University of Kassel

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Thesis

Establishment of a Classification Scheme to structure the Post-Harvest Diversity of Yacon Storage Roots (*Smallanthus sonchifolius* (Poepp. & Endl.) H. Robinson)

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1 INTRODUCTION

1.1 Review of Literature relating to the Crop Yacon

1.1.1 Distribution and Domestication of Yacon in the Andean Region

Yacon (yacón, llacón, llakuma, aricoma, jiquima) (*Smallanthus sonchifolius* (Poepp. & Endl.) H. Robinson) belongs with other 21 *Smallanthus* species to the family of the Asteraceae. The origin of yacon and its relatives are the humid slopes in the Andean region of Latin America. In Peru seven *Smallanthus* species are found, from which yacon is the only domesticated species (Brako and Zarucchi, 1993). According to Grau and Rea (1997) the origin of the term "yacon" probably comes from the indigenous language Quechua and is a composition of two words: *yaccu* = insipid and *unu* = agua.

It is supposed that the domestication of yacon began in the *Yungas* (1,000 to 2,300 masl) or mountain jungle in the north of Bolivia or in the south of Peru (Grau *et al.,* 2001). However, the presence of yacon has declined and its area of cultivation has been reduced. It is still grown in many smallholder locations throughout the Andes from Ecuador to northwestern Argentina. Usually a few plants or rows are cultivated in field corners or backyards to complement the food supply during the year through piece-meal harvest (Hermann *et al.,* 1999). In some regions yacon is occasionally cultivated in small plots for sale to the local market (Grau *et al.,* 2001). At present the commercial production is rising due to an increasing demand for yacon.

1.1.2 Ecology

Grau and Rea (1997) mentioned that yacon shows a high plasticity, as it is able to grow in a wide altitudinal range between 0 and 3,500 masl. Cultivation at sea level can be found, for example, in New Zealand and Japan. The optimum temperature for growth is 18-25 °C, but it is able to tolerate temperatures up to 40 °C without mayor yield loss, if sufficient amounts of water are supplied. Generally, the optimum precipitation is around 800 mm. Yacon is adapted to a wide variety of soils, but prefers rich, moderately deep to deep, light, well-structured and well-drained soils. Growth is poor in heavy soils. Yacon tolerates a wide pH range from acid to weakly alkaline.

1.1.3 Cultivation Techniques

In Peru usually from the beginning of September until the end of November, depending on rainfall, offsets are planted manually, by a plant density of 70 to 100 cm between rows and 60 to 80 cm between plants. During the cultivation cycle, pest and weed control does not play a significant role, due to the rapid growth of yacon and natural agents are present and effective (Lizárraga *et al*., 1997). Roots reach maturity after six to seven months at the medium altitude sites (600 – 2,500 masl), and after up to a year at high altitude sites (>2,500 masl). The average yield is around 30 t ha^{-1} fresh weight (FW) equal to between 1 and 15 kg per plant, but harvests of up to 100 t ha^{-1} have been achieved (Kakihara *et al*., 1996). Normally the harvest occurs at the end of the rainy season when the aerial parts are dying off (C. Arbizu, CIP-Lima, 2002, pers. comm.).

1.1.4 Botanical and morphological Description

Grau and Rea (1997) describe yacon as a perennial herb of 1.5 to 3 m height. The root system is composed of 4-20 fleshy tuberous storage roots that can reach a length of 25 cm by 10 cm diameter, and an extensive system of thin fibrous roots. The shape of the storage roots reminds of sweet potato (*Ipomoea batatas* (L.) Poir.). The flesh colour of the storage roots varies considerably: white, cream, white with purple striations, purple, pink and yellow. The tuberous root bark is brown, pink, purplish, cream or ivory white and very thin (1-2 mm). Yacon is propagated vegetatively with 8-12 cm long offsets or propagules (´seeds´) taken from the root stock (´corona´). Storage roots without attached stem are not able to produce shoots. The stem is cylindrical or subangular, ramified in most clones, hollows at maturity, densely pubescent and a green to purplish coloured bark. Lower leaves are broadly ovate and hastate or subhastate, connate and auriculate at the base; upper leaves are ovate-lanceolate, without lobes and hastate base; upper and lower surfaces are densely pubescent. The inflorescences are terminal, composed of one to five axes, each one with three capitula (Fig.1). The colour of the flower varies between yellow to bright orange; ray flowers are two or three toothed. Usually sterile seeds are produced; the sexual propagation in yacon is less frequent than in other *Smallanthus* species.

1.1.5 Beneficial Aspects

The crop is cultivated for its tuberous storage roots, which possess a sweet flavour due to several carbohydrates including fructose, glucose and sucrose and oligofructans. Dried leaves can be prepared as a relaxing-tea. Therefore, the main advantages which justify the cultivation of this crop are its adaptability to a wide range of climates and soils and its potential for incorporation into agroforestry systems, erosion control, and the potential use of both underground and aerial plant parts as forage. Even so a wide range of processing alternatives, good post-harvest life and, if managed properly, exceptional qualities for low calorie diets and natural medicines make a cultivation attractive (Grau and Rea, 1997).

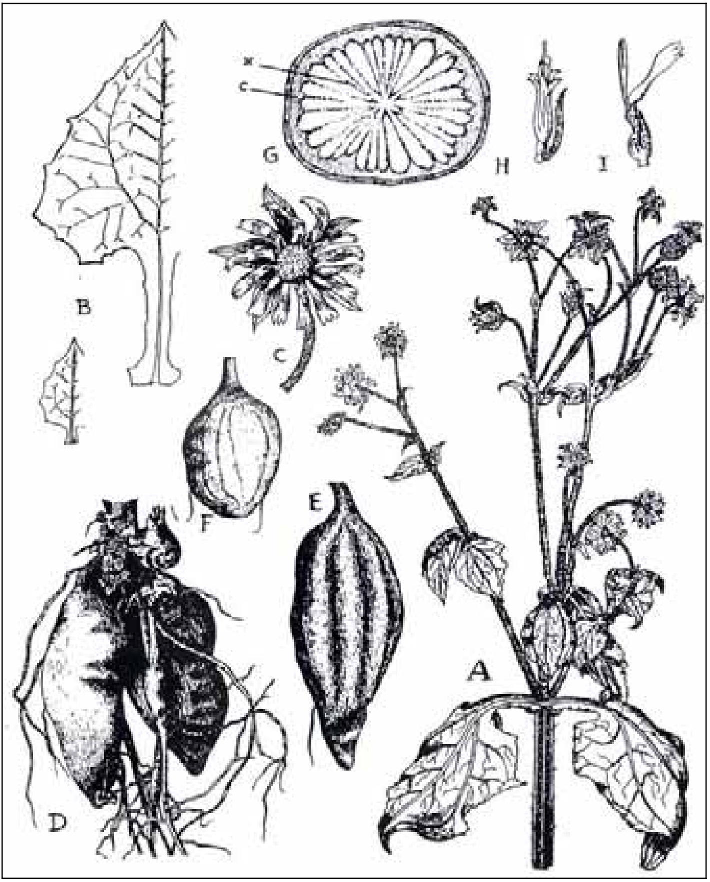

Figure 1: Yacon *(Smallanthus sonchifolius)* morphological aspects (León, 1964). A: flowering branches. B: leaves. C: flowerhead. D-F: tuberous roots. G: transverse section of the tuberous root (x, xylem, c, cortex tissues). H: staminate disk flower. I: pistilate ray flower.

1.2 Components of Yacon Storage Roots

The principal component of the yacon root is water (93 - 70 % of FW). About 90 % of the dry weight (DW) are carbohydrates. The content of fibre, vitamins, minerals and protein in the roots is small (Grau *et al*. (2001) (Tab. 1). For centuries yacon was cultivated only on a small scale. Although the medicinal properties of this root were partly known, recently, more attention has been paid to its beneficial ingredients, especially the carbohydrates. Investigations were carried out and the composition of storage carbohydrate was analysed (Ohyama *et al*., 1990; Asami, 1991).

