaluated by spectrophotometry and HPLC. Cooking significantly reduced the AA concentration of all the varieties with boiling reducing the AA concentration to a lesser degree than either baking or microwaving . One hundred g of boiled potatoes of the variety 704393 could provide between 17 and 20% of the RDA of AA. Comparison of the carotenoid compositions of raw and cooked tubers of some varieties revealed that cooking significantly reduced the violaxanthin and antheraxanthin concentration of all the varieties. However the lutein and zeaxanthin concentration of cooked tubers of some of the varieties evaluated was higher than in raw tubers. One hundred grams of the cooked yellow fleshed varieties provide a significant amount of zeaxanthin (above 500 ug) to the human diet. The total phenolic and total anthoacyanin concentrations of the pink and purple fleshed varieties evaluated were higher in cooked than raw potatoes. It seems that cooking has no a negative effect on the lutein, zeaxanthin, total phenolic and total anthocyanin concentration of potatoes.

Cooked potatoes have a significant amount of vitamin C cooked yellow fleshed potatoes are a good source of zeaxathin, and cooked red and purple fleshed potatoes are a good source of anthocyanins.

Keywords: Potato, cooking, vitamin C, carotenoid, total phenolics, total anthocyanins.

## Introduction

Dietary antioxidants include ascorbic acid (AA), carotenoids and polyphenols. They are believed to play a key role in the body's defense system against reactive oxygen species, which are known to be involved in the pathogenesis of aging and many degenerative diseases such as cardiovascular diseases and cancers.

Potato contains important concentrations of AA, carotenoids and polyphenols. Freshly harvested raw, peeled potato tubers have been reported to contain up to 46 mg AA / 100 g FW (Han et al., 2004; Burgos et al., 2008) depending upon the variety, the maturity of the tubers at harvest, procedures for sampling and almost to as great an extent, upon the environmental conditions under which they were grown. Significant and predominant amounts of zeaxanthin and anteraxanthin have been reported in deep yellow fleshed potatoes while in yellow potatoes the reported carotenoid profile is composed of violaxanthin, antheraxanthin, lutein and zeaxantin; and in cream fleshed potatoes of lutein and betacarotene (Burgos et al., 2008). The principal phenolic acid in potatoes is chlorogenic acid. Red and purple potatoes also contain anthocyanins. Whole unpeeled potatoes with fully-pigmented flesh can have up to 40 mg / 100 g FW total anthocyanins. Red-fleshed potatoes contain acylated glucosides of pelargonidin while purple potatoes contain in additon, acylated glucosides of malvidin, petunidin, peonidin, and delphinin (Brown 2005).

In recent years, considerable information has been published about the composition of raw potatoes, but little or no attention has been given to the composition of cooked potatoes. In this context, the objective of this study was to determine the effect of cooking on the concentration of ascorbic acid, carotenoids, total phenolic (TP) and total anthocyanin (TA) concentrations of cooked potato.

## Materials and methods

The AA concentration of raw and cooked tubers of 6 varieties was determined using a spectrophotometric method using the method developed by Egoaville et al., 1988. Tubers were cooked by 3 different methods: boiling, baking and microwaving.

The individual carotenoid concentrations of raw and cooked (boiled) tubers of 2 light yellow fleshed varieties, 2 yellow fleshed varieties and 2 deep yellow fleshed varieties was determined by HPLC using the method described in Burgos et al., 2008.

The TP and TA concentration of raw and cooked (boiled) tubers of 5 different colored-fleshed potatoes was analyzed by spectrophotometry using the methods reported by Waterhouse, 2002 and Jansen and Flamme, 2006; respectively.

The effects of cooking were analyzed by ANOVA, considering the genotypes as random effects, and cooking (cooked vs. uncooked) treatments as fixed effects, and means were compared by Tukey's test. All statistical tests were performed using SAS/STAT (version 9.1) software.17 (SAS, 1999).

## Results and discussion

### *Ascorbic acid*

ANOVA indicated a significant non-crossover interaction between cooking method and variety. For the 6 varieties, boiling reduced the AA concentration to a lesser degree than either baking or microwaving (Figure 1). The percentage of AA retention ranged from 53 to 97%, from 6 to 66% and from 6 to 39% in boiled, baked and microwaved potatoes, respectively. A similar percentage of AA retention in boiled potatoes (53 to 97%) was found by Augustin et al (1978a) who also used potatoes cooked with their peels. However the percentages of AA retention in baked and microwaved potatoes found in this study are lower than those found by Augustin et al (1978a) (from 69 to 77% and from 77 to 58% in baked and microwaved potatoes respectively. A recent study reported higher percentage of retention of the AA concentration when potatoes are microwaved (67 to 79%) than boiled (12 to 23%) (Han et al., 2004). However this difference is likely due to the different methods used to prepare the boiled samples. Han et al. (2004) boiled plugs obtained from the central parts of tubers by penetrating the tuber with a cork borer from the stem end to the rose end while in the present study tubers were boiled with their skins intact, peeled after cooking, quartered longitudinally and sliced for taking the laboratory sample.

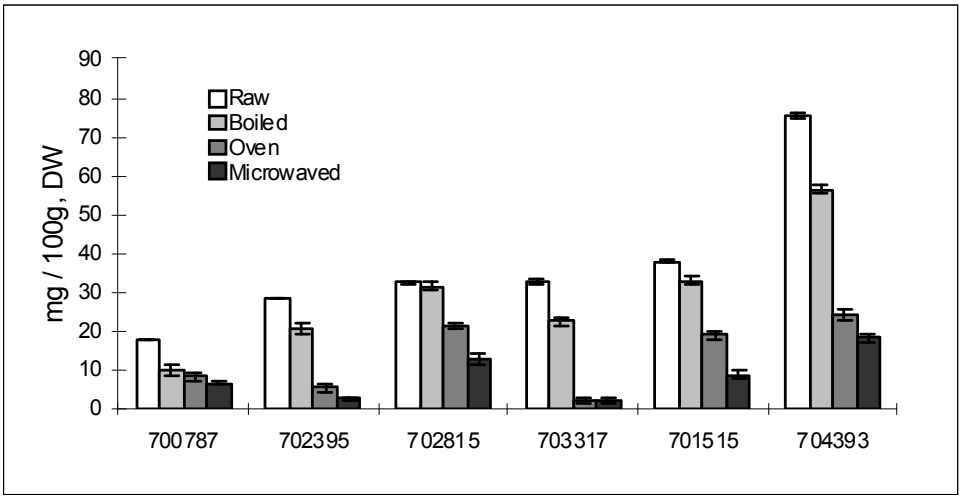


**Figure 1. Effect of 3 methods of cooking on the ascorbic acid concentration of tubers of 6 native varieties**

The native variety 704393 showed the highest AA concentration after boiling. One hundred g of boiled potatoes of this variety could provide between 17 and 20% of the RDA of AA, which is suggested to be 100 - 120 mg / day, to achieve cellular saturation and optimum risk reduction of heart disease, stroke and cancer in healthy individuals (Naidu, 2003).

### *Carotenoids*

Combined analysis of variance of the individual carotenoid concentrations of raw and cooked tubers revealed a significant interaction between cooking and variety, showing that the effect of cooking on the concentration of violaxanthin, anteraxanthin, lutein, zeaxanthin and betacarotene varies among varieties.

The 6 varieties showed significantly reduced violaxanthin and anteraxanthin concentration after cooking (Figure 2) with retention percentages ranging from 0 to 17% and from 0 to 54%, respectively. Similarly, previous studies have shown that epoxide carotenoids of mango, white fleshed sweetpotatoes, tomatoes and several green vegetables, are very sensitive to most food preparation conditions (Gody and Rodriguez-Amaya, 1987; Almeida and Panteado, 1988 and Khachick et al., 1992).

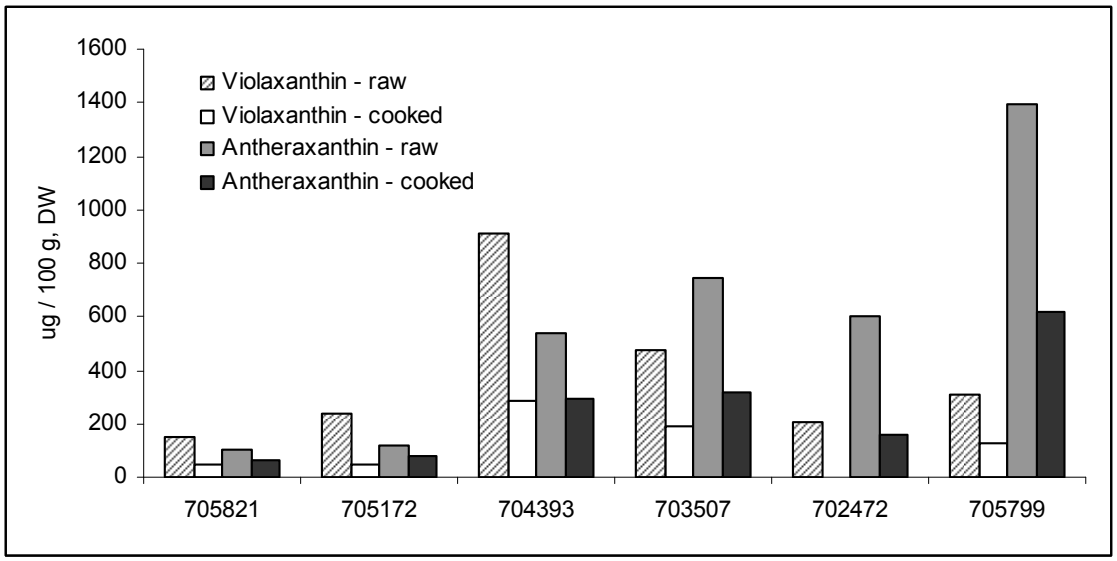


**Figure 2. Effect of boiling on the violaxanthin and antheraxanthin concentration of potato tubers**

The 2 deep yellow fleshed varieties evaluated in this study and 1 of the yellow fleshed varieties showed no significant diferences in the lutein and zeaxanthin concentration of raw and cooked tubers. However the yellow fleshed variety 703507 showed a significant increment in the concentration of both carotenoids after cooking. The light yellow fleshed varieties also showed a tendency toward increase lutein concentrations after cooking but the increment was not statistically significant. Since enzymes are inactivated by the heat treatment during cooking, these results are difficult to explain. However they may be attributable to the fact that lutein and zeaxanthin were stable after cooking and cooking facilitated the extraction of these carotenoids.

The lutein and zexanthin concentration of cooked potatoes ranged from 73 to 178 ug / 100 g, FW and from 0 to 551 ug / 100 g, FW. Lutein and zexanthin provide protection againts age related macular degeneration. The cooked potatoes of the deep yellow fleshed varieties showed significant amount of zeaxanthin (above 500 ug / 100 g, FW). The fact that the cooked tubers of the deep yellow fleshed varieties showed high zeaxanthin concentration is interesting since zeaxanthin is found in significant levels in relatively few dietary components including some maize cultivars and yellow orange pepper varieties (Minguez-Mosquera and Hornero-Mendez, 1994). However future studies should include evaluation of the bioavailabity of potato zeaxanthin to have a better idea of its contribution to the diet.

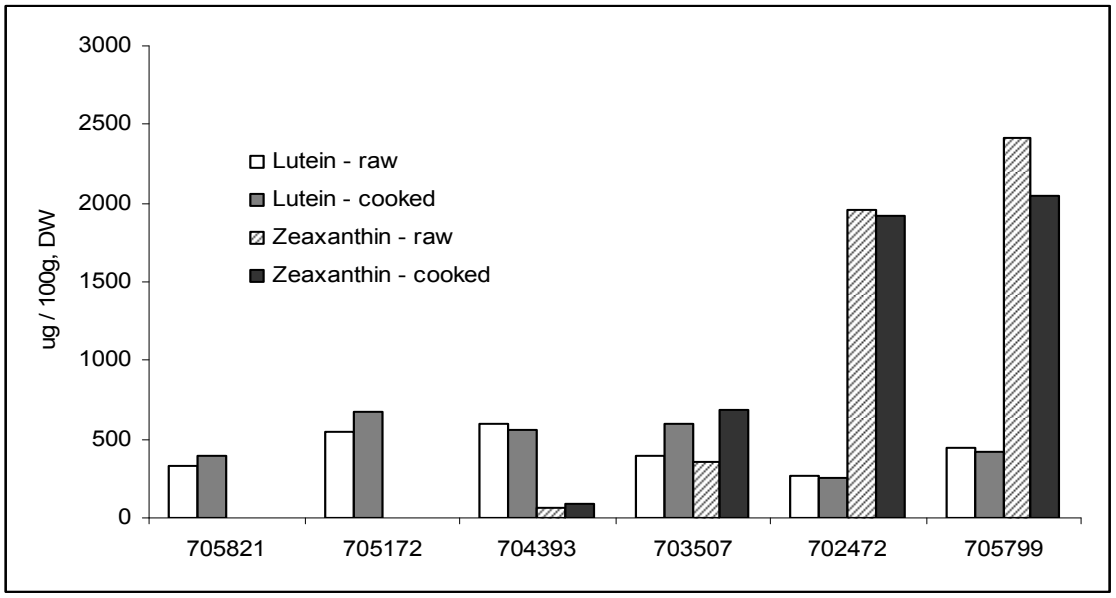


**Figure 3. Effect of boiling on the lutein and zeaxanthin concentration of potato tubers**

## Total phenolic compounds and total anthocyanin

Combined analysis of variance of the TP and TA concentrations of raw and cooked tubers revealed a significant interaction between cooking and variety showing that the effect of cooking on the concentration of TP and TA varies among varieties.

The cream and yellow fleshed varieties showed lower TP after cooking. The pink and purple fleshed varieties showed a higher TP and TA after cooking while in the deep purple fleshed variety the TP increased after cooking and the TA showed no significant differences. The higher concentration of TP and TA in cooked tubers may be attributable to more efficient extraction from cooked samples (Figure 4).