1.2.1 Carbohydrate Composition in the Yacon Storage Roots

The carbohydrate composition of yacon varies considerably throughout the growing cycle and after harvest (Asami *et al*., 1991; Graefe, 2002). Grau and Rea (1997) assumed that the different concentrations of oligofructans (also called fructo-oligosaccharide = FOS) in the dry matter of the storage roots was attributed to the different time after harvest at which analyses were undertaken. According to this, Hermann *et al.* (1999) mentioned that the increasing de-polymerization of fructans increased sweetness and caused a concomitant rise in the Refractometric index (RI). With increasing time of post-harvest storage, fructans and sucrose are depolymerised by hydrolysis into glucose and fructose.

1.2.2 Oligofructans in the Yacon Storage Roots

In yacon roots an oligofructan similar to inulin with a polymerization degree (DP) of 3 – 10 and a β - (1, 2) bond was identified. Due to the low DP of the oligofructans in yacon roots it is not an inulin like the oligofructans in other members of the Asteraceae in which the DP amounts to about 35 (Ohyama *et al*., 1990).

It is well known that oligofructans have a number of medicinal properties. The inclusion of oligofructans in the human diet supports the development of probiotic bacterial flora and decreases the colonization of *salmonella* in the intestine. Because oligofructans are not metabolized by humans, they can be incorporated in a low calorie diet for diabetics (Grau *et al*. (2001). The high concentration of fructose and oligofructans in the roots justifies its potential for the development of “yacon syrup” as a low caloric sweetener (Hermann *et al.*

1999). Additionally the sweetening effect of fructose is about twice as strong as that of sucrose (Badui, 1993).

In spite of the very promising potential of its active ingredients, until now large scale yacon cultivation and possible industrialization have not been adequately researched (Melgarejo, 1999). Knowledge about the crop is limited and a lot of research is still required. Furthermore there exists a potential to use wild relatives in breeding programs that could improve desirable traits such as a thicker root bark, looser storage root arrangement and higher oligofructan levels (Grau and Rea, 1997). Grau *et al*. (2001) suggested that *S. macroscyphus* could be incorporated into breeding programs to improve the production of FOS with a DP > 6 and to shorten the vegetation cycle.

Table 1: Chemical composition of yacon accessions per 1 kg of root fresh matter (Hermann *et al.,* 1999).

Carbohydrate	Mean
Dry Matter (g)	115
Fructans (g)	62
Free glucose (g)	3.4
Free fructose (g)	8.5
Free sucrose (g)	14
Total carbohydrates (g)	106
Protein (g)	3.7
Fibre (g)	3.6
Fat (mg)	244
Ash (mg)	5.027
Calcium (mg)	87
Phosphorus (mg)	240
Potassium (mg)	2.282

1.3 Biodiversity

In spite of its clonal propagation yacon shows considerable morphological and physiological variation. The main variability in traits of the tuberous roots is found in Ecuador and in northern and southern Peru. Arbizu and Robles (1986) indicated that the major genetic diversity of yacon appears to be in the eastern Andean part between the Apurimac river basin (12 °S) in Peru and the La Paz river basin in Bolivia (17 °S). The variability in flesh colour is highest in southern Peru and northern Bolivia, where variants with white, cream, yellow and purple flesh can be found. There is less variability in

Ecuador, southern Bolivia and northwestern Argentina, from where only white and yellow clones have been reported.

However, it is difficult to distinguish the variants and to find adequate characteristics that identify a clone, because plants from a certain geographic range can have a form that reflects the environmental circumstances of the area where it is grown. These characteristics have a low heritability which can disappear when the variants grow in the same environment (Grau and Rea, 1997).

During the last decades the diversity of cultivated yacon has decreased due to genetic erosion during the last decades (Velasquez, 1996). According to the most recent survey, less than a million people in the Andes consumed or knew of yacon. Also, farmers prefer basic food crops like potato, wheat, barley, beans etc., which have substituted yacon in the farmers’ diet (Grau and Rea, 1997).

Nowadays, this trend seems to be changing, because of the interest in the medicinal qualities of the crop. Yacon has recently been introduced to other continents. For example, it is cultivated in several states of the USA, however without reaching yet a commercial production level. Experiments were carried out in Northern New Zealand, where the crop has reached the supermarkets as a specialty vegetable. In Japan, Brazil and Korea, yacon is cultivated commercially. In the Czech Republic and other Central European countries, attempts were made to establish yacon production, but this has largely failed due to the long winter season (Grau and Rea, 1997).

1.4 Yacon Gene Banks

In order to benefit from yacon on a large scale and to reach a reliable and secure supply, the plant’s biodiversity should be better exploited. Currently, the objectives of breeding programs and conservation of quality genetic material can not be achieved given the limited knowledge about wild and cultivated yacon variants. The marginal crop cultivation techniques of small holders have contributed to this problem.

Prior to 1980 no clear taxonomic key for yacon existed (Rea, 1998). Recently a network of institutions in Latin America began to collect and to systematically document yacon material in gene banks, based on a collaborating program of RTA (Raíces y Tuberculos Andinos), which was initiated in 1992. Holle and Talledo (2001) remarked that the implementation of a conservation system needs to classify the biological diversity which is available in the gene banks. This would require some knowledge about the heritability of traits, the identification of the parallel forms of each group of organisms and of duplicates, and the evaluation of the genetic variance of the species in order to conserve germplasm of each species variety as an evolutionary unit. In this context, the collections must be documented recording the location, the collector and already existing germplasm.

Currently, the following institutions are working on the conservation of RTA germplasm (Arbizu and Holle, 1997):

1. A collection of 32 yacon accessions, which are characterized morphologically and molecularly is managed by INIAP (Autonomous National Institute of Agricultural Research) in Pichincha, Ecuador (3,058 masl). The material is planted once a year, and duplicates are maintained *in vitro* at 5 °C. A major part of the accessions comes from the provinces of Cañar, Azuay and Loja in southern Ecuador.

2. In Bolivia, material from 30 accessions is held, also *in situ* (17 families), in the La Paz department. In Argentina, only minor collections of yacon exist.

3. In Peru, 417 accessions have been collected. However, a large number of those are duplicates (Arbizu and Holle, 1997).

   The collections of yacon material are held in:

   a) The los Baños del Inca research station of the National University of Cajamarca (UNC), Cajamarca, at 2,536 masl, This collection consists of 90 accessions and maintains the yacon variants of the northern departments of Peru.

   b) The International Potato Centre (CIP), which maintains a collection of 44 accessions in Lima (240 masl) and Mariscal Castilla (2,550 masl). Up to now, only 41 accessions have been characterized morphologically.

   c) The National Research and Technology Institute of Agriculture and Nutrition (INIA) holds 119 accessions in Cusco (3,392 masl).

d) The Regional Centre of Andean Biodiversity Research (CRIBA) at the Universidad Nacional de San Antonio Abad del Cusco (UNSAAC) manages 157 accessions from southern Peru in Ahuabamba, Cusco (2,100 masl), and has also initiated an *in situ* program at five localities.

e) One further collection in Ayacucho holds 7 accessions.

1.5 Information about Plant genetic Resources

1.5.1 Documentation of Gene Banks

Any information related to plant genetic resources increases the usefulness of the germplasm resources to regular and potential users. The availability of data describing the conserved germplasm helps administrators, curators and users in the monitoring of inventories and seed germination, as well as in the tracking and shipping of germplasm. The evaluation of the genetic diversity and selection of germplasm in the collections enhances their utilization, supports the future collecting and help to coordinate interactions between the collecting institutions (Perry, 1992).