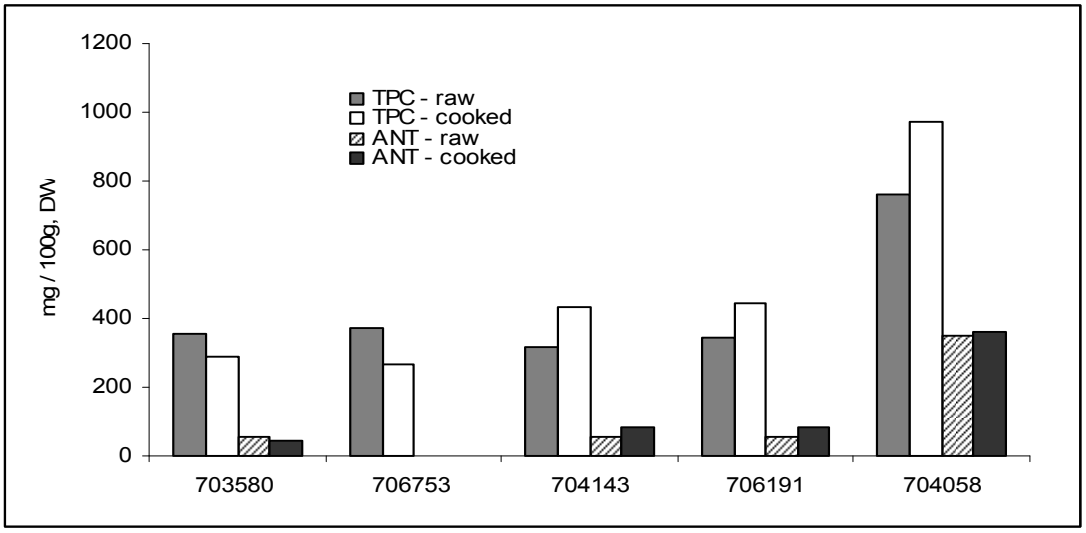


**Figure 4. Effect of boiling on the total phenolics and total anthocyanin concentration of potato tubers**

The total phenolic compound concentration of raw and cooked potatoes ranged from 78.10 to 169.77 and from 65.03 to 211.43 mg / 100 g, FW, respectively with the deep purple fleshed variety 704058 showing the highest total phenolic concentration. The highest value of TP reported in this study is similar to the highest value reported by Reyes et al, 2005 (181 mg / 100 g, FW) for red and purple fleshed potatoes. Previous studies in raw potatoes have reported that chlorogenic acid dominates the polyphenolic profile of potato cultivars (Andre et al, 2007; Lewis et al, 1998). Future studies are needed to confirm if chlorogenic acid dominates the polyphenolic profile of cooked potatoes. In addition it will be important to evaluate the bioavailabity of potato polyphenols and anthocyanins.

The total anthocyanin concentration of raw and cooked potatoes ranged from 0 to 77.83 and 0 to 78.10 mg / 100 g, FW; respectively, with the deep purple fleshed variety 704058 showing the highest total anthocyanin concentration.

This research demonstrates that the degree and sometimes the direction of effects of cooking on the concentration of AA, carotenoid, TP and TA vary among varieties.

Boiled tubers had higher AA concentration than baked or microwaved tubers. One hundred g of boiled potatoes of the variety with the highest AA concentration 704393 could provide adults with 17 – 20 % of the RDA of AA, but the actual contribution can be higher depending on the amount of potato consumed.

Cooked yellow fleshed potatoes are a good source of zeaxathin while cooked red and purple fleshed potatoes are a good source of anthocyanins.

## Acnowledgements

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# A color chart to screen for high β-carotene in OFSP breeding

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## Abstract

Orange fleshed sweetpotato (OFSP) varieties are considered as the first biofortified varieties among major food crops. About 100g fresh sweetpotato storage roots or less contain enough β-carotene to provide the daily pro-vitamin A needs of a pre-schooler. However, determination of β-carotene by chemicals methods is expensive. Since the storage root flesh color is highly correlated with the β–carotene concentrations in sweetpotato, color charts can be used to breed β–carotene rich sweetpotato varieties with nearly zero costs. The objectives of this study were to determine the β–carotene concentration of sweetpotato storage roots with a wide range of colors, to characterize the flesh color by color charts, and to associate each color with the corresponding β–carotene concentration. A total of 248 roots coming from 31 genotypes (2 roots per plot, 2 plot replications and 2 environments: La Molina and San Ramon) were classified by their flesh color using the Royal Horticulture Society color chart. Freeze dried samples of every roots were prepared and analyzed for total and β-carotene concentration by HPLC. Most of the roots showed a first and a secondary flesh color. Roots were grouped in 10 groups according to its primary flesh color. All roots with deep orange and orange primary flesh color showed significant β–carotene concentration (above 4 mg / 100 g fresh weight or 300 ug RAE). The β–carotene concentration of intermediate and pale orange primary flesh color ranged from 0.5 to 8 mg / 100 g fresh weight depending on the color intensity of the primary or secondary colors and their proportion. Roots with yellow orange, pale orange, yellow, intermediate yellow, pale yellow and cream primary flesh color had only very low amounts of β-carotene. The evaluated color chart might be a useful tool in breeding programs to select for high β–carotene cultivars.

**Keywords**: sweetpotato, β–carotene, color chart, breeding.

## Introduction

The potential of orange-fleshed sweetpotato to contribute to a food-based approach to combating VAD in Sub-Saharan Africa has been shown (Hagenimana and Low, 2000; Low et al., 2001). About 100g of orange-fleshed sweetpotato have a β-carotene content of 60 µg/g on fresh matter basis and can provide all the Recommended Daily Intake (RDI) of vitamin A for children (450 ug RAE/day, FAO/WHO, 2002). The efficacy of β-carotene-rich orange-fleshed sweetpotato variety Resisto in improving the vitamin A status has recently been demonstrated in South African primary school children (van Jaarsveld et al., 2005). However, orange-flesh is associated with low dry matter and the preference in Sub-Saharan Africa is a high dry matter sweetpotato, which is usually white or cream flesh and low in β-carotene concentration.

Sweetpotato breeding at International Potato Center (CIP) is ongoing to increase the dry matter content of β-carotene-rich orange fleshed sweetpotato and to improve the sensory characteristics, and at the same time to increase resistance to viruses and stress. Since often thousands of genotypes need to be evaluated in breeding, the screening for high β–carotene genotypes requires simple, fast and inexpensive methods. A strategy to select for high β–carotene genotypes is to screen the storage root color first - using a color chart - and eliminating genotypes with faint color; then to screen by NIRS to eliminate more genotypes and finally to select few genotypes which are submitted to the costly HPLC analysis. Official descriptors for sweetpotato include the use of a color chart for flesh color characterization (CIP/AVRDC/IBPGR, 1991), however this color chart does not include the ample range of yellow and orange flesh colors that sweetpotato flesh can have. Additionally, there is not a clear definition of which colors are related with a significant pro-vitamin A concentrations. Furthermore, the root flesh color is mostly a combination of colors which makes more difficult the color classification

The objectives of this study were to determine the β–carotene concentration of sweetpotato roots with a wide range of colors, characterize the flesh color, and to associate each color with the corresponding β–carotene concentration in order to generate recommendations for the use of a color chart for selecting for high β–carotene sweetpotato clones in a breeding program.

## Materials and methods

### *Plant material, sampling and sample preparation*

Sweetpotato roots samples were taken from 31 genotypes, which were grown in La Molina and San Ramon, Peru. For each genotype, 2 roots per plot in the field were gathered at random and brought to the laboratory. Each root was washed with tap water, peeled, longitudinally halved, classified according to flesh color and then quartered. Three to four slices of two opposite wedges were taken to comprise a fresh root sample of 50 g approximately. The fresh sample was placed in a plastic bag, frozen at –20°C, dried in a freeze dryer, milled, placed in a polyethylene bag and stored at -20°C until carotenoid analysis. In total 248 samples were prepared.

### *Flesh color classification*

Halved storage roots were observed and each root was classified according its primary and secondary flesh color using the Royal Horticulture Society color chart. The primary flesh color was defined as the font or principal color in the flesh and the secondary color was defined as the spots and veins colors in the flesh. The colors described in the RHS color chart were grouped in 10 groups, as follows:

Group 1: Deep orange-fleshed clones. Primary flesh color similar to 28A, 28B, 30C and 30D (dark tangerine orange)

Group 2: Orange-fleshed clones. Primary flesh color similar to 24A, 25A, 25B, 25C, 26A and 26B.

Group 3: Intermediate orange-fleshed clones. Primary flesh color similar to 24C, 26C, 26D, 28C, 28D, 29A and 29B.

Group 4: Pale orange-fleshed clones. Primary flesh color similar to 23D, 24D, 25D, 27A, 27B, 27D, 29C and 29D.

Group 5: Yellow orange-fleshed clones. Primary flesh color similar to 15D, 18A, 20B, 16B and 16C.

Group 6: Pale yellow-orange-fleshed clones. Primary flesh color similar to 14D, 15D, 16D, 18B, 18C, 18D, 19B and 20C.

Group 7: Yellow fleshed clones. Primary flesh color similar to 2C, 4B, 5C, 6C, 7D, 8A, 8B, and 13C.

Group 8: Intermediate yellow fleshed clones. Primary flesh color similar to 10A, 10B, 10C, 11B and 12C.

Group 9: Pale yellow fleshed clones. Primary flesh color similar to 2D, 8C, 9D 10D and 11C.

Group 10: Cream fleshed clones. Primary flesh color similar to 8D, 11D, 12D and 13D.

### *Total and individual carotenoid determinations*

Carotenoid analysis was carried out according to Kimura et al. (2007). Briefly, 0.1 - 1g of the freeze dried and milled sweetpotato sample was extracted with acetone by grinding with a mortal and pestle. Extraction was repeated until the residue was devoid of color. The resulting extracts were brought to a volume of 25ml with petroleum ether. The total carotenoid concentration was calculated using the absorbance value measured in a spectrophotometer (Shimadzu UV 160A) at 450nm and the extinction coefficient for mixtures of β-carotene (2592) (Davies, 1976). For individual carotenoid analysis, 15 mL of the extract were dried with nitrogen gas (N2), redissolved in 1 mL of HPLC grade acetone (Fisher) and filtered through a 0.22 µm PTFE syringe filter (Millipore). In total 10 µL of the filtered extract were injected into a Waters HPLC machine, equipped with a separation system (model 2995), quaternary pump, autosampler, in line degasser and photodiode array detector (model 2696) controlled by Empower software. Separation was carried out on a YMC C30 polymeric column (3µm, 4.6 x 250mm) using as mobile phase an isocratic elution of methanol:methyl-tert-butyl eter (80:20) with a flow rate set as 0.8 ml/min. Detection of β-carotene was done at maximum absorption wavelengths of 450nm. Identification of the β-carotene was based on the combined analysis of the retention times, co-chromatography with pure

standards from Sigma and CaroteNature (Lupsingen, Switzerland) and the visible absorption spectra obtained by the photodiodide array detector. Quantification was done by external calibration. Total carotenoids and β-carotene were expressed as micrograms (µg) per 100 g fresh weight (FW).

## Results and discussion

The range of variation for the β-carotene and the total carotenoid concentrations in each of the 10 groups formed according to the primary flesh color is given in Table1.

**Table 1. The β-carotene and the total carotenoid concentrations in 10 groups formed according to the primary flesh color**

| Group | N | mg / 100g, FW | | ug RAE / 100 g, FW | |
|---|---|---|---|---|---|
| | | β-carotene range | Total carotenoid range | A[†] | B[‡] |
| Deep orange | 50 | 4.29 - 18.55 | 6.46 - 24.26 | 357 - 1546 | 253 - 1082 |
| Orange | 7 | 5.08 - 6.12 | 7.51 - 10.59 | 424 - 628 | 351 - 434 |
| Intermediate orange | 30 | 2.08 - 8.36 | 4.09 - 11.73 | 173 -696 | 121 - 487 |
| Pale orange | 15 | 0.56 - 4.47 | 0.73 - 8.32 | 47 – 372 | 32 - 260 |
| Yellow orange | 12 | 0.16 - 2.60 | 1.03 - 5.06 | 14 – 216 | 10 - 152 |
| Pale yellow orange | 48 | 0.02 - 2.51 | 0.68 - 5.60 | 1.5 – 208 | 1.1 - 146 |
| Yellow | 14 | 0 - 0.28 | 0.76 - 2.98 | 0 – 23 | 0 - 16 |
| Intermediate yellow | 20 | 0 - 1.32 | 0.86 - 3.19 | 0 – 110 | 0 - 77 |
| Pale yellow | 27 | 0 - 1.47 | 0.39 - 4.40 | 0 – 123 | 0 - 86 |
| Cream | 25 | 0 - 0.48 | 0.00 - 4.43 | 0 - 40 | 0 – 28 |

[†]A: RAE considering 12 ug of β-carotene to be equivalent to 1 ug of retinal (IOM, 2001)

[‡]B: RAE considering 12 ug of β-carotene to be equivalent to 1 ug of retinal (IOM, 2001) and assuming a 70% retention after boiling

Roots with orange and deep orange as primary flesh colors showed concentrations of β-carotene and total carotenoids ranging from 4.29 to 18.55 and 6.46 to 24.26 mg / 100g FW, respectively. The β-carotene range is similar to that found for other orange-fleshed varieties (6.7 - 128 mg / 100g FW) by Huang et al. (1999) and by van Jaarsveld et al. (2004) for the variety Resisto (13.2 to 19.4 mg / 100g FW). Storage roots with intermediate orange primary flesh color showed concentrations of β-carotene and total carotenoid concentrations ranging from 2.08 to 8.36 and 4.09 to 11.73 mg / 100g FW, respectively. Considering 12 ug of β-carotene to be equivalent to 1 ug of retinal (IOM, 2001) and assuming a 70% retention after boiling, 100g of the orange and deep orange roots evaluated in this study provide between 56 and 241% of the RDI of vitamin A for children under five years old (450 ug RE/ day; FAO/WHO, 2002) and 100g of the intermediate orange roots provide between 27 and 108% of this recommendation.

Most of the orange or deep and intermediate orange fleshed roots showed a secondary color storage root (pale yellow orange, pale orange and intermediate orange). The wide range of variation in carotenoid concentrations could be explained by two factors: (i) the color intensity of the primary or secondary colors and (ii) the proportion of the secondary color with respect to the primary flesh color. For example, two storage roots with the same primary (deep orange) and secondary (intermediate orange) flesh colors (Fig. 1 a and b). However, the fact that the secondary color represents a bigger proportion with respect to the primary color in the first storage root compared to the second storage root results in higher β-carotene concentrations in the second storage root (12.39 mg / 100 g, FW) compared to the first storage root (7.76 mg / 100 g, FW). Another example is shown in Fig. 1c and d. Both storage roots are intermediate orange for primary and secondary flesh color. However the fact that the secondary color represent a bigger proportion with respect to the primary color in the first storage root

compared to the second storage root results in higher β-carotene concentration in the second storage root compared (7.23 mg / 100g, FW) compared to the first storage root (4.61 mg / 100g, FW).

Roots with pale orange as the primary flesh color showed β-carotene and total carotenoid concentration ranging from 0.56 to 4.47 mg / 100g FW, and from 0.73 to 8.32 mg / 100g FW, respectively. Pale orange fleshed roots showed high β-carotene concentration when the secondary color were orange or intermediate orange and when the secondary storage root color had a large proportion (some small spots or veins) of the flesh (above 3.00 mg / 100g FW) (Fig. 2). Roots with pale yellow orange, yellow, intermediate yellow, yellow orange, cream and pale yellow showed very low β-carotene concentrations (Table 1).

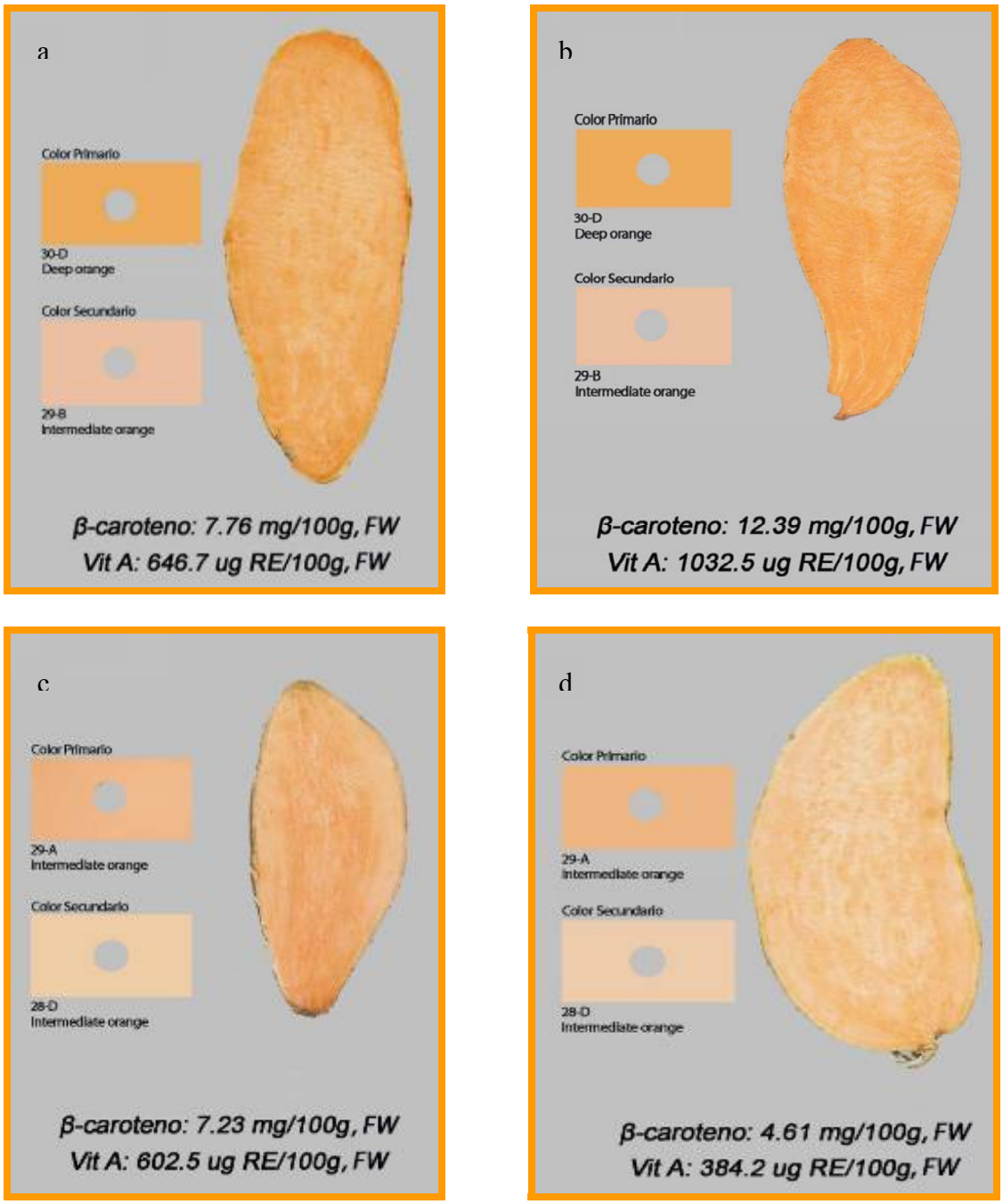


**Figure 1. Examples of sweetpotato storage roots used in the developed color chart.**

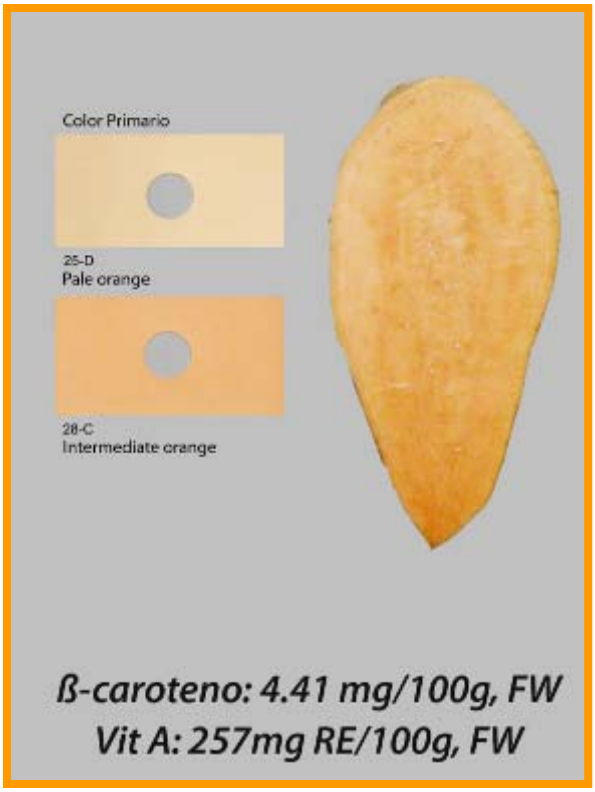


**Figure 2. Roots with pale orange as the primary flesh color**

## Recommendations

Assuming a 70% retention after boiling, 100 g of roots with 3 mg of β– carotene would provide more than 35% of the RDI of vitamin A for children under five years (450 ug RE/ day; FAO/WHO, 2002). Taking this into account, recommendations for selecting high β-carotene roots by using the RHS color chart are::

3. Roots with orange, deep orange and intermediate orange as primary flesh color and orange and intermediate orange as secondary colors have a significant amount of β-carotene.
4. Roots with intermediate orange as primary flesh color and pale orange as secondary colors have a significant amounts of β-carotene only if the secondary color represents only small proportion of the primary color.
5. Roots with pale orange as primary flesh color have a significant amount of β-carotene only if the secondary colors are orange and intermediate orange and represent a big proportion of the primary color.
6. Roots with yellow orange, pale orange, yellow, intermediate yellow, pale yellow and cream have no significant amount of β-carotene.

## Acnowledgements

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# Darkening in open-air sun dried orange-fleshed sweetpotato products being promoted for their high pro-vitamin A carotenoid content

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## Abstract

Pro-vitamin A carotenoid retention studies are vital in the process of promoting orange-fleshed sweetpotato (OFSP) as a staple in communities affected by vitamin A deficiency. Drying is the affordable processing technology in sub Saharan African rural settings. This paper presents issues pertaining to darkening in open-air sun dried products in relation to carotenoid content and retention levels. OFSP varieties (*Ejumula*, SPK004, SPK004/6 and SPK004/6/6) were open-air sun dried to two types of products (*amukeke* and *inginyo*). All *trans*-β-carotene content in raw OFSP was highest for *Ejumula* (261.4±29.9 μg/g dwt) and lowest for SPK004 (93.4±9.4). Overall *inginyo* scrapped exhibited the highest carotenoid retention (72.9±10.5%) compared to *amukeke* (22.7±6.3%). Among the *inginyo* products, *Ejumula* contained the highest carotenoid content (193.0±2.2 μg/g dwt) while among *amukeke* products SPK004/6 had the highest content (106.2±2.4 μg/g dwt). As expected all open-air sun dried sweetpotato products darkened due to phenolic and enzymatic activities found in sweetpotato. *Inginyo* scrapped, $A_{(450)}$=0.31-0.64, and un-scrapped products, $A_{(450)}$ = 0.49-0.76, exhibited highly darkened appearances ($p<0.05$) compared to *amukeke*, $A_{(450)}$ =0.29-0.51. The un scrapped *inginyo* was unacceptably darkened compared to the scrapped *inginyo* and required the method to be modified. Ejumula darkened the most ($p<0.05$) implying it contained the highest phenolic content and enzymatic browning phenomenon. SPK004/6 and SPK004/6/6 are improved OFSP varieties exhibited in-between darkening. Darkening is an attribute that can be addressed in the ongoing breeding activities of OFSP varieties. Modifications of specific traditional processing technologies should be pertinent to the promotion process for wider utilization of OFSP.

**Keywords:** carotenoid, darkening, orange-fleshed sweetpotato, open-air sun dried.

## Introduction

In Uganda, sweetpotato fresh roots are mainly consumed boiled or steamed (Owori *et al.*, 2007). In the dry season, sweetpotato is stored as *amukeke* (dried sliced storage roots) and *inginyo* (dried crushed storage roots) more so in Northern and Eastern Uganda (Bashaasha and Scott, 2001). Therefore chipping, drying and storing orange-fleshed sweetpotato (OFSP) for year round use can overcome seasonal shortages of vitamin A in many low income households during the dry season. In order for rural communities to benefit from the high pro-vitamin A content of the OFSP there is need to ascertain the pro-vitamin A retained from the traditional or indigenous processing methods. It is evident that data relating to the form in which the foods are consumed by the population are urgently needed and the influence of processing on pro-vitamin A levels has to be determined. Simulation of the actual traditional handling and processing techniques is necessary to determine how much pro-vitamin A is retained as a result of these processes.

There is an on-going effort to promote and disseminate the OFSP among Ugandan farmers. Pro-vitamin A carotenoids are highly susceptible to degradation during preparation and processing (Rodriguez-Amaya and Kimura, 2004). Furthermore inadequate knowledge exists on the retention of pro-vitamin A carotenoids after traditional processing of OFSP. Present knowledge on retention is variable and inconclusive in particular for rural processing techniques. This is of great concern as the ultimate success of the OFSP in alleviating VAD lies in the amount of β-carotene retained after processing prior to consumption. With the current promotion of the OFSP in Uganda it is imperative that retention studies are carried out to establish the β-carotene content of

traditionally processed OFSP. Most the processing operations in the rural communities are rudimentary and result in varied qualities of the end product.

The objective of the study was to compare retention levels of pro-vitamin A carotenoid in traditionally sun dried OFSP products and determine the extent of darkening (discoloration) of the dried OFSP products among varieties.

## Materials and methods

### *Materials*

Four orange-fleshed sweetpotato (OFSP) variety of seven months maturity were harvested from Namulonge Agricultural and Animal Production Research Institute (NAARI), Uganda.

All reagents used were of analytical grade, unless otherwise stated, and obtained from BDH suppliers in Kampala, Uganda. Carotenoid standards (All–*trans*-β-carotene and 8'-Apo-β- carotenal) were purchased from CaroteNature (Lupsingen, Switzerland).

### *Sampling protocol and handling of sweet potatoes*

A two stage sampling plan was used, where sound medium sized OFSP roots were randomly selected from 3 subplots in the NAARI research field to constitute a pooled sample for each variety. The pooled samples were placed in black polyethene bags and transported to the Food Science and Technology Laboratory, Makerere University. Sweet potato roots in each pooled sample were gently mixed by shaking in sisal bags (5 times), laid out in a straight line and roots selected using systematic random sampling to obtain a field sample of 40 roots for each variety. Intact roots were stored in the laboratory at *ca*. 22◦C in subdued light prior to drying.

### *Open-air sun drying to produce amukeke and inginyo*

Figures 1 and 2 were processes used to produce the open-air sun dried products (*amukeke* and *inginyo*). Small sized roots (< 200 g) were selected for drying to *inginyo* and medium to large sized roots (> 200 g) dried to *amukeke*.

### *Parameters measured*

Moisture content was determined on triplicate samples each for the unprocessed and processed sweetpotato by drying in a Gallenkamp hot box oven fitted with a fan (Model SG93/08/850, UK) at 70◦C for 20 hours to constant dry weight.

The degree/ extent of darkening (discoloration) of the dried products was measured according to Walter and Purcell's (1980) method. Ten grams of sample was mixed in 50 ml of a cold buffer (pH 6.3) constituted of 0.05 M phosphate and 0.15 M sodium chloride. The contents were held at 5◦C for 2 hours and centrifuged at 4,000*g* for 10 minutes. The supernatant was collected, filtered through a 0.2 µm filter and filtrate kept in an ice bath. A portion was allowed to warm to room temperature and its absorbance measured at 450 nm recorded as degree of darkening / browning.

All *trans*-β-carotene content was measured using the HPLC technique as described by Mulokozi and Svanberg (2003) and Rodriguez-Amaya and Kimura (2004). Percent true carotenoid retention was computed based on the all *trans*-β-carotene content.

All unprocessed and open-air sun dried samples were flushed with nitrogen and packaged using a Mini Jumbo vacuum sealer (HENKELMAN 3000711837/2007, Netherlands). Samples stored in a freezer at -55◦C prior subsequent analyses.

### *Experimental design and statistical analysis*

The study design was a 4 x 2 factorial experiment where factor one was the Orange-fleshed sweet potato variety (*Ejumula*, SPK004, SPK004/6 and SPK004/6/6.) and factor two type of open-air sun dried product (*inginyo* and

*amukeke*). SPSS statistical programme (ver. 12) was used for data analysis, ANOVA for testing significant differences among variety and product type at 0.05%.