1.5.2 Morphological Classification of Yacon

In spite of the claim of germplasm banks that morphological criteria for the differentiation of yacon types have been identified it is difficult to characterize the conserved plant material. The high variation in morphological features prevents the application of adequate descriptors like those in the officially accepted descriptor lists for other species, which are published by the IPGRI, for example the descriptors of oca (*Oxalis tuberosa*) (IPGRI and CIP, 2001).

Although field collections, conservation and evaluation of yacon clones exist, the gene banks and the *in situ* collections of yacon could not agree on homogene descriptors, and there likely exist many duplicates with different names.

In many studies yacon accessions were characterized by individual criteria and a different number of descriptors. In Cajamarca, Huaman (1991) carried out an experiment with 45 accessions to determine the relevance of 46 descriptors. In the trial of Taboada (1998) which was carried out in Cusco, 72 descriptors had been used to distinguish the clones. In Oxapampa Melgarejo (1999) chose seven descriptors to identify variants. In the study of Paz (1997) three types of yacon were differentiated by root colour and pigmentation in Bolivia. Franco and Rodriguez (1997) characterized 60 biotypes with twelve features. Meza and Cruz (1995) only used the root bark to group the accessions.

Given the unequal characterization of the yacon accessions among the gene banks, Holle and Talledo (2001) concluded that a homogeneity and standardization of descriptors would be needed for an efficient management of the collected accessions. This avoids duplicates and makes it possible to exchange information about the documented data between the institutions. Following this idea, Arbizu *et al.* (2001) proposed a list of 20 descriptors (Appendix A), which should be recognized by various Peruvian institutions as standard criterions to identify accessions of *S. sonchifolius*. However, until today the list is not completed and the reliability of some descriptors has not been confirmed.

Table 2: Potential traits for a morphological and physiological characterization of yacon clones (Seminario, 1995).

Morphological characteristics	Physiological characteristics
• erect and semi-erect plant type • internode length, stem colour • stem and leaf pubescence • number of flower heads • colour of flower heads • shape and tooth number of the corolla • root grouping • root shape • root skin colour • root flesh colour • number of tuberous roots per plant	○ flowering habit and duration ○ tuberous root yield and quality ○ dry matter content ○ oligofructan content ○ reducing sugar content ○ changes in sugar patterns during post-harvest period

1.5.3 Passport Data

The way of documenting and maintaining information about the germplasm differs from institution to institution, which makes any information exchange difficult. Due to the incomplete passport data, for persons except the curator an accession's origin often remains unclear. Hijmans (2002), for example, showed in a survey the necessity for complete passport data to determine relations between the agroecological conditions at the site of the original distribution and agronomic traits for potatoes. Also Hershey *et al.*

(1994) mentioned that the geographic origin is of a fundamental importance for the genetic diversity. The FAO (1996) gives several recommendations about the optimal conservation and utilization of germplasm and in the CGIAR centres a “System-wide Information Network on Genetic Resources” (SINGER) is under development.

1.5.4 Evaluation of agronomic Traits in Yacon

The evaluation of the variation in agronomic and consumer related traits is of most importance for the genetic improvement of a crop (Hershey, 1992). Melgarejo (1999) indicated different yield and soluble solid concentration for the tested accessions. Hermann *et al*. (1999) observed differences in the refractometric index and yield of the investigated accessions. Kuroda (1992) tested seven accessions in tissue culture and was able to select a line with a higher sugar concentration. Kuroda and Ishihara (1993) determined high sugar variability in yacon. Nuñez *et al*. (2001) selected three of ten accessions with a higher concentration of FOS.

1.6 Objectives of the Study

This study focuses on the establishment of classification criteria to structure the post-harvest diversity in storage roots of yacon. To use yacon on a larger scale and to reach a reliable and secure supply, advantage must be taken of the plant’s biodiversity and potential genetic resources.

In cooperation with CIP, UNC and CRIBA, which manage the main yacon gene banks in Peru, this study aims at presenting a classification scheme to improve the accessibility to the Peruvian germplasm and to foster the rapid and efficient exchange of information and a uniform way of documentation. In the long run, the appearance of duplicates in the gene banks should diminish and a quick and uncomplicated updating of the accession specific information should be possible.

In order provide a quick and precise overview about the post-harvest characteristics in the germplasm, the fresh-matter yield and specific yield formation properties, refractometric index (RI) and morphological characteristics of the storage roots, grown at the sites of the respective gene banks, were evaluated and entered into a central database. To avoid post-harvest compositional changes in the roots and to conserve the unspoiled appearance of the roots, the analyses were carried out at the gene banks immediately after harvest.

2 MATERIAL AND METHODS

2.1 Origin and Identification of the Yacon Germplasm

The field work was carried out during the harvest time of 2002 at the germplasm collections of International Potato Centre (CIP) in Mariscal Castilla, Regional Centre of Andean Biodiversity Research (CRIBA) in Ahuabamba and National University of Cajamarca (UNC) in Cajamarca, where the yacon accessions were maintained *ex situ* (Fig. 2 and Tab. 3).

To properly characterise the accessions, the passport data that were obtained from the germplasm banks were compiled, checked, corrected and joined together into a central database (Appendix E). The database terms were selected according to the guidelines of the Singer Data Dictionary (http://singer.cgiar.org), FAO and IPGRI (2001) and additional suggestions of CIP. Whenever needed, the coordinates of the accessions were corrected. At CRIBA, for example, coordinates were not available. Geographic data were calculated and compiled by using DIVA-GIS software (Hijmans, R. *et* al, 2002) and maps on the scale of 1:100,000 from the National Geographic Institute (ING), Lima - Peru.

Generally, the yacon germplasm was grown in plots of more or less 1ha without any additional application of fertilizer. The arrangement of the yacon plants in the field was not repeated, that is each accession was planted in one single plot only.

At CIP 34 accessions were used for analysis. Three seven month old plants of each accession were analyzed. At CRIBA 80 accessions were harvested after a vegetation period of eight months. Three plants of each accession were available. At UNC about 88 accessions were maintained. Here four plants per accession of an average age of 2.5 years were analyzed. The harvest took place without machinery but with special spades called “Chaquitaclla”, which are generally used by the local farmers to avoid damage on the storage roots.