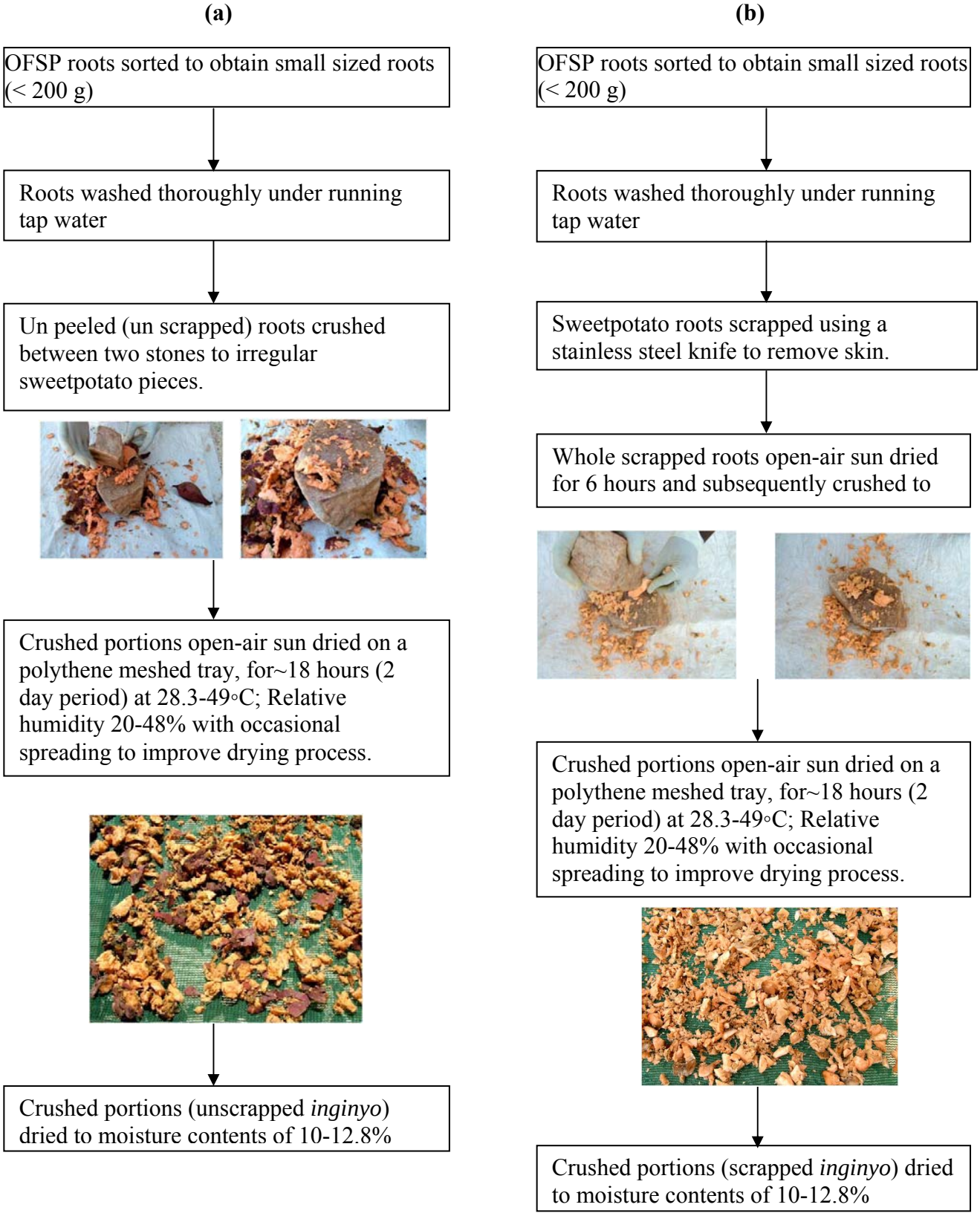


**Figure 1 (a) Rural open-air sun drying of small sized sweetpotato to produce (*inginyo*) (b) Slightly modified method to reduce darkening of *inginyo* products**

OFSP were sorted to obtain medium to large sized roots (> 200 g)

↓

Roots washed to remove extraneous matter

↓

Roots peeled using stainless steel knife and quartered longitudinally

↓

Two opposite quarters of each root were retained and washed thoroughly under running tap water

↓

Quartered portions hand sliced to approximately 4 mm slices.

↓

Sliced samples open-air sun dried for ~18 hours (2 day period) at 31.4-50◦C; Relative humidity 18.7-46% with occasional turning to improve the drying.

**Figure 2. Rural open-air sun drying of medium to large sized sweetpotato to *amukeke***

## Results and discussion

### *Darkening of open-air sun dried products*

Open-air sun drying of sweetpotato is prevalent in Sub Saharan region. *Inginyo* and *Amukeke* constitute main dried sweetpotato products in Eastern region of Uganda. Figure 3 shows *inginyo* products dried from the four OFSP varieties. Figure 3 a shows produced according to the indigenous method of Eastern Uganda and figure (b) using slightly modified method to reduce the darkening appearance.


**Figure 3. (a) *Inginyo* products following the indigenous open-air sun drying method (b) *Inginyo* products from a slightly modified method to reduce the darkening appearance**

*Inginyo* is a traditional term in *Ateso* (local language) literally referring to small sized sweetpotato roots and now used to refer to crushed dried sweetpotato. Small sweetpotato roots are difficult to peel and therefore constitute the main raw material for the manufacture of *inginyo*. *Amukeke* in *Ateso* literally refers to peeled and dried sliced sweetpotato chips. Medium to large sized roots are used to produce *amukeke*. Unlike *inginyo*, *amukeke* is not for flour production and there not milled to flour. In Eastern Uganda, traditionally sweetpotato roots are not scrapped or peeled. Whole intact roots may be washed prior to crashing and open-air sun dried.

The extent of darkening of the open-air dried products is shown in Figure 4. Darkening was most pronounced for the *inginyo* products compared to the *amukeke* products (Figure 4). The phenomenon of darkening or the undesirable discolouration in sweetpotato is attributed to the interaction of phenolics and the polyphenol oxidase (Walter and Schadel, 1981). Darkening of the *inginyo* products was observed for all OFSP varieties following the indigenous processing method (Figure 3a). A slight modification of the processing method reduced the darkening appearance (Figure 3b).

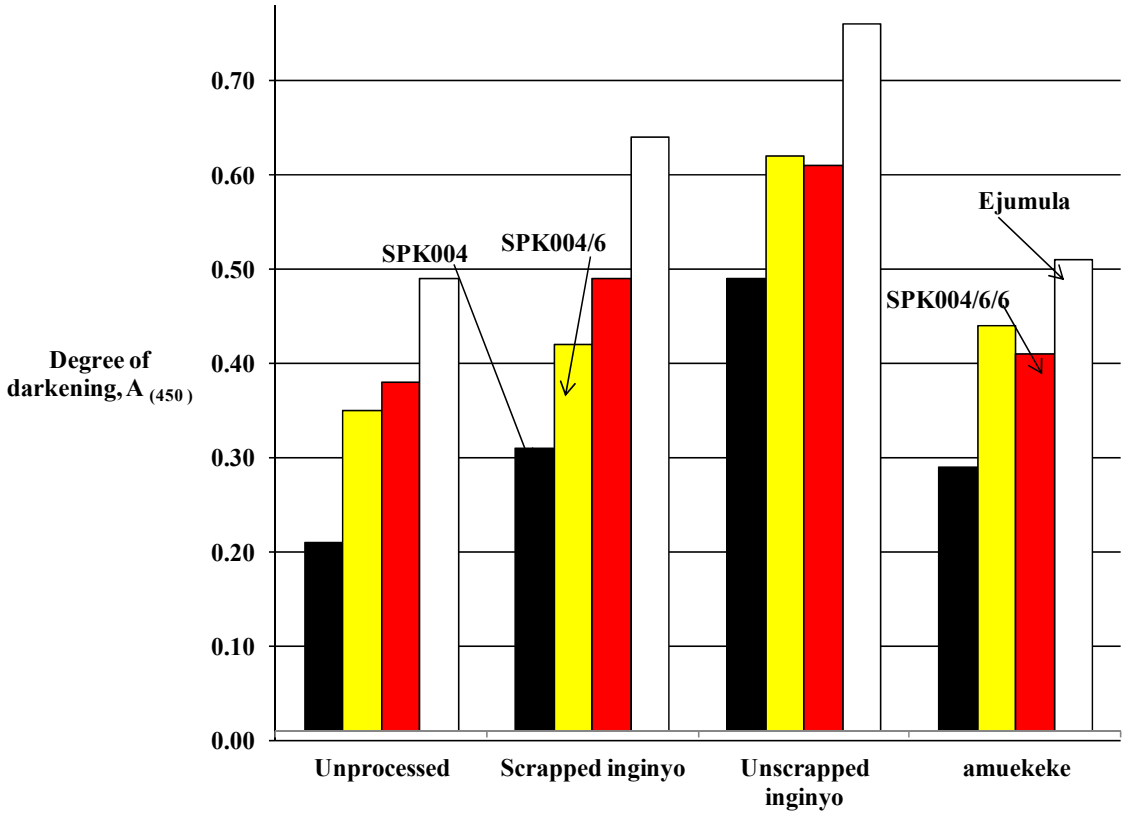


**Figure 4 Degree of darkening (discolouration) of open-air sun dried products from four orange-fleshed sweetpotato varieties (SPK004, SPK004/6, SPK004/6/6 AND Ejumula). Absorbance reading at 450 nm was computed as the degree of darkening that had occurred in the products**

Among the dried products the unscrapped (not peeled) *inginyo* exhibited the highest degree of darkening and the most undesirable appearance ($p<0.05$) compared to the scrapped *inginyo* and *amukeke* products (Figure 4). This is expected since phenolics are highest or concentrated in the sweetpotato peel, progressively decrease from the skin to inner tissue of the root (William and Schadel, 1992). Among the sweetpotato varieties Ejumula exhibited the highest degree of darkening of 0.49 for the unprocessed to 0.76 for unscrapped *inginyo* and SPK004 the least (Figure 4). SPK004/6 and SPK004/6/6, recently released OFSP varieties, were comparable in relation to degree of (Figure 4).

### *Pro-vitamin A carotenoid content*

The dry matter contents of the OFSP varieties ranged from 31.2 to 39.2% (Table 1). SPK004 and SPK004/6 had the highest and lowest dry matter, respectively. The dry matter measured for all varieties were higher than those reported by Bengtsson *et al.* (2008) for the same varieties and Hagenimana *et al.* (1999) for other six OFSP varieties studied.

**Table 1. All *trans*-•-carotene content and percent retention of open-air sun dried products**

| Sweetpotato variety | Dry matter (%) | All *trans*-•-carotene (•g/g), dwt | | | % retention* | |
|---|---|---|---|---|---|---|
| | | Un processed | *amukeke* | *inginyo* | *amukeke* | *inginyo* |
| SPK004 | 39.2±1.5 | 93.4 ± 9.4* | 21.1 ± 1.8 | - | 23.4 ± 2.4 | - |
| SPK004/6 | 31.2±1.0 | 205.4 ± 28.2 | 51.8 ± 1.1 | 106.2 ± 2.4 | 29.2 ± 0.0 | 59.8 ± 0.1 |
| SPK004/6/6 | 36.3±0.7 | 192.5 ± 28.1 | 39.4 ± 0.2 | 130.7 ± 2.4 | 25.0 ± 0.5 | 82.9 ± 0.6 |
| Ejumula | 33.6±1.6 | 261.4 ± 29.9 | 34.4 ± 0.6 | 193.0 ± 2.2 | 13.3 ± 0.3 | 74.6 ± 1.9 |

*All values are means of triplicate analyses

All *trans*-β-carotene content of the un processed OFSP ranged from 93.4 to 261.4 µg /g, dwb (Table 1) varied considerably ($p<0.05$) among the different varieties. Similar values for Ejumula have been reported by Bengtsson *et al.* (2008) for Ejumula with the exception of the other OFSP varieties that registered lower all *trans*-β-carotene content probably due to different maturity age of the OFSPs used in the two different studies.

Percentage retention of all *trans*-β-carotene was extremely low ($p<0.05$) for *amukeke* (22.7±6.3%) compared to *inginyo* (72.4± 10.5%) products, irrespective of OFSP variety. Percentage retention ranged from 13.3 to 29.2% (Table 1). Scrapping and drying of whole intact roots (for ~ 6 hours) prior to crushing when making *inginyo* appeared to result in greater β-carotene retention compared to *amukeke* production for all cultivars (Table 1). Low percentage retention levels observed for *amukeke* products could be attributed to exposure to direct sunlight and continued oxidative enzymatic activity during drying. Considerable carotenoid degradation has been associated with open-air sun drying compared to other drying methods such as oven and solar drying. Stollman (2005) showed higher β-carotene content values for solar dried Ejumula chips than open-air sun dried chips exposed to direct sun light. She attributed these findings to shorter drying times and minimal exposure to direct sunlight for the solar drying method.

Bengtsson *et al.* (2008), however, registered no significant difference in all *trans*-β-carotene percentage retention for Ejumula slices subjected to forced air oven drying (88.2%), solar drying (91.1%) and open-air sun drying (83.8%). Notable, is the substantially high retention value for open-air sun drying compared to that reported in our study (Table 1). This could be attributed to differences in OFSP chip/ slice thickness and drying conditions. The relatively lower drying temperature (29◦C) and short drying duration as was the case for Bengtsson *et al.* (2008) could probably have enhanced pro-vitamin A retention as opposed to retention levels observed in the present study. Bechoff *et al.* (2009) evaluated the effect of sun drying Ejumula and SPK004 (Kakamega) under wet and dry weather conditions on pro-vitamin A carotenoid retention, where greater losses of carotenoid in the wet weather (11%) compared to dry weather (7%) were recorded.

All OFSP variety processed to *amukeke* are unlikely to meet the recommended Vitamin A (µg RAE / day) intake levels for under five olds (400 µg RAE /day). While OFSP varieties processed to *inginyo*, excluding SPK004, may likely meet the recommended Vitamin A for under five year olds, particularly Ejumula. However, it is important to note that the dried products are primary processed products requiring further processing, usually boiling in Eastern Uganda, will result in further carotenoid losses during preparation. Use of OFSP varieties with high pro-vitamin carotenoid content, irrespective of their percent retention level, such as Ejumula would be most appropriate.

Low *et al.* (2005) evaluated three methods of drying Resisto OFSP by drying chips sliced in a selected Mozambique village as is the norm (approximately ¼-cm thickness and not peeled). Samples dried under the shade of a tree had a higher RAE value (1,050 µg /100 g) than those did that were shaded by a woven mat (975 µg/100 g). The sample dried under a mat covered with black plastic had the lowest RAE value (892 µg/ 100 g, dwt). Direct sun drying has a destructive effect on pro-vitamin A carotenoid. However, OFSP varieties with significant amounts of beta-carotene may retain high amounts of carotene even when dried under direct sunlight (Low *et al.* 2005).

## Conclusion

A sizeable amount of data has been collected in regard to retention studies of caroteniods. This study however, has revealed production of *inginyo* dried product had better retention levels compared to *amukeke*. This is vital information for communities where OFSP are being promoted. Despite the darkening appearance of sweetpotato, high retentions were registered for Ejumula variety. The need to complement retention studies with modifying indigenous or traditional processing methods to benefit the communities is crucial.