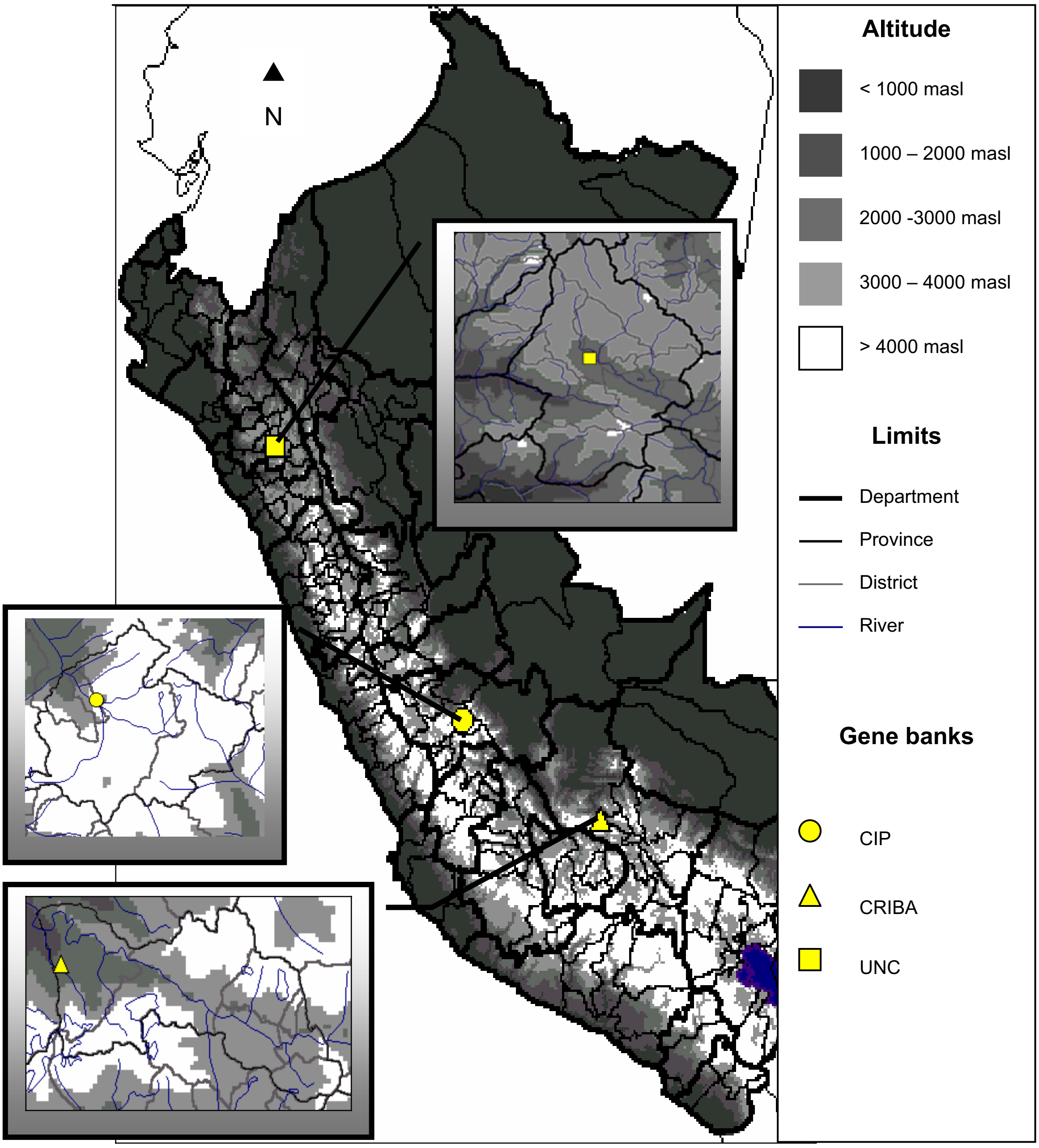

Figure 2: Map of Peru with the location of the gene banks of International Potato Centre (CIP), Regional Centre of Andean Biodiversity Research (CRIBA) and National University of Cajamarca (UNC).

2.2 Analyzed Parameters

2.2.1 Fresh Weight (FW) and Number of Storage Roots

Immediately after harvest, the roots were cleaned, weighed and subdivided into five weight categories >60 g, 60-<100 g, 100-<150 g, 150-<200 g and ≥200 g. Per accession, the mean average of all the weights was considered and the mean average of the quantity of storage roots were determined within each weight class with the aim to establish a distribution of weight and frequency, thereby revealing the specific yield formation properties of each accession (Fig. 3).

Table 3: Location and description of the three gene banks of International Potato Centre (CIP), Regional Centre of Andean Biodiversity Research (CRIBA) and National University of Cajamarca (UNC). (For the data of precipitation and Temperature during the year 2000 look at Appendix B)

Germplasm bank	**CIP**	**CRIBA**	**UNC**
State	Junin	Cusco	Cajamarca
Province	Concepcion	Urubamba	Cajamarca
District	Mariscal Castilla	Machu Picchu	Los Baños del Inca
Locality	Mariscal Castilla	Ahuabamba	Universidad
Longitude	-75.084	-72.552	-78.5
Latitude	-11.601	-13.201	-7.166
Altitude (m)	2,550	2,100	2,536
Annual Temperature Average (C°)	15*1)	18*3)	15*4)
Annual Precipitation (mm)	1,039*1	1,200*3)	551*4)
Relative Humidity (%)	92*1)	60*3)	70*4)
Soil texture	Clayey loam*2)	Loam*3)	Clayey loam*5)
pH (in H_2O)	4.3*2)	4.2*3)	7*5)
Number of Accessions	34	80	88

*1) Source from the CIP, Lima (2000); *2) Source from the laboratory of analisis for soil, plant, water and fertilizer, National University Agraria La Molina (UNALM), Lima (2001); *3) Source from L. Lizarraga (pers. comm., 2002), CRIBA, Ahuabamba; *4) Source from the meteorological station A. Weberbauer, UNC-Senamhi, 2000; *5) Source from the soil laboratory of the UNC, Cajamarca (2000);

2.2.2 Refractometric Index in Storage Roots

The refractometric index of the storage roots (RI) was measured with a portable refractometer (Brix scale 0-32 %) immediately after harvest, to determine the natural concentration of soluble solids in the roots. Typically the RI is a measure of soluble solids and is highly correlated with the sugar concentration and sweetness of yacon (Hermann, 1999 and Graefe, 2002). Following recommendations on sampling yacon root sap for RI determination made by Ynouye (unpublished data, 2002), a slice of 1 cm thickness was transversally cut out of each root's central part. The slice was squeezed out and a drop of root sap was transferred to the refractometer to measure the sugar concentration. For the analysis seven roots per plant were used and roots from all weight classes were taken to determine the relation between RI and weight class. However, existing number of plants per accession in the germplasm banks seemed insufficient thereafter, in order to obtain trustworthy statements about representative RI values per accession.

2.2.3 Colouring of the Root Stock and the Root Flesh

The colour of the root stock was determined according to the descriptor list, proposed by Arbizu *et al.,* 2001) (Appendix A).The colour of the root flesh was determined at the moment of cutting the roots to measure the RI. The flesh colour was compared according to the colour chart from the Royal Horticultural Society, London (1995). Four main colour groups were identified. The orange group was represented by orange colour types, according to the plates 24 (B - D) and 25 (D). The white group was represented by white (plate 155), greyed white (plate 156) and green white types (plate 157). The intermediate stage of the orange and white types was called cream group with colour variations among the yellow white (plate 158) and orange white (plate 159) levels. In some accessions, secondary purple pigmentation deposits were observed, whereby a difference was made between the different kinds of pigment distribution within the flesh (Fig. 4).

2.2.4 Morphological Characteristics of the Storage Roots

To analyse the specific morphological features of each accession, representative roots and a part of the root stock were documented photographically (Appendix G).
Subsequently the accessions were categorized systematically by parameters to evaluate the post-harvest handling, such as yield uniformity, peeling aptitude, length-width-relation, predominant root-type-pattern and surface structure type of the root.
According to the variation size in root weight and in the length-width relation of the roots, the yield uniformity of an accession was indicated by high variation or low variation in the yield (Appendix E). The peeling aptitude is an important qualitative trait to determine the suitability for processing procedures. Accessions with irregular formed roots were considered as unsuitable and showed a good aptitude if the roots were regular formed.

According to their length-width relation the roots were classified into elongated or shortened roots (Fig. 5). If a root with a ridged surface structure was found in the accession, it was noted as ridged, or if not, as smooth (Fig. 6). To determine the predominant root type pattern of an accession, seven root types were established (Fig. 7 and Tab. 4), the roots being differentiated by strict features accordingly.