## Acknowledgments

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# Relationship among yield components of eight introduced yellow and orange fleshed sweetpotato in Rwanda

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Sweetpotato (*Ipomea batatas*) is a staple food grown and consumed through Rwanda. It is considered a food security crop for its ability to be harvested continuously for home consumption and its ability to grow in soils where cereals and some leguminous crop fail due to poor growth conditions. As in most Sub-Saharan countries, yields are generally low due to poor adaptability of the available sweetpotato varieties. Orange-fleshed sweetpotatoes have high total carotenoids and are seen as a cheaper and complementary source of vitamin A for the rural poor families who are the most vulnerable to vitamin A deficiency. This study therefore was conducted to evaluate the relationship of yield components existing among 8 yellow and orange fleshed introduced sweetpotato genotypes namely Cacearpedo that was considered as a control, Naspot-5, Carrot-C, Gueri, Kazinga, K 118, K135, and Ukerewe in terms of resistance to sweetpotato virus diseases, *alternaria*, yields, in mid altitudes conditions of Rwanda for 2 consecutive seasons 2008A and 2008B. Genotype Kazinga was very susceptible to the attack of *alternaria* and virus, also had a low capacity to sprout and to reach the maturity stage safely. Whereas varieties Ukerewe, Carrot-c, K135 and K118 respectively showed a considerable resistance against SPVD and alternaria diseases. Variety Carrot-c responded positively in terms of yield comparatively to Cacearpedo with 14.05T/ha while Cacearpedo had 12.76 T/ha. Varieties like Carrot-c, Cacearpedo, Ukerewe and Gueri were respectively the first fourth in marketable roots. Varieties Carrot-c, Cacearpedo, K118 and Naspot-5 yielded high in term of total number of roots. A comparison for yielding components of these 8 sweetpotato genotypes showed a negative correlation between biomass and total roots yield, total dry matter and total roots yield. While, a positive correlation was found between number of marketable roots and total yield roots. This study shows that Ukerewe, Carrot-C, Cacearpedo, and Gueri are like to be adopted since they showed good agronomic performance.

**Keywords**: Yield components, orange fleshed sweetpotato, biomass, dry matter.

## Introduction

The importance of sweetpotato in daily Rwandan diets has to be underlined. According to Tardif (1993 et *al)* and Ndirigwe (2006), the sweetpotato is one among the two most crops (common beans and sweetpotato) which help so much in the traditional alimentation of many Rwandese.

The crop is cultivated throughout the country mainly by peasant farmers, and is especially important in densely populated areas of the plateau central of Rwanda (Mid altitude) ( Ferris *et al*., 2002). It is a flexible source of food as it can be grown on soils of limited fertility and is relatively drought tolerant. Also, planting and harvest periods are more flexible than those of maize and other cereals. Provided the importance of sweetpotato in Rwandan society, our study aimed at improving our farmer's varieties which are known to be low yielding, no resistant to a big range of pests and diseases varieties and poor in beta carotene a precursor of vitamin A. Eight exotic varieties already tested in sub Saharan countries, which are high nutrient value (yellow and orange-fleshed sweet potato varieties enriched in beta –carotene: a precursor of vitamin A which intervenes in eye-sight) were introduced in Rwanda for yield performance evaluation. Therefore, this study was conducted to evaluate the relationship of yield components existing among 8 introduced sweetpotato which namely *Cacearpedo that* was considered as a control, *Naspot-5, Carrot-C, Gueri, Kazinga, K 118, K135, and Ukerewe* in terms of resistance to virus, *alternaria* sweetpotato diseases, yields, in mid altitude conditions of Rwanda.

## Materials and methods

Eight new genotypes of sweetpotato which names are as follows*: Cacearpedo, Carrot-c, Naspot-5, Gueri, K118, K135, Kazinga* and *Ukerewe* were used in the study and were compared to *Cacearpedo* as check. The experiment

was set up in a randomized complete block design with four replications at Rubona Station. The experiment was carried out at ISAR Rubona Station during 2008A and 2008B (lat. 2°29' S, Long. 29° 46'E, and 1650masl) with the average temperature of 19°C and the annual rainfall average of 1271mm (ISAR, 2008). Trials were established at the beginning of the rainy season. The inter-row spacing was 80cm and spacing between ridges 30cm. Apical cuttings were planted on 4 ridges measuring 4.5 m long formed a single plot, resulting in plant population of 16 plants/ridge (64 plants/ plot). Cuttings were planted at a depth of ± 15 cm with at least 2 nodes underground in random completed block design (RCBD) with 4 replicates. Weeding and hilling up took place about one month after planting. At harvesting time, foliage weight was recorded and used to evaluate cultivars potential for providing planting material. Plants in the two central ridges of each plot were uprooted and used to estimate the marketable and unmarketable roots. Fresh roots were counted, weighted and graded into marketable (≥3cm of diameter) and unmarketable yield less than 3cm. ANOVA was performed using Genstat and Excel software was used to draw different graphs.

## Results and discussions

### *Yield of marketable roots (large roots)*

Results (Table 1) showed significant difference among genotypes at P>0.05 with 3 homogenous groups. Yield of marketable roots varied from 14.05 to 4.14 T/ha. Variety *Gueri, K118* and *Ukerewe* had recorded high weight of marketable roots than the control. Genotype *Kazinga* was the lowest variety in weight of marketable roots during the 2 seasons, implying that is no adapted.

**Table 1. Mean yield performance in T/ha of the 8 genotypes at Rubona during 2008A and 2008B**

| Genotypes | Yield T/ha | Homogeneous Groups |
|---|---|---|
| Carrot-c | 14.05 | A |
| Cacearpedo | 12.76 | ABC |
| Ukerewe | 12.20 | ABC |
| Gueri | 12.00 | ABC |
| Naspot-5 | 10.82 | ABC |
| K118 | 8.18 | BC |
| K135 | 7.43 | BC |
| Kazinga | 4.14 | C |

Lsd: 2,11

Results (not shown) showed that 96.8% of variation in total number of roots was explained by variation in roots weight. Considering the biomass of eight sweetpotato genotypes, the analysis of variance for biomass showed that genotypes varied highly among them at (p< 0.001). The mean separation showed that there are six homogenous groups. There is a highly significant difference among those genotypes. The variety *K118* ranked first in biomass yield and *Kazinga* ranked last (results not shown). The difference between the first three varieties and the check was highly significant. Different genotypes differ in number of roots and aptitude to yield (Mwanga *et al.*, 2004) which all have a inheritance of genetic pool (Huaman, 1992). Different studies showed that genotypes with higher number of roots, generally provide at harvest time high yield (Ndolo *et al.*, 2001; ATDT, 2002 and Ndirigwe, 2006).

Figure 1 shows that 93.09 % of variation in biomass was explained by variation in yield that was expressed in ton per hectare. Varieties which had a big number of biomass came last in yielding performance. *K118* recorded high biomass yield but was the third last in root yield .This also verifies for *K135*. A net negative correlation between biomass and yield was obvious. Those eight sweetpotato genotypes showed higher vigor of plants during growing period and remarkable resistance to virus and *alternaria* diseases. Varieties, *Carrot-c, Cacearpedo, Ukerewe, and Gueri,* showed excellent potential in terms of yield ton per hectare 14.05, 12.76, 12.20, and 12.00 respectively. The variety *Naspot-5* and *Kazinga* revealed higher sensibility to virus attack compared to *Cacearpedo (*check). The variety *Carrot-c* ranked first in terms of total number of roots, but it ranked last in terms of yield; this implies that *Carrot-c* has a big number of non marketable roots. The variety *Ukerewe* has performed well in all parameters. This study shows that *Ukerewe, Carrot-C, Cacearpedo, and Gueri* are like to be adopted since they showed good agronomic performance .They were also positive correlation between yield components.

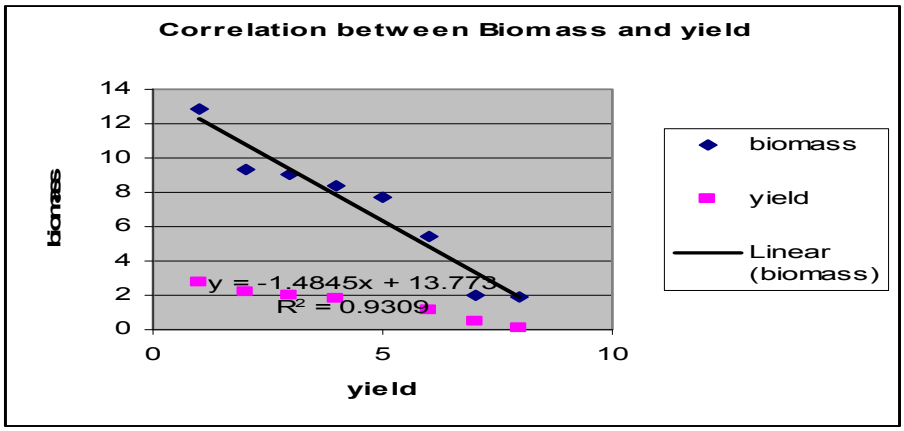


**Figure 1. Correlation between biomass and yield of 8 sweetpotato varieties**

### *Total dry matter of the 8 sweetpotato genotypes*

The analysis of variance of the total dry matter (result not shown) showed no significant difference among genotypes at P>0.05. The Total dry matter did not vary significantly among genotypes .The percentage of total dry matter rate varied from 36.8 to 28.7 %. Variety *K118* had high percentage of germination than the control. Genotype *K 118* was the lowest variety in total dry matter but in general, the exotic genotypes had high mean dry matter content compared to the check.

Figure 2 shows that 33.82 % of variation in dry matter was explained by variation in yield that was expressed in ton per hectare. Varieties with high total dry matter ranked low in yield record. This finding states that there was a negative correlation between total dry matter and yield. This is contrary with the findings made by Dixon and Nukenine (2001) and Grüneberg *et al.* (2003) who indicates respectively in cassava and sweetpotato that root dry matter content responds dynamically to changes in the environments as regards to starch deposition and mobilization which consequently increases the yield. In conclusion, a comparison for yielding components of these 8 sweetpotato genotypes showed a negative correlation between biomass and total roots yield, total dry matter and total roots yield. While, positive correlation was found between number of marketable roots and total yield roots. This study shows that Ukerewe, Carrot-C, Cacearpedo, and Gueri are like to be adopted since they showed good agronomic performance.

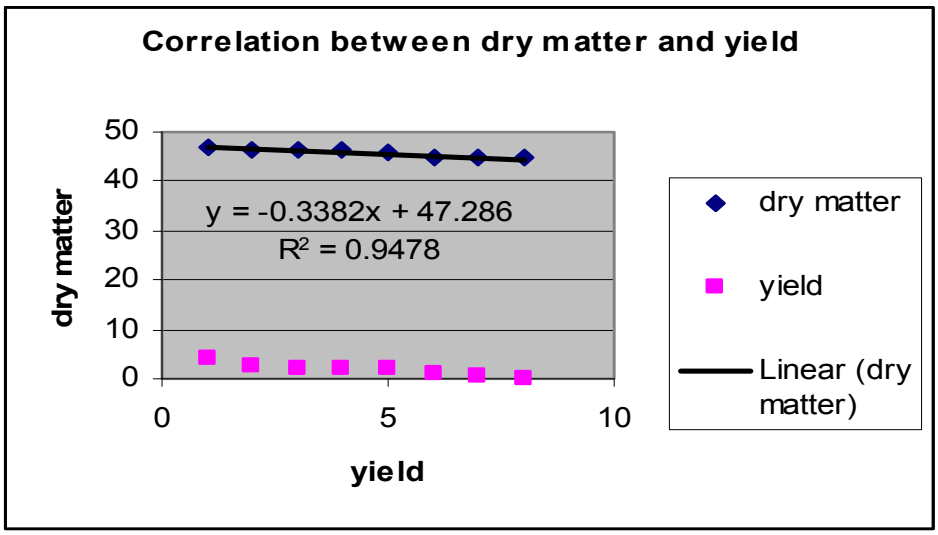


**Figure 2. Correlation between the total dry matter and yield**

Further studies are needed for orange fleshed sweetpotato varieties where high dry matter content varieties tend to give low yield compare to white fleshed sweetpotato genotypes.

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# Agronomic performance of regional local popular orange-fleshed sweetpotato cultivars in Kenya

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## Abstract

Vitamin A deficiency is a major nutritional problem in Kenya, leading to night blindness and high mortality rate in infants. Worldwide, an estimated 3-million preschool-age children have visible eye damage due to vitamin A deficiency (VAD), and annually over 300,000 children die within a few months after getting blind. Consumption of orange-fleshed sweetpotato (OFSP) that is high in provitamin A (β-carotene), can improve body stores of vitamin A, hence reducing the risk of deficiency. Most of the high -carotene content varieties in Kenya have low root dry matter contents while consumers prefer varieties with dry and floury roots. Fourteen local OFSP cultivars selected by the East and Central African (ECA) countries were evaluated at KARI-KARI-Kakamega, Kabete Campus of the University of Nairobi, KARI-KARI-Mtwapa and KARI-KARI-Katumani between 2006 and 2008 to assess their performance in different sweetpotato growing zones in Kenya. Farmers from the neighboring communities evaluated and ranked the cultivars based on field performance and quality of cooked roots. Varieties 199062.1, Ukerewe, Mayai, and Ejumula consistently gave high yields over four locations. Yields were highest at KARI-KARI-Kakamega and lowest at KARI-Mtwapa while virus infection was highest at KARI-KARI-Kakamega. The overall ranking of cultivars by farmers was not consistent with the root yields. At Kabete and KARI-Mtwapa, cultivars Ukerewe and Pipi were ranked high. Farmers at KARI-Kakamega ranked SPK004 highest followed by Ukerewe, Ejumula, Carrot C, Mayai, and 199062.1. Mayai, K135, SPK004 and Pipi were ranked high at KARI-Katumani.

**Keywords**: b-carotene, yield, dry matter, virus infection.

## Introduction

Sweetpotato (*Ipomoea batatas* (L) Lam.) is one of the most important staple crops in the densely populated parts of eastern and Central Africa. It is one of the world's highest yielding crops in terms of production per unit area, exceeding that of major cereals such as rice, and with higher food value (Woolfe, 1992). In Kenya swetpotato is widely grown by the small scale farmers, mainly women, and is a key livelihood resource for food supply and cash income. Moreover, its value adding potential is now increasingly recognized, given the crops' rapidly expanding industrial and commercial applications. Sweetpotato vines and roots are also used as animal feed particularly in the expanding zero grazing livestock systems in Kenya. Compared to many other crops, sweetpotato requires few inputs and relatively less labour, making it suitable for the resource poor households. Its ability to produce relatively good yields under marginal conditions, its flexible planting and harvesting times, makes it a "classic" food security crop. Sweetpotato is grown in Kenya in nearly all agro-ecologies with the highest concentration in the Lower Midland and Upper Midland zones (Ndolo et. al., 2001).