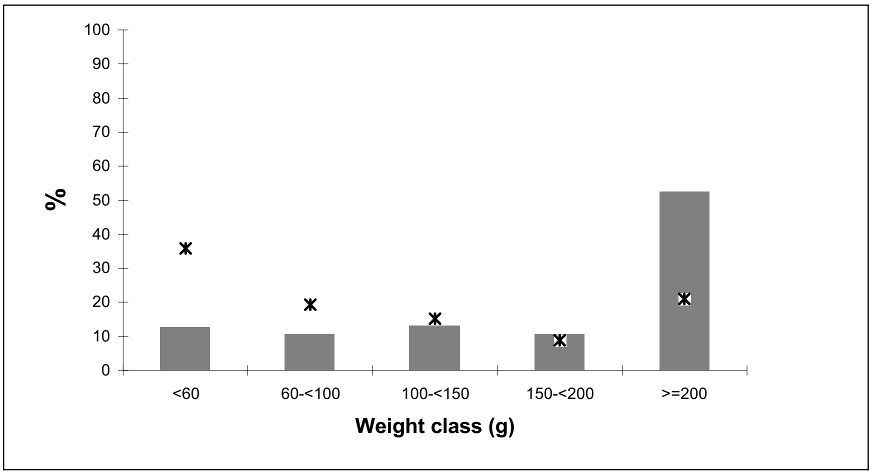

Figure 3: Weight distribution of roots per weight class and plant (bars) and frequency distribution of the number of roots per weight class and plant (asterisks) for about 200 accession exemplifying types of profiles. (see Appendix F for all accessions).

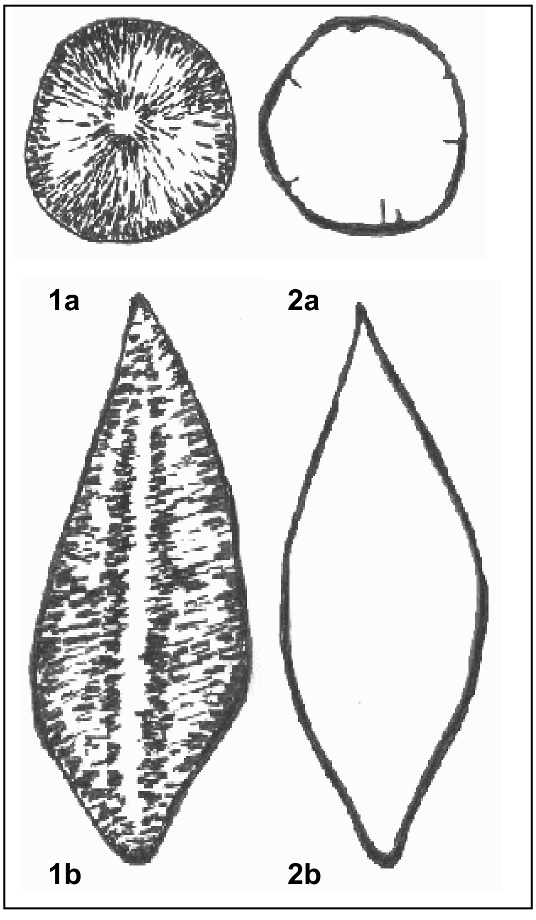

Figure 4: Secondary pigmentation in yacon storage roots. 1a = cross section of a root with radially distributed secondary pigmentation; 1b = longitudinal section of a root with radially distributed secondary pigmentation; 2a = cross section of a root with marginally distributed secondary pigmentation; 2b = longitudinal section of a root with marginally distributed secondary pigmentation.

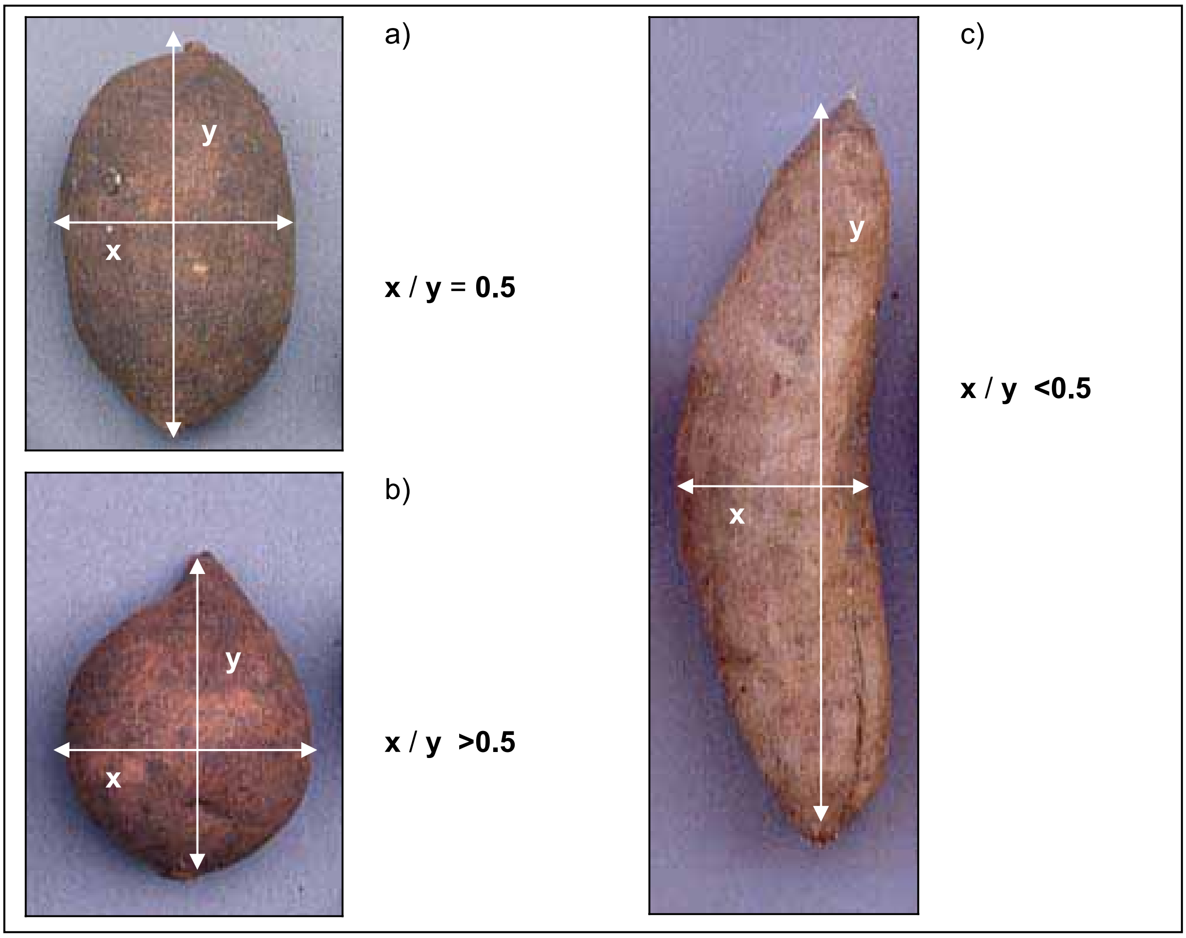

Figure 5: Relation between width and length of yacon storage roots. To determine if a root was elongated or shortened, the maximal transverse axis (x) was divided by the maximal longitudinal axis (y). At a ratio of 0.5 (a) or >0.5 (b) the root was considered as “shortened”. At a ratio of <0.5 (c) the root was considered as “elongated”.

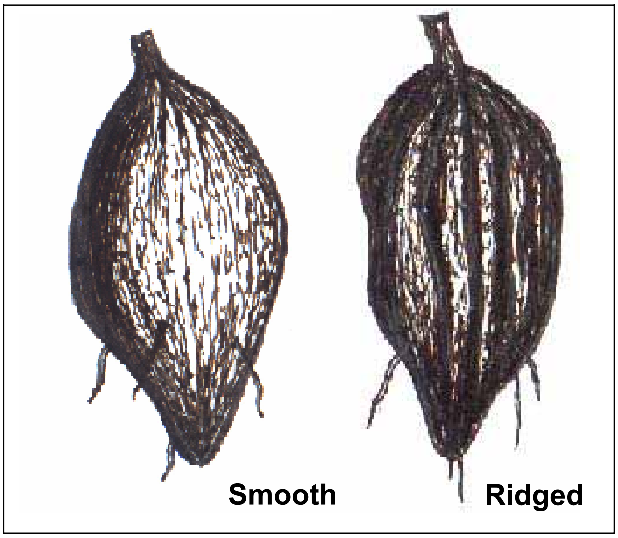

Figure 6: Types of surface structure of yacon storage roots.

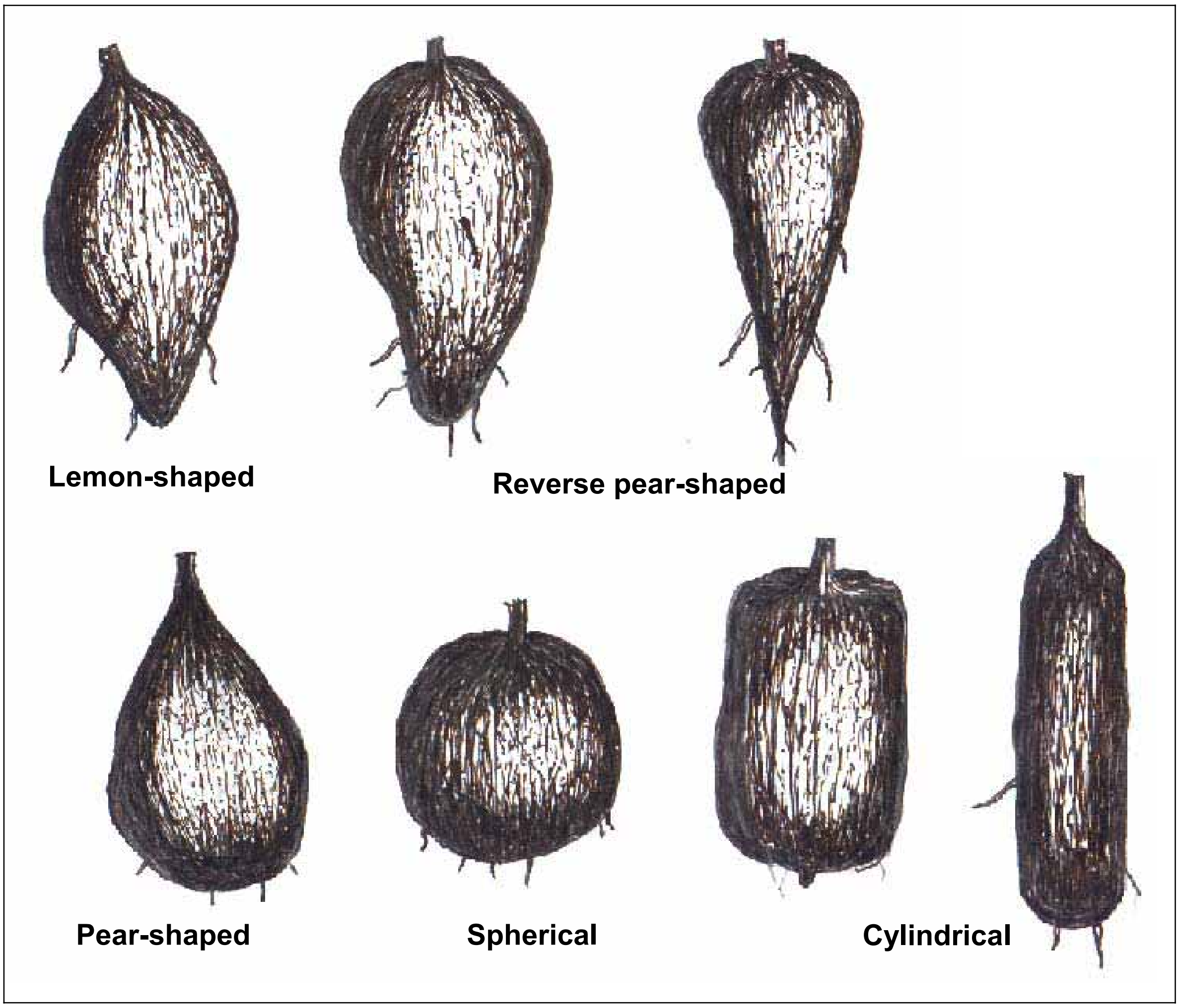

Figure 7: Principal storage root types of yacon.

Table 4: Description and codification of the root types in Fig. 7.

Shape type	**Lemon**	**Reverse pear**	**Pear**	**Spherical**	**Cylindrical**
Description	Narrows from the central part to both ends.	The main root part is in the upper part. The lower end finishes truncated or like an acute cone.	Opposite of reverse pear shaped, however, the upper part finishes pointed or truncated.	Formed like a ball, the axes of width and longitude are nearly equal.	Shaped like a cylinder. The ends can be truncated or pointed.

2.3 Data Processing and Analysis

To visualize the variation in yield, root number and RI, the standard deviation (STD of the means) are indicated. Within the accessions the variation in the RI was particularly high, therefore, it was decided to additionally present the lower (LCL) and upper confidence limits (UCL) of the means (Appendix E).

The range of the five weight classes was chosen subjectively to record the distribution of the major yield part in an adequately resolved yield profile. In order to determine if that was a relation between RI and the root weight, a correlation of RI on weight class was calculated.

Because various root types within an accession appeared frequently, only the predominant root types were considered for the individual root shape pattern. In accessions with the appearance of both elongated and shortened roots ,the mean of the length-width ratio (Fig. 5) of all roots was a decisive factor for a classification into an elongated or shortened shape type.

2.3.1 Yield Uniformity

The uniformity expresses the variation of shapes (elongated, shortened) and individual root weight within the yield of an accession. The smaller the value of uniformity the greater the homogeneity in yield. For classification, accessions with an uniformity smaller than 10 % were considered as uniform (Appendix C and E).

$$U = CV1 \times CV2 / 100$$

where

U = Uniformity

CV1 = coefficient of variation for length-width relation

CV2 = coefficient of variation for individual root weight of roots that weighed more than60g.

2.3.2 Yield Index

Important parameters in assessing the yield profile of an accession are per plant

1) amount of yield per weight class

2) number of root per weight class.

Naturally, these two numbers are correlated. Since it is cumbersome to compare multiple numbers among accessions, a yield index (YI) was calculated based on the assumption that larger roots are of greater interest in practice:

$$\mathbf{YI} = 0.01 \times W1 + 0.02 \times W2 + 0.03 \times W3 + 0.04 \times W4 + 0.05 \times W5$$

where

YI = yield index

W1 = the percentage of the root number per accession of a given plant that was composed of roots that weighed less than 60 g.

W2 = the percentage of the root number per accession of a given plant that was composed of roots that weighed between 60 g and less than 100 g.

W3 = the percentage of the root number per accession of a given plant that was composed of roots that weighed between 100 g and less than 150 g.

W4 = the percentage of the root number per accession of a given plant that was composed of roots that weighed between 150 g and less than 200 g.

W5 = the percentage of the root number per accession of a given plant that was composed of roots that weighed ≥200 g.

To rank the importance on YI, scores from 0.01 to 0.05 were assigned to the weight classes. The greater the YI of an accession, the larger the portion of roots in desirable weight classes.

2.3.3 Codification of the Parameters

To make the data accessible, codes were assigned to the analyzed parameters and entered into the central database (Appendix E).