A part from the contribution of sweetpotato to food security and cash income generation, it is also a major source of carbohydrates, providing essential nutrients in diets, particularly β-carotene used for the control Vitamin A deficiency (Low *et al*. 1996). Vitamin A deficiency remains a major nutritional problem in Kenya, significantly leading to night blindness and mortality of infants. An estimated 3-million preschool-age children worldwide have visible eye damage due to vitamin A deficiency (VAD). In women, VAD results in reproductive disorders, increases the risk of pregnancy mortality, as well as giving birth to underweight children. Strategies to control vitamin A deficiency include utilization of -Carotene-rich crops, such as orange-fleshed sweetpotato (OFSP) (Ruel, 2001). Daily consumption of the beta carotene dense orange-fleshed variety provides about 2.5 times the vitamin A requirements for 4 to 8-year-old children, and improved liver vitamin A stores (van Jarsveld et al. 2005).

The Kenya Agricultural Research Institute (KARI) in collaboration with the International Potato Centre (CIP) and the Sweetpotato Regional Network (PRAPACE) has identified some β-carotene (pro-vitamin A) rich OFSP varieties. Most of these varieties have not been well taken up by farmers because of their poor adaptability (especially for the introductions), and low root dry matter contents. The diverse nature of agro-ecologies where sweetpotato grows, and the widespread need to combat vitamin A deficiency, makes the need to develop more OFSP varieties. A number of popular local OFSP varieties from the East and central African countries were introduced into Kenya through CIP. The objective of this study was to evaluate these varieties in different sweetpotato growing zones in Kenya and identify adapted and acceptable varieties for dissemination to farmers.

## Material and methods

Fourteen varieties (Table 1) identified were evaluated at KARI-KARI-Kakamega (mid altitude, high virus pressure), Kabete Campus of the University of Nairobi (High altitude, low virus pressure) KARI-KARI-Mtwapa (coastal lowlands) and KARI-KARI-Katumani (drought and high weevil infestation) between 2006 and 2008. These locations represent the major sweetpotato growing areas of Kenya. The climatic characteristics of the sites as described by Jaetzold and Schmidt (1983) are given in Table 2. Vine tip cuttings, 25 to 30 cm long were used as planting material. Each plot was planted in 5 rows, 1 m apart, 5.1 m long, and 0.3 m between plants (33,300 plants $ha^{-1}$) in a randomized complete block with three replications. The OFSP variety SPK004 was included in all locations as a check for dry matter content while NASPOT 1 was used as a check for high yield. Plants were harvested after 150-180 days of growth. The two middle rows in each plot were used for data collection. At harvest, the foliage was cut at a height of 10 cm from the ground level and weighed. The storage roots were separated into marketable and unmarketable roots, counted and weighed. Marketable roots included all those with a cross-sectional diameter of at least 3 cm. Data were also collected on virus infection and root dry matter (DM) content. The DM was determined by oven drying 200g of chopped root samples at $70^0$ C for 48 hours. Virus damage was assessed by visual scoring for virus damage on leaves, 90 days after planting, using a score of 1-5 per plot where: 1 = no apparent virus symptoms; 2 = mild symptoms on a few plants; 3 = mild symptoms on many plants, some stunting; 4 = mild symptoms on many plants, stunting of many plants; 5 = most plants stunted.Standard data sheets developed by CIP were used for data collection.

**Table 1. Characteristics of popular orange-fleshed clones used in the study**

| Clone | Country of Origin | Remarks |
|---|---|---|
| 1. Carrot C | Tanzania | Local collection, deep orange |
| 2. K135 | Kenya | Local collection, orange |
| 3. Zambezi | Zambia | Local collection, deep orange |
| 4. Mayai | Tanzania | Local collection, deep orange |
| 5. K566632 | Kenya | Local collection |
| 6. Gweri | Uganda | Local collection |
| 7. Pipi | Kenya | Local collection |
| 8. K 118 | Kenya | Local collection |
| 9. Ukerewe | Tanzania | Local collection |
| 10. 199062.1 | CIP | Breeding material |
| 11. Ejumula | Uganda | Standard local check- orange, released in Uganda |
| 12. SPK004 (KARI-Kakamega 4) | Kenya | Standard local improved check-Released in Kenya and Uganda |
| 13. Naspot1 | Uganda | Standard check for high yields |
| 14. Resisto | USA | Standard check for high beta-carotene |

**Table 2. Climatic characteristics of the sweetpotato testing sites in Kenya**

| Site | AEZ* | Mean temperaturas (°C) | Annual rainfall (mm) | Altitude (m) | Soil types |
|---|---|---|---|---|---|
| KARI-Kakamega | UM1 | 20.6-22.8 | 1900 | 1585 | Humic nitosols |
| Kabete | UM3 | 19.5-19.9 | 1046 | 1800 | Humic nitosols |
| KARI-Mtwapa | CL3 | 24.0-26.6 | 1200 | 15 | Orthic ferralsols |
| KARI-Katumani | UM4 | 13.9-24.7 | 717 | 1600 | Rhodic/orthic ferralsols |

Source - Jaetzold and Schmidt (1983)

*Agro-ecological zones: UM = upper midlands; LM = lower midlands; CL3 Coastal lowlands

Farmers from the adjacent communities were invited to the trial sites on the day of harvest sites to evaluate varieties based on the field performance and cooked roots attributes. Field performance attributes considered were foliage production, tolerance to drought, virus resistance, and tolerance to weevil, size and shape of roots, number of mature roots, root skin colour, root flesh colour and general acceptability. Attributes of cooked roots were appearance, taste, smell/flavor, flouriness /starchiness, fibrousness and general appreciation. Each farmer was asked to assign bean seeds to represent the appreciation of the variety's performance in each particular attribute under consideration. The number of seeds ranged from one to five whereby**:** one seed means very bad, two seeds = bad, three seeds = moderate, four seeds = good and five seeds = very good. Pre-labeled bags bearing variety name, replication and criterion being assessed were placed in each plot in all the replications. Evaluation was done by considering one attribute at a time. Farmers were asked to place one to five seeds in each bag and move through the entire field. When the attribute had been assessed for all the varieties in the entire field, bags were collected and bundled together. The process was repeated for other attributes until completed. The total number of seeds placed by all participants in each bag for a particular attribute was recorded. The number of seeds assigned to all attributes in all replications for a particular variety was summed up. The variety with the highest number of seeds for all the field performance attributes was ranked first for field performance. Root sample of each variety from one replication was cooked and evaluated in a similar way as for field performance. The overall ranking of the clones was done by adding all the seeds assigned to each clone for field and cooked root attributes and the clone with the highest sum ranked first. Overall ranks for each variety at three sites were summed up to get the rank sum. The rank sums were ranked again such that a variety with the lowest rank sum was assigned rank one and that with the greatest rank sum ranked last.

Data analysis was carried out using SAS software (SAS, 2001). Analysis of variance was conducted for each location to assess variation within location and among locations for all the traits measured. Mean separation for each trait was done by calculating LSD values. All location-year and season combinations were treated as individual environments. Stability assessment of varieties was done using Finlay and Wilkinson (1963) regression coefficient (b1). Combined analysis of variance was done to verify G x E interactions across environments.

## Results and discusion

Highly significant variety, environment and variety x environment interactions were observed for all traits measured (Table 3). Environment x variety interactions suggested that the ranking of clones at each environment was not constant. Significant interaction was expected because experimental sites differed in soil types, mean temperature and annual rainfall (Table 2). The genotypes also originated from a genetically diverse background. Mean yield of the varieties was highest at KARI-KARI-Kakamega and KARI-Katumani and lowest at KARI-Mtwapa. The high yield at KARI-KARI-Kakamega was expected as the area received higher rainfall and has deeper soils than the other locations. Low root yield at KARI-Mtwapa was attributed to the low rainfall received during the trial period and shallow sandy soils which restricted root expansion. Only one single observation was made at KARI-Katumani because the other two trials failed to reach the harvesting stage because of inadequate moisture. Unexpectedly, the single season when cropping was successful realized high yields due to the unusually high rainfall. There may be need to conduct more trials at this site to make conclusive recommendations. Variety199062.1 consistently gave high root yield across all sites, while variety K118 produced the lowest. Although 199062.1 had the highest root yield, its root dry matter content was low which may affect its promotion among the Kenyan adult consumers who prefer varieties with high root DM content.

This variety will, however, be ideal for processing and consumption by the children who tend to prefer roots with low root dry matter contents. The highest yielding varieties at KARI-Kakamega were 199062.1 (26.0 tons/ha) followed with Mayai (21.9 tons/ha), Ukerewe (20.2 tons/ha) and K566632 (20.2 tons/ha) while the lowest was Resisto (11.2 tons/ha). The crop yield at KARI-Kakamega was affected by the sweetpotato virus and the hailstones which hit the crop at the early stages of root bulking during the 2007 long rain season. The highest yielding varieties at KARI-Mtwapa were 199062.1, Mayai and the local check SPK004. Ejumula and K118 which performed moderately well at KARI-Kakamega had the lowest yield at this site. Similarly 199062.1, K566632 and Mayai were the best clones in terms of root yield at Kabete. Two varieties K135 and Resisto which had low yields at KARI-Kakamega outperformed other varieties in KARI-Katumani. These were followed by Mayai, Ukerewe and 199062.1.

**Table 3. Mean root yield and virus infection of local orange-fleshed sweetpotato varieties at four experimental sites in Kenya**

| Variety | Sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | KARI-Kakamega | | KARI-Mtwapa | | Kabete | | KARI-Katumani | |
| | Total root yield t/ha | Virus infection (1-5) | Total root yield t/ha | Virus infection (1-5) | Total root yield t/ha | Virus infection (1-5) | Total root yield t/ha | Virus infection (1-5) |
| Resisto | 11.2 | 3.3 | 6.7 | 1.7 | 8.3 | 2.3 | 19.2 | 1.3 |
| Carrot C | 17.1 | 4.3 | 6.0 | 2.0 | 8.4 | 2.3 | 11.0 | 1.7 |
| Naspot 1 | 14.2 | 3.3 | 10.8 | 1.0 | 15.0 | 2.0 | 18.0 | 1.3 |
| Gweri | 12.6 | 2.9 | 8.6 | 1.0 | 5.8 | 2.0 | 10.0 | 1.0 |
| Ejumula | 18.8 | 3.8 | 4.9 | 2.0 | 9.6 | 2.0 | 16.2 | 1.7 |
| SPK004 | 12.6 | 3.0 | 13.6 | 1.3 | 10.5 | 2.0 | 11.9 | 1.7 |
| K118 | 14.8 | 4.1 | 4.3 | 2.3 | 7.4 | 1.7 | 14.4 | 2.0 |
| K135 | 13.7 | 4.0 | 8.5 | 1.7 | 8.8 | 1.7 | 21.3 | 2.0 |
| 199062.1 | 26.0 | 3.1 | 18.0 | 1.3 | 15.4 | 1.7 | 14.6 | 3.0 |
| Ukerewe | 20.2 | 3.3 | 11.6 | 1.3 | 11.7 | 1.7 | 15.2 | 1.7 |
| Pipi | 13.9 | 3.9 | 11.6 | 1.0 | 9.9 | 1.3 | 11.3 | 1.0 |
| Mayai | 21.9 | 4.3 | 13.3 | 2.0 | 12.0 | 1.3 | 20.0 | 1.3 |
| K566632 | 20.2 | 4.7 | 6.2 | 2.3 | 12.5 | 1.3 | 9.7 | 1.7 |
| Zambezi | 12.5 | 4.4 | 10.2 | 2.3 | 10.7 | 1.0 | 11.3 | 2.0 |
| Mean | **16.6** | **3.8** | **9.6** | **1.7** | **10.4** | **1.7** | **14.4** | **1.6** |
| LSD (0.05) | **8.8** | **0.7** | **4.8** | **0.9** | **4.2** | **0.9** | **7.0** | **1.1** |
| CV% | **448.7** | **19.6** | **26.6** | **30.8** | **35.3** | **36.6** | **29.1** | **36.5** |

The mean yield of marketable roots constituted 87.0 % of the mean total root yield (Table 4). High marketable root yield is important to the farmer since this is most important commercial part of the plant. The mean number of roots per plant ranged between 2.9 and 5.4. The number of roots per plant is important in sweetpotato production since it is positively correlated to the root yield (Whyte, 1992). It is also an important selection criterion for farmers practicing piecemeal harvesting since the presence of many small roots at harvesting may indicate that there is conditioned potential for production hence a longer production period (Ndolo et. al., 1995). Varieties 199062.1, Ukerewe, K566632 and Mayai which gave high root yield in most sites produced more than 4 roots per plant. These results suggest a negative correlation between root and foliage yield in these varieties. Most of the high yielding varieties except for Ukerewe had low vine production.

Farmer variety assessment results for Kabete, KARI-Mtwapa and KARI-Kakamega are given in Table 5. Naspot 1, Ukerewe, Pipi, SPK004 and 19962.1 were ranked high by farmers at KARI-Mtwapa and Kabete on the basis of field performance and quality of the cooked roots. Farmers at Kakamega ranked SPK004 highest followed by Ukerewe, Ejumula, Carrot C, Mayai, K135, K118 and 199062.1. The combined overall ranking of the varieties indicated that the two check varieties SPK004 and Naspot one were the best. The other best ranked orange-fleshed sweetpotato varieties were Ukerewe, 199062.1 and Mayai. These varieties were also the most outstanding varieties in terms of root yield.

**Table 4. Aggregated data for root yield, number of roots per plant, foliage yield, virus infection, dry matter and taste test score content of 14 sweetpotato varieties planted at 4 locations in Kenya**

| Variety | Marketable root yield (t/ha) | Total root yield (t/ha) | % Marketable roots | No. of roots/plant | Foliage weight (t/ha) | Virus score (1-5) | DM% |
|---|---|---|---|---|---|---|---|
| K56663 | 12.1 | 14.8 | 81.8 | 5.4 | 16.7 | 3.1 | 26.8 |
| Carrot C | 10.4 | 12.4 | 83.9 | 4.7 | 20.0 | 2.9 | 31.0 |
| K118 | 9.7 | 11.3 | 85.8 | 3.5 | 24.9 | 2.8 | 32.9 |
| Mayai | 15.6 | 17.8 | 87.6 | 4.6 | 18.0 | 2.8 | 29.0 |
| 199062.1 | 18.4 | 20.5 | 89.8 | 4.8 | 16.2 | 2.7 | 22.3 |
| Zambezi | 9.2 | 11.5 | 80.0 | 5.0 | 16.7 | 2.7 | 30.2 |
| K135 | 10.6 | 12.3 | 86.2 | 3.9 | 26.0 | 2.6 | 29.8 |
| Ejumula | 12.3 | 13.8 | 89.1 | 4.0 | 16.7 | 2.6 | 29.9 |
| Ukerewe | 14.0 | 15.7 | 89.2 | 5.0 | 20.2 | 2.5 | 30.0 |
| Pipi | 10.8 | 12.2 | 88.5 | 4.0 | 27.4 | 2.5 | 29.7 |
| Resisto | 9.1 | 10.8 | 84.3 | 5.0 | 15.7 | 2.4 | 21.0 |
| SPK004 | 10.8 | 12.0 | 90.0 | 3.2 | 22.9 | 2.3 | 28.9 |
| Gweri | 9.0 | 9.9 | 90.9 | 3.5 | 34.8 | 2.1 | 30.0 |
| Naspot 1 | 13.1 | 14.5 | 90.3 | 2.9 | 20.9 | 2.0 | 29.9 |
| Mean | 11.8 | 13.6 | 87.0 | 4.2 | 21.3 | 2.6 | 28.7 |
| LSD (0.05) | 2.8 | 2.9 | 6.9 | 0.9 | 4.7 | 0.4 | 4.8 |
| CV% | 39.3 | 35.6 | 23.8 | 33.6 | 36.6 | 25.2 | 18.08 |

**Table 5. Overall ranking of sweetpotato varieties at three trial sites in Kenya based on attributes for field performance and quality of cooked roots**

| Variety | Kabete | Mtwapa | Kakamega | Rank sum | Overall rank |
|---|---|---|---|---|---|
| K135 | 7 | 6 | 7 | 20 | 7 |
| Pipi | 3 | 3 | 12 | 18 | 6 |
| Naspot1 | 1 | 1 | 9 | 11 | 2 |
| Gweri | 12 | 9 | 8 | 29 | 11 |
| Ukerewe | 2 | 8 | 2 | 12 | 3 |
| Ejumula | 9 | 12 | 3 | 24 | 8 |
| Carrot C | 10 | 11 | 4 | 25 | 9 |
| K118 | 10 | 14 | 6 | 30 | 12 |
| Mayai | 6 | 4 | 5 | 15 | 4 |
| Zambezi | 8 | 8 | 10 | 26 | 10 |
| 199062.1 | 5 | 5 | 7 | 17 | 5 |
| SPK004 | 4 | 1 | 1 | 6 | 1 |
| Resisto | 13 | 13 | 14 | 40 | 14 |
| K566632 | 14 | 10 | 13 | 37 | 13 |

Table 6 gives the means and stability parameters based on Finlay and Wilkinson b-value (Finlay and Wilkinson, 1963) coefficient of determination ($R^2$). The varieties used in the study vary in their reaction to environments and this variation is often linear. Significant linear were found between the yields measured and location indices, location index being the mean value for a characteristic of all varieties tested. The regressions accounted for most of the variations in the variety x environment interactions. Varieties 199062.1, Mayai, K566632 and Ukarewe with yields greater than the variety mean and b-values significantly greater than unity were considered generally not adaptable or stable and may be recommended for favourable environments. Only variety K118 and K135 were stable but had yields below the environmental mean. Such varieties can recommend for poor environments.

**Table 6. Variety mean, b-value Standard deviation and $R^2$ of popular orange-fleshed sweetpotato varieties planted in seven environments in Kenya**

| Variety | Total root wt. t/ha) | b-value | $R^2$ |
|---|---|---|---|
| 199062.1 | 19.9 | 1.22 | 0.67 |
| Carrot C | 11.8 | 1.27 | 0.85 |
| Ejumula | 12.8 | 1.65 | 0.90 |
| Gweri | 9.5 | 0.73 | 0.60 |
| K118 | 10.9 | 1.10 | 0.84 |
| K135 | 12.1 | 0.70 | 0.50 |
| K566632 | 14.1 | 1.39 | 0.80 |
| Mayai | 17.4 | 0.89 | 0.37 |
| Naspot 1 | 13.8 | 1.97 | 0.40 |
| Pipi | 11.9 | 0.73 | 0.60 |
| Resisto | 10.8 | 1.86 | 0.80 |
| SPK004 | 11.7 | 0.32 | 0.43 |
| Ukerewe | 15.3 | 1.20 | 0.90 |
| Zambezi | 11.3 | 0.42 | 0.67 |

The significant root yield differences among the varieties in the four sites suggest the need to focus on only the best varieties within these sites. Since sweetpotato varieties are affected by the variability of the ecological conditions, it is important for varieties to be tested across zones before they are released to farmers for production. The varieties 199062.1, Ukerewe, and Mayai, which performed well in most locations and had acceptable root yields, will be recommended for release to farmers. there will be need for further evaluation of these varieties at KARI-Mtwapa and KARI-Katumani where only one season data were obtained to gain confidence in the results.

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# Release and diffusion orange sweetpotato cultivars, 'NASPOT 9 O', 'NASPOT 10 O' in Uganda

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## Abstract

Two orange-fleshed sweetpotato (Ipomoea batatas L. (Lam.) cultivars, NASPOT 9 O (Namulonge Sweetpotato 9 orange-fleshed) and NASPOT 10 O were approved for release by the Ugandan Plant Variety Release Committee in July 2007. The two cultivars were evaluated for five seasons, on-station at Namulonge in seedling, observation, preliminary, and intermediate trials, between 2002 and 2004 to confirm field resistance to sweetpotato virus disease (SPVD). They were further evaluated for three seasons, on-station and on-farm between 2004 and 2006 in replicated, standardized, multi-location yield trials. The root yields of the cultivars fluctuated across agroecologies in both on-station and on-farm trials (5.3-35.4 t•ha$^{-1}$), but were above the national average of 4.0 t•ha$^{-1}$. The yield of the two cultivars were similar to the local check cultivars in most sites on-station and on-farm. The two cultivars have acceptable storage root shapes when grown in light soils. They also have high average dry matter content (about 30%), and good to excellent consumer acceptance. NASPOT 9 O and NASPOT 10 O have high pro-vitamin A, hence potential to alleviate widespread vitamin A deficiency. However, the cultivars were susceptible to sweetpotato weevils in no choice laboratory tests and under dry season field conditions but have moderate field resistance to Alternaria stem blight. The cultivars have moderate field resistance to SPVD which is the most devastating disease of sweetpotato in Uganda. Since their release, they have spread widely, promoted by government, non-government organizations, and farmer groups.

*Keywords:* Alternaria bataticola *blight,* Cylas puncticollis*,* Cylas brenneus*, selection.*

## Introduction

Two orange-fleshed sweetpotato (Ipomoea batatas L. (Lam.) cultivars, NASPOT 9 O and NASPOT 10 O were approved for release by the Uganda Plant Variety Release Committee in July 2007 (Mwanga et al., 2007a). The cultivars were part of the fourth group of sweetpotato cultivars to be officially released by the Sweetpotato Program in Uganda. The first three groups were released in different years; six in 1995 (Mwanga et al., 2001), six in 1999 (Mwanga et al., 2003), and two in 2004 (Mwanga et al., 2007c). The two orange-flehed cultivars described herein are pro-vitamin A (beta-carotene) rich. They have acceptable storage root shapes when grown in light soils. They also have high dry matter content (about 30%), and good to excellent consumer acceptance, particularly among women and children below six years (Wamaniala, 2008; Potts and Nagujja, 2007; Mwanga et al, 2007b, Odongo et al. 2002). The cultivars have moderate levels of field resistance to sweetpotato virus disease (SPVD) and Alternaria bataticola blight, and high storage root yields compared to the average national storage root yield of 4.0 t•ha$^{-1}$ (International Potato Center, 1999). The release of these cultivars provides consumers and farmers with high quality sweetpotatoes with storage roots that are high in pro-vitamin A content. The high pro-vitamin A content in the two cultivars presents potential to alleviate widespread vitamin A deficiency in Uganda and other developing countries (Low et al. 2007; Jaarsveld et al. 2005; Ruel, 2001; UDHS, 2001).

## Origin and nomenclature

Throughout evaluation at the National Crops Resources Research Institute (NaCRRI), Namulonge and in on-station and on-farm trials in major selected agroecologies in Uganda, the two clones were coded using the following nomenclature: Namulonge *Ipomoea* selection (NIS)/the initial year selected/the female parent/the selection (genotype) number/similarity code number (if present). The codes for the releases were 'NASPOT 9 O' and 'NASPOT 10 O'. The two cultivars are seedling selections from the sweetpotato program at NaCRRI; the population from which they were selected was bulked seed from an open-pollinated polycross nursery of 24 parents grown during 2000-2001. The 24 parents in the polycross block consisted of 10 released cultivars, 3 introductions, 5 advanced clones from the Ugandan sweetpotato breeding program and 6 landrace cultivars (Table 1). Zapallo (PI420027), Jewel (PI440031), and Beauregard (PI440132) were introductions from the International Potato Center (CIP), Lima, Peru, as pathogen-free in vitro plantlets. The landraces and the districts (in parenthesis) from where they were collected were 'Arivumaku-2' and 'Ngujja' (Arua), 'Kala' (Kumi), 'Kanyasi' (Kabale), 'Araka' (Soroti), and 'Bunduguza' (Kamuli). The 24 parents were included in the polycross nursery for improvement or as sources of one or a combination of genes for desirable traits such as orange-fleshed roots (pro-vitamin A), high dry matter (30%), early maturity (3-4 months), resistance to SPVD and Alternaria stem blight (Table 1).

## Evaluation of cultivars

The two cultivars were evaluated for five seasons on-station at Namulonge in seedling, observation, preliminary and intermediate trials between 2002 and 2004, and for three seasons in on-station and on-farm trials between 2004 and 2006 in replicated, standardized, multi-location yield trials (3 major agoecologies). The agroecologies agroecologies were: (1) the warm, sub-humid short grasslands where sweetpotato weevils and drought are important; (2) the warm, moist, tall grasslands where SPVD is severe; and (3) the cool, moist, south-western highlands where Alternaria stem blight (AB) and low soil fertility stresses are prevalent. Mwanga *et al.* (2007a) provides detailed descriptions of pedigree, test sites, cultivars, planting materials, on-station and on-farm trials, planting and harvesting dates, farmer selection criteria, experimental designs, stability analysis, production package, and cultivar maintenance. For pest and disease rating scale the following coding was used: S =Susceptible - considerable damage or numbers present to severe damage or very high numbers present, respectively; moderately resistant (MR) = moderate damage or moderate numbers present (resistant = little or no apparent damage or few or no insects present).

The agroecologies (sites) are represented as follows: Namulonge is the warm, moist, tall grasslands (high SPVD pressure agroecology); Ngetta and Serere are in the warm, sub-humid short grasslands (has high weevil population during dry periods); and Kachwekano is the cool, moist, south-western highlands (has high Alternaria blight pressure). In Table 3 yield was a mean of four replications. Planting was in a randomized complete block design (RCBD); 80 plants on 5 ridges (1 m x 30 cm) per plot; only the 48 middle plants were harvested for yield determination. Other details were as follows: DMC = Dry matter content, SPVD and Alternaria blight severity rating scale, 1 = no symptoms; 2 = mild symptoms; 3 = mild symptoms; 4 = severe symptoms; and 5 = very severe symptoms.

A total of eight multilocational on-station and 13 on-farm trials were conducted under rain-fed conditions but only data for 2004/2005-2006 are presented where the original number of clones (68,874) selected from the seedling nursery had been reduced to less than 10 for on-farm trials (Mwanga *et al.*, 2007a). The cultivars were evaluated to confirm resistance to SPVD, AB, and sweetpotato weevils, *Cylas puncticollis* (Boheman) and *C. brunneus* (Fabricius) (Tables 2 and 3). Classifications of the relative resistance to disease and weevil damage were based on field evaluation under natural disease and weevil population pressures as described by Mwanga *et al.* (2002, 2007b,). Root samples of cultivars were analyzed for pro-vitamin A concentration using spectrophotometry and high performance liquid chromatography (HPLC). The level of disease infection varied from low to high depending on agroecology; Namulonge for high SPVD pressure, Kachwekano for high AB pressure; and Serere and Ngetta for high weevil populations during dry periods. Storage root dry matter content, root yield, and taste and storage root yield, were also evaluated. The mean root yields of the released cultivars across sites varied in on-station (Table 3) and on-farm trials (Table 4), but they were above the national average of 4.0 t•ha$^{-1}$. Though 'NASPOT 9 O' and 'NASPOT 10 O' varied in root yield and biomass, they have orange fleshed-storage roots (Fig. 1) with more pro-vitamin A than Dimbuka-Bukulula, and Tanzania which have cream-fleshed roots.

For on-firm trials, Mpigi and Wakiso districts represent the warm, moist tall grasslands, Nakasongola and Busia, the warm sub-humid short grasslands, and Kabale, the cool moist south-west highlands. Yields were based on 10-15 farms per district, gross plot was 30 $m^2$ (30 mounds), middle or net plot harvested was 12 $m^2$ (12 mounds of 36 plants); each farm in a district was treated as a replicate. Taste rank was based on the aggregate pair-wise comparison of the panel (farmers); n = number of farmers in the tasting panel, m = male, f =female; 1 = most preferred; 6 = least preferred.

The observed wide variation in yield is attributed to variation in environmental factors such as erratic rain during some seasons, and differences in farm management and soil types in the different agroecologies. The wide variation in pro-vitamin A (beta-carotene) content is attributed to various factors such as agroclimatic factors [e.g. different soil types, time of sampling (wet/ dry season)], different methods used in its determination, age and size of the sampled roots, methods of harvesting and post-harvest handling of root samples, processing and storage]. Although relative ranking in taste preference varied on different farms the released cultivars had high acceptability on most farms (Table 4).

## Diffusion of cultivars

The global HarvestPlus Program (Pfeiffer and McClafferty, 2007; HarvestPlus, 2007) was involved in an effectiveness case study to promote orange-fleshed sweetpotato (OFSP) to alleviate vitamin A deficiency in Uganda. The OFSP high pro-vitamin A cultivars, 'NASPOT 9 O' and 'NASPOT 10 O' (Bengtsson *et al.,* 2008), were given new names, 'Vita' and 'Kabode', respectively in the HarvestPlus project areas (Wamaniala, 2008). By September 2008, three seasons after the farmers in the three HarvestPlus project target districts received the cultivars, 3,261 farmers were growing them in Bukedea, 3,504 in Kamuli, and 3,511 in Mukono. This represented 100, 90, and 80% adoption rates in the respective districts (Wamaniala, 2008). The released cultivars have already reached 19 other districts in Uganda; Amuria, Busia, Jinja, Kabale, Kampala, Karamoja, Katakwi, Kayunga, Kumi, Lira, Manafwa, Masaka, Mayuge, Mpigi, Nakasongola, Padel, Soroti, Tororo, and Wakiso, albeit absence of a seed company that deals in sweetpotato planting materials (Potts and Nagujja 2007; Wamaniala, 2008).