Yield uniformity:
0 = high variation
1 = low variation

Peeling aptitude:
0 = bad
1 = good

Shape:
1 = shortened
2 = elongated

Root surface structure:
0 = smooth
1 = ridged

Predominant root type pattern:
1 = lemon shaped
2 = reverse pear shaped
3 = pear shaped
4 = spherical
5 = cylindrical

Colour of the root flesh:
1 = white
2 = cream
3 = yellow

Distribution of the secondary pigmentation:
0 = without
1 = radial
2 = marginal

Colour of the root stock:
1 = white
2 = white with red-purple
3 = red-purple

3 RESULTS

3.1 Yield

3.1.1 Fresh Weight of the Storage Roots

The fresh weight (FW) of the roots varied strongly among the accessions, yielding from zero to almost 17 kg per plant. Differences between the accessions were large. The CVs indicated a fluctuation of up to 80 % for the average FW, which was 3.3 kg per plant (Tab. 5). A number of high yielding accessions were found, in which a FW more than 8 kg per plant was obtained, but other accessions did not even yield 1 kg per plant (Appendix E). Particularly high yields were obtained for the accessions Y-065, Y-031, Y-104 and Y-067 (about 5 kg FW more than the total average of the FW) at the genebank of CRIBA, where the highest variability in yield was found (Fig. 8).

Table 5: Average FW and number of storage roots from different germplasm banks in Peru used for this study.

	FW (kg) per plant		**Number per plant**	
*Germplasm bank**	*Mean*	*STD*	*Mean*	*STD*
CIP	2.43	1.25	15	6
CRIBA	4.87	3.74	21	13
UNC	2.19	1.48	12	7
Mean	3.29	2.80	16	9

*CIP = International Potato Centre, Mariscal Castilla; CRIBA = Regional Centre of Andean Biodiversity Research, Ahuabamba; UNC = National University of Cajamarca, Cajamarca

3.1.2 Storage Root Number

The number of storage roots per plant varied between 1 and 43, in the accessions Y-068, Y-065, respectively (accessions without roots are not considered) (Fig.9). In general, the variability in root number was high at all genebanks, however in the genebank at CIP no accession yielded less than 10 roots per plant (Appendix E). The accessions at CRIBA showed the highest mean average root number per plant, but also the largest fluctuation in root number was found (Tab.5).

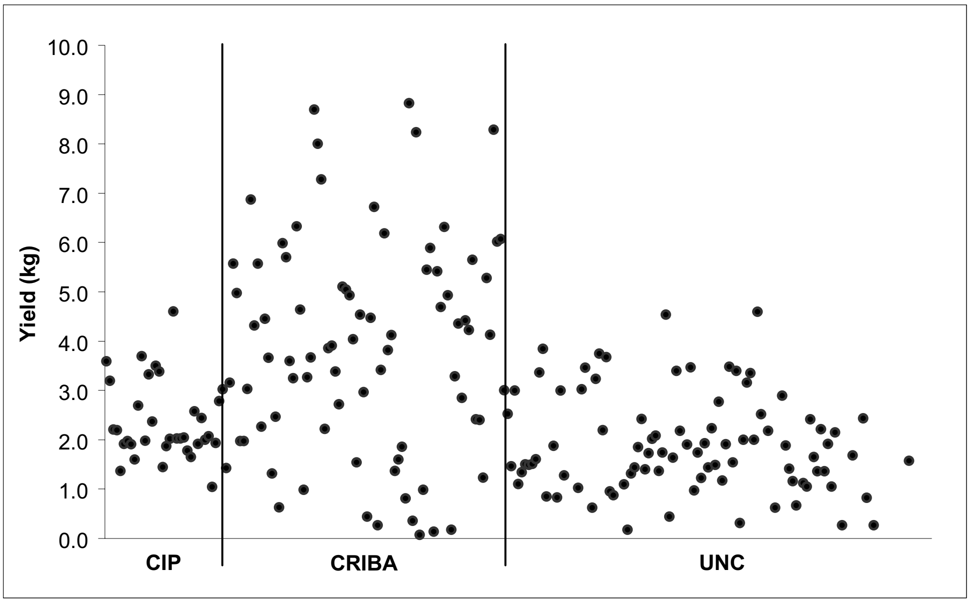

Figure 8: Yield means per plant of the accessions at the gene banks (2002). CIP = International Potato Centre, Mariscal Castilla; CRIBA = Regional Centre of Andean Biodiversity Research, Ahuabamba; UNC = National University of Cajamarca, Cajamarca.

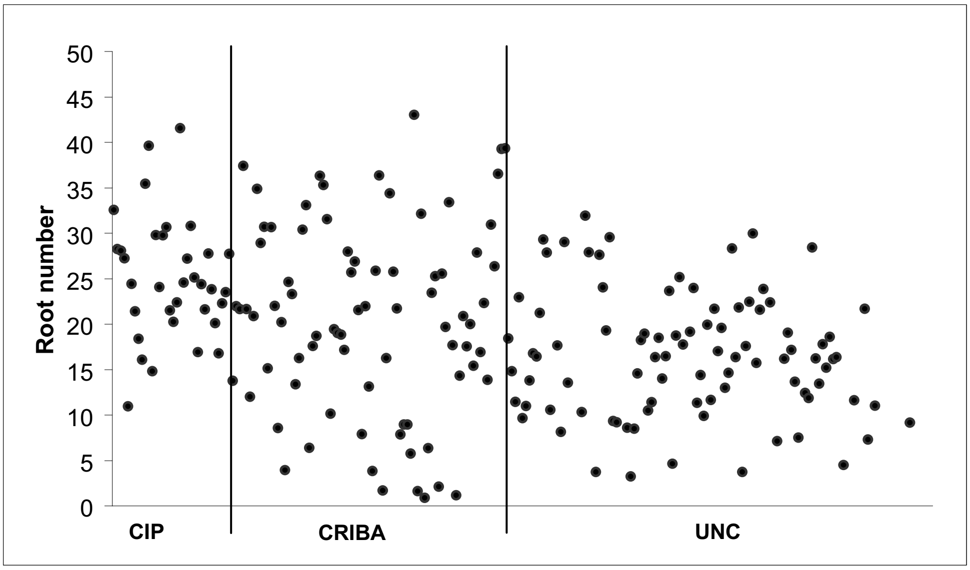

Figure 9: Root number means per plant of the accessions at the gene banks (2002). CIP = International Potato Centre, Mariscal Castilla; CRIBA = Regional Centre of Andean Biodiversity Research, Ahuabamba; UNC = National University of Cajamarca, Cajamarca.

3.1.3 Distribution of the Root Weight and Frequency

In general the main part of the yield was due to roots in the weight class ≥200 g. 45 % of the harvested roots had a root weight of ≥100 g. The frequency of roots per weight class decreased continuously with an increasing yield, however the number of roots in the weight class ≥200 g was as high as in the weight class 60-<100 g. The yield profiles of the accessions with extremes in FW and root number were very different. High yielding accessions such as CLLUNC-072 and Y–065 had a similar profile with the highest share in roots ≥200 g and a smaller amount of roots that weighed less than 60 g. In the accessions with poor yields, the root frequency distribution was shifted towards the lower weight classes. Exceptions were the accessions CYDPA-07011, CLLUNC-035 and CLLUNC-099, for which no roots appeared in the class ≥150 g.

The mean distribution of root weight and frequency differed between the gene banks. At CRIBA nearly 90 % and at UNC more than 65 % of the weight was determined in the weight classes ≥100 g, while at CIP the share of weight amounted 55 %.

At CIP and UNC around less than 40 % of the roots had a root weight ≥100 g, which was different to the distribution of the frequency at CRIBA, where 60 % weighed more than 100 g (Appendix F).

3.1.4 Yield Index

The mean YI amounted 2.6 and had a STD of 0.6, which indicates, that in relation to the variability of absolute root numbers, a moderate variation within the accessions was found. The highest mean average YI with an amount of 3.0 was found at the gene bank of CRIBA and the lowest at CIP, where the YI amounted 2.1 (Appendix E). Overall the percentage of the roots in larger weight classes was higher at CRIBA than at CIP (Appendix F).