## Availability of cultivars

The cultivars are maintained as pathogen-tested plants in the screenhouse at the Quarantine Station, Muguga, Kenya, and are maintained in the field by NaCRRI in Uganda. Requests for these cultivars should be addressed to: Seed Unit, CIP, P.O. Box 25171, Nairobi, Kenya. Requests for planting materials within Uganda should be directed to: Sweetpotato Program, NaCRRI, P.O. Box 7084, Kampala.

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**Table 1. Origin and main attributes of 24 sweetpotato parents used in the 2001/2002 polycross nursery at Namulonge, Uganda**

| Female parent | Origin of parent | Year released/ status/ germplasm (GM) | Desirable / undesirable trait |
|---|---|---|---|
| SPK004 (Kakamega) | Kenya | 2004 | Orange-flesh (OF) of storage roots, high dry matter (HDM)(≥30%), moderately resistant to sweetpotato virus disease (SPVD) |
| Ejumula | Uganda (landrace) | 2004 | OF, HDM, highly susceptible to SPVD |
| NASPOT1 | Uganda (bred clone) | 1999 | OF, HDM, high root yield, susceptible to Alternaria blight (AB) |
| NASPOT3 | Uganda (bred clone) | 1999 | HDM, moderately resistant to SPVD |
| NASPOT4 | Uganda (bred clone) | 1999 | Resistant to SPVD |
| NASPOT5 | Uganda (bred clone) | 1999 | OF, HDM, resistant to SPVD, susceptible to AB |
| New Kawogo | Uganda (landrace) | 1995 | HDM, resistant to SPVD, susceptible to AB, aggressive to weeds |
| Bwanjule | Uganda (landrace) | 1995 | HDM, resistant to SPVD |
| Sowola | Uganda (landrace) | 1995 | HDM, early maturity, light canopy |
| Tanzania | Uganda (landrace) | 1995 | HDM, taste, moderately resistant to SPVD |
| Zapallo (420027) | CIP / Peru | GM | OF, moderate resistance to AB, susceptible to SPVD |
| Beauregard (44013) | CIP / Peru | GM | OF, good root shape, susceptible to SPVD |
| Jewel (440132) | CIP / Peru | GM | OF, susceptible to SPVD |
| NIS/199/23/60 | Uganda (bred clone) | Breeding line | OF, susceptible to SPVD |
| NIS/93/29 | Uganda (bred clone) | Breeding line | HDM, resistant to SPVD |
| NIS/199/18/1 | Uganda (bred clone) | Breeding line | OF, susceptible to SPVD |
| NIS/199/4/4 | Uganda (bred clone) | Breeding line | OF, HDM, susceptible to SPVD |
| NI/1990/Sowola-6 | Uganda (bred clone) | Breeding line | OF, susceptible to SPVD |
| Ngujja | Uganda (landrace) | GM | OF, susceptible to SPVD |
| Arivumaku-2 | Uganda (landrace) | GM | OF, low root yield |
| Bunduguza | Uganda (landrace) | GM | HDM, resistance to sweetpotato weevil |
| Araka | Uganda (landrace) | GM | Adapted to short grassland area |
| Kala | Uganda (landrace) | GM | OF, HDM, |
| Kanyasi | Uganda (landrace) | GM | HDM, susceptible to AB |

**Table 2. Yield, quality attributes and disease and insect pest reaction of two orange sweetpotato cultivars released in Uganda in July 2007**

| Attribute | Naspot9 O | Naspot10 O | Tanzania (local check) |
|---|---|---|---|
| Dry matter % (range) | 30.1 (27.5-31.1) | 30.5 (27.8-32.5) | 32.0 (27.5-35.5) |
| Cooked texture | Somewhat dry | Somewhat dry | Somewhat dry |
| Sweetness | Moderate | Moderate | Moderate |
| Field reaction to weevils | Susceptible (S) | S | S |
| Field reaction to sweetpotato | | | |
| virus disease (SPVD) | Moderately resistant (MR) | MR | MR |
| Field reaction to | | | |
| Alternaria stem blight | MR | MR | MR |
| Maturity (days) | 125 | 110 | 120 |
| Mean and (range) of | | | |
| storage root yields | | | |
| in various yield trials ($t \cdot ha^{-1}$) | 16.5 (8.1-27.6) | 16.0 (5.3-35.4) | 17.6 (3.9-32.9) |
| Mean storage root yield | | | |
| (% of local check) | 94 | 91 | 100 |
| Beta-carotene content (•/g DM) | 314.5 (206.3-460.3) | 246.2 (185.6-324.8) | 21.5 (13.8-36.3) |

**Table 3. Yield of four sweetpotato cultivars including 'NASPOT 9 O' and 'NASPOT 10 O' in four sites in Uganda [dry matter content- DMC; sweetpotato virus disease – SPVD; if not applicable – NA are indicated)**

| Cultivar | Site | | | | Mean across sites | Biomass across sites (t•ha$^{-1}$) | DMC across sites % | SPVD at Namu longe | Alternria at Kachwe kano |
|---|---|---|---|---|---|---|---|---|---|
| | Namu longe | Kachwe kano | Ngetta | Serere | | | | | |
| | Storage root yield$^{y}$ (t•ha$^{-1}$) | | | | | | | | |
| | ***2004*** | | | | | | | | |
| NASPOT 9 O | 50.4 | 33.7 | 12.8 | 6.0 | 25.7 | 62.5 | 29.4 | 1.8 | 2.3 |
| NASPOT 10 O | 38.3 | 28.0 | 9.8 | 7.9 | 21.0 | 43.2 | 32.6 | 2.3 | 2.0 |
| Dimbuka-Bukululа | 58.4 | 52.1 | 19.5 | 15.9 | 36.5 | 64.0 | 32.3 | 3.0 | 3.0 |
| Tanzania (Check) | 32.9 | 58.4 | 16.5 | 5.3 | 28.3 | 77.3 | 34.6 | 2.2 | 2.0 |
| Mean | 47.0 | 45.1 | 13.2 | 8.8 | 28.6 | 68.7 | 31.6 | 2.2 | 2.2 |
| $LSD_{0.05}$ | 13.1 | 15.8 | 5.0 | 3.8 | 5.4 | 9.3 | NA | 0.4 | 0.9 |
| | ***2005*** | | | | | | | | |
| NASPOT 7 | 28.7 | 19.7 | 7.4 | 13.2 | 17.3 | 42.8 | 31.5 | 1.4 | 2.0 |
| NASPOT 8 | 23.5 | 20.7 | 8.1 | 4.6 | 14.2 | 40.4 | 31.4 | 1.3 | 2.0 |
| NASPOT 9 O | 17.1 | 11.2 | 15.6 | 9.5 | 13.4 | 28.4 | 30.3 | 2.3 | 2.3 |
| NASPOT 10 O | 16.4 | 15.4 | 12.1 | 19.7 | 31.8 | 34.3 | 30.6 | 2.1 | 2.3 |
| Dimbuka-Bukululа | 16.5 | 29.0 | 15.6 | 14.5 | 18.9 | 32.8 | 32.9 | 2.1 | 3.0 |
| Tanzania (Check) | 24.3 | 20.9 | 14.8 | 11.7 | 17.9 | 28.8 | 30.9 | 1.6 | 2.0 |
| Mean | 21.1 | 19.5 | 12.3 | 12.2 | 18.9 | 34.6 | 31.3 | 1.8 | 2.3 |
| $LSD_{0.05}$ | 5.3 | 6.3 | 2.8 | 5.0 | 2.3 | 5.8 | NA | 0.9 | 0.9 |
| | ***2006*** | | | | | | | | |
| NASPOT 7 | 41.7 | 52.5 | 8.7 | 17.5 | 30.1 | 57.9 | 30.5 | 2.3 | 1.5 |
| NASPOT 8 | 28.6 | 35.7 | 7.0 | 32.3 | 25.9 | 50.0 | 30.1 | 2.3 | 1.3 |
| NASPOT 9 O | 25.4 | 32.0 | 6.8 | 21.7 | 21.5 | 43.7 | 30.3 | 2.8 | 1.8 |
| NASPOT 10 O | 26.6 | 28.6 | 5.8 | 31.8 | 23.2 | 48.6 | 33.9 | 2.3 | 1.5 |
| Dimbuka-Bukululа | 53.0 | 51.4 | 11.2 | 50.2 | 41.5 | 63.9 | 32.3 | 3.0 | 2.0 |
| Tanzania (Check) | 22.9 | 20.7 | 10.1 | 16.1 | 17.5 | 52.8 | 31.5 | 3.0 | 1.9 |
| Mean | 33.0 | 36.8 | 8.3 | 28.3 | 26.6 | 52.8 | 31.4 | 2.6 | 1.7 |
| $LSD_{0.05}$ | 14.5 | 14.2 | 3.5 | 8.4 | 6.2 | 13.2 | NA | 0.6 | 0.8 |

**Table 4. Performance of six sweetpotato varieties including 'NASPOT 9 O' and 'NASPOT 10 O' in on-farm trials in Uganda (m = men, f = female, NA = not applicable)**

| District/Year | Cultivar | Yield($t \cdot ha^{-1}$) | | | Disease severity | | Taste rank |
|---|---|---|---|---|---|---|---|
| | | Root | Biomass | | SPVD | Alternaria | |
| | | | | | | | |
| Mpigi 2005 | | | | | | | (n=15; m=4, f=11) |
| | NASPOT 7 | 11.2 | 30.7 | | 2.2 | 3.0 | 6 |
| | NASPOT 8 | 15.0 | 30.1 | | 2.0 | 1.2 | 3 |
| | NASPOT 9 O | 13.7 | 26.1 | | 2.0 | 1.5 | 2 |
| | NASPOT 10 O | 10.5 | 20.4 | | 2.0 | 1.4 | 1 |
| | Dimbuka-Bukulula | 17.8 | 35.1 | | 2.4 | 1.6 | 4 |
| | Namubiru (Check) | 8.2 | 20.0 | | 2.6 | 1.4 | 5 |
| | Mean | 12.7 | 27.1 | | 2.2 | 1.7 | NA |
| | $LSD_{0.05}$ | 4.5 | 8.8 | | NS | 0.8 | NA |
| Mpigi 2006 | | | | | | | (n=24; m=5, f=19) |
| | NASPOT 7 | 7.3 | 20.2 | | 2.4 | 3.4 | 5 |
| | NASPOT 8 | 12.7 | 29.4 | | 2.6 | 2.2 | 3 |
| | NASPOT 9 O | 13.3 | 23.9 | | 2.6 | 2.0 | 1 |
| | NASPOT 10 O | 9.7 | 20.8 | | 2.6 | 2.0 | 2 |
| | Dimbuka-Bukulula | 12.4 | 27.5 | | 3.0 | 2.2 | 4 |
| | Semanda (Check) | 12.1 | 31.3 | | 3.0 | 2.6 | 6 |
| | Mean | 11.3 | 25.5 | | 2.7 | 2.4 | NA |
| | $LSD_{0.05}$ | 4.1 | 8.0 | | 0.5 | 0.9 | NA |
| Busia 2006 | | | | | | | (n=20; m=3, f=17) |
| | NASPOT 7 | 14.0 | 28.5 | | 2.0 | 1.0 | 3 |
| | NASPOT 8 | 16.5 | 32.6 | | 2.0 | 1.0 | 5 |
| | NASPOT 9 O | 14.9 | 22.9 | | 1.8 | 1.4 | 2 |
| | NASPOT 10 O | 14.9 | 22.1 | | 2.0 | 1.0 | 1 |
| | Dimbuka-Bukulula | 16.3 | 23.6 | | 2.4 | 1.0 | 6 |
| | Musiita (Check) | 16.8 | 27.8 | | 1.8 | 1.0 | 4 |
| | Mean | 15.6 | 26.3 | | 2.0 | 1.1 | NA |
| | LSD0.05 | NS | 8.3 | | NS | 0.2 | NA |
| Kabale 2006 | | | | | | | (n=23; m=5, f=18) |
| | NASPOT 7 | 16.1 | 31.5 | | 2.2 | 1.3 | 4 |
| | NASPOT 8 | 23.0 | 78.4 | | 1.7 | 1.0 | 5 |
| | NASPOT 9 O | 15.4 | 31.5 | | 2.0 | 1.2 | 1 |
| | NASPOT 10 O | 17.2 | 34.4 | | 2.0 | 1.2 | 6 |
| | Dimbuka-Bukulula | 21.0 | 43.7 | | 2.0 | 1.2 | 2 |
| | Nderera (Check) | 24.0 | 49.7 | | 2.2 | 1.2 | 3 |
| | Mean | 19.5 | 44.9 | | 2.0 | 1.2 | NA |
| | LSD0.05 | NS | 3.6 | | NS | NS | NA |
| Nakasongola 2006 | | | | | | | (n=18; m=4, f=14) |
| | NASPOT 7 | 15.5 | 32.8 | | 2.0 | 1.1 | 5 |
| | NASPOT 8 | 14.4 | 30.4 | | 1.8 | 1.2 | 3 |
| | NASPOT 9 O | 13.3 | 24.3 | | 1.8 | 1.0 | 1 |
| | NASPOT 10 O | 14.4 | 30.0 | | 1.8 | 1.3 | 2 |

| District/Year | Cultivar | Yield(t·ha$^{-1}$) | | | Disease severity | | Taste rank |
|---|---|---|---|---|---|---|---|
| | | Root | Biomass | | SPVD | Alternaria | |
| | | | | | | | |
| | Dimbuka-Bukululа | 18.7 | 34.0 | | 2.0 | 1.1 | 4 |
| | Nayiloni (Check) | 9.8 | 25.6 | | 2.0 | 1.0 | 6 |
| | Mean | 14.4 | 29.5 | | 1.9 | 1.1 | NA |
| | LSD0.05 | 5.1 | 5.6 | | NS | NS | NA |
| Wakiso 2006 | | | | | | | (n=21; m=5, f=16)) |
| | NASPOT 7 | 9.2 | 30.9 | | 2.2 | 1.2 | 6 |
| | NASPOT 8 | 11.4 | 33.7 | | 1.4 | 1.1 | 3 |
| | NASPOT 9 O | 9.5 | 29.6 | | 1.8 | 1.3 | 5 |
| | NASPOT 10 O | 5.8 | 17.9 | | 2.0 | 1.4 | 2 |
| | Dimbuka-Bukululа | 11.1 | 36.1 | | 2.2 | 1.2 | 4 |
| | Nansana (Check) | 9.9 | 36.2 | | 2.6 | 1.2 | 1 |
| | Mean | 9.5 | 30.7 | | 2.0 | 1.2 | NA |
| | $LSD_{0.05}$ | 2.9 | 3.2 | | 0.5 | NS | NA |


**Figure 1. Cross section of roots and shoots of 'Dimbuka-Bukululа' compared with 'NASPOT 9 O', and 'NASPOT 10 O'**