3.2 Refractometric Index in Storage Roots

The variation of RI among the roots was high, as the CV amounted to 40%. Minimum and maximum RI extremes were 13 °Brix (Appendix E). Most measurements were between 6.6 and 12 °Brix. In 50 % of all accessions the RI was found in the range of 7.1 – 11.7 °Brix. Lower soluble solid concentrations were found in 30 % and higher concentrations in 20 % of all accessions. In the genebank at CIP the highest mean average RI was presented. At CRIBA the mean of RI was in many accessions less than the mean of the accessions at all genebanks together (Tab. 6). Outlying RI values were obtained for Y-095, Y093 and Y096, in which RI was about 17 °Brix (Fig.10 and Appendix E).

Table 6: Average soluble solids concentration in storage roots from different germplasm banks in Peru.

	RI (°BRIX)	
*Germplasm bank**	*Mean*	*STD*
CIP	12.3	2.8
CRIBA	7.1	3.2
UNC	9.8	3.4
Mean	9.3	3.7

*CIP = International Potato Centre, Mariscal Castilla; CRIBA = Regional Centre of Andean Biodiversity Research, Ahuabamba; UNC = National University of Cajamarca, Cajamarca.

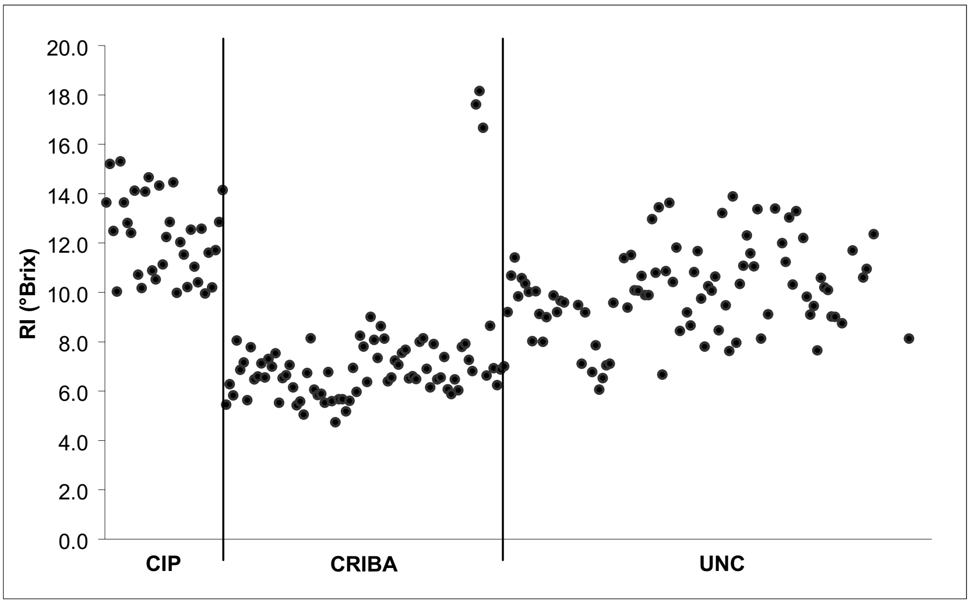

Figure 10: RI means (°Brix) of the accessions at the gene banks (2002). CIP = International Potato Centre, Mariscal Castilla; CRIBA = Regional Centre of Andean Biodiversity Research, Ahuabamba; UNC = National University of Cajamarca, Cajamarca.

3.3 Influence of Weight on the RI in the Storage Roots

A slight correlation between weight class and °Brix was found. The highest average RI was found in roots that weighed between 60 g and less than 100 g (10.1 ° Brix) and the lowest (8.5 °Brix) in the weight class ≥200 g FW (Tab. 7).

Table 7: Average RI (°Brix) in storage roots of different weight classes.

	RI (°Brix)			
Weight class (g)	*Mean*	*STD*	*LCL 0.95**	*UCL 0.95**
≥200	8.5	3.18	8.2	8.7
150 - <200	8.8	3.48	8.5	9.1
100 - <150	9.6	3.76	9.3	9.8
60 - <100	10.1	3.92	9.8	10.3
<60	9.4	3.90	9.1	9.8

*LCL 0.95= Lower confidence limit at 95 % probability; UCL 0.95= Upper confidence limit at 95 % probability.

3.4 Phenotypic Characteristics of Storage Roots

Within the accessions the parameters varied strongly and could not always be used as an adequate characterization to describe the clone. However, some accessions manifested uniform appearances in storage roots, which were regarded as representative (Fig. 11).

3.4.1 Colouring of Root Stock and Roots

The root stock colour was white in 15 %, white with red-purple in 30 % and red-purple in 55 % of all accessions.

About 36 % of all accessions had a yellow, 40 % a cream and 24 % a white coloured root flesh. About 4 % of the roots, which were all from the germplasm bank at CRIBA, showed a secondary purple pigmentation. In some accessions fluctuations within the roots occurred between orange / cream and cream / white, that a clear differentiation into more precise colour gradates was difficult. The secondary purple pigmentation and its distribution, on the other hand, were considered as very constant (Fig. 12).

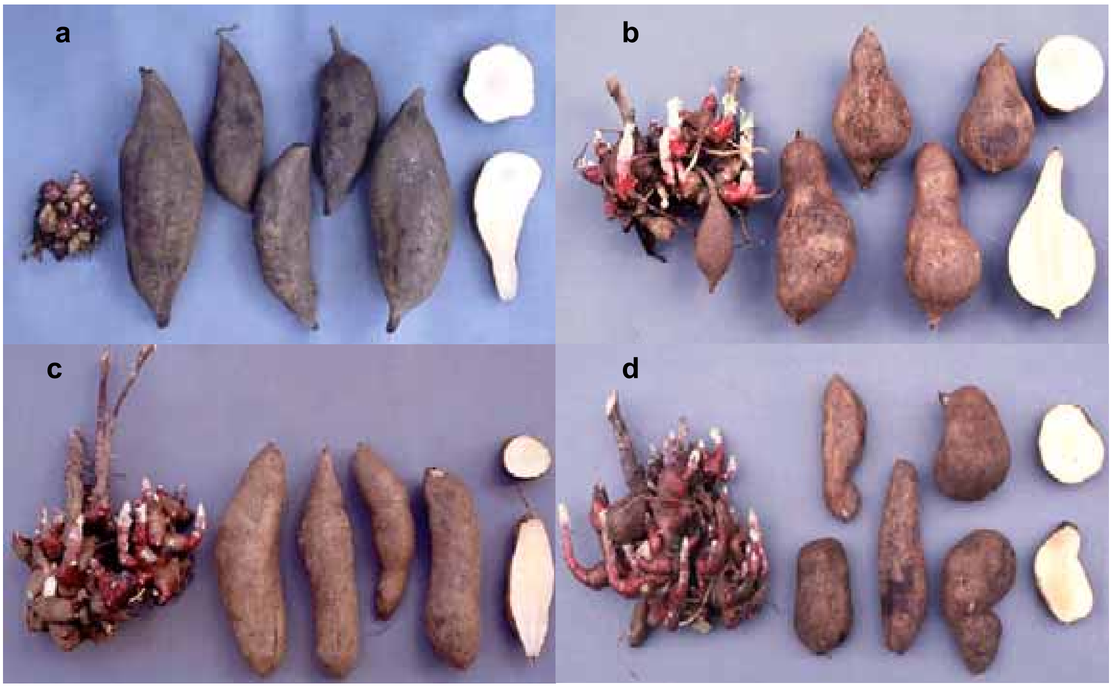

Figure 11: Accessions with high characteristic root type pattern. a) In Y-089 (CRIBA, 2002) the roots were predominately lemon-shaped and elongated. b) Shortened pear-shaped roots were characteristic for CLLUNC-031 (UNC, 2002). c) The roots of CLLUNC-022 (UNC, 2002) were elongated cylindrical. d) In CLLUNC-086 (UNC, 2002) the roots were variable in shape.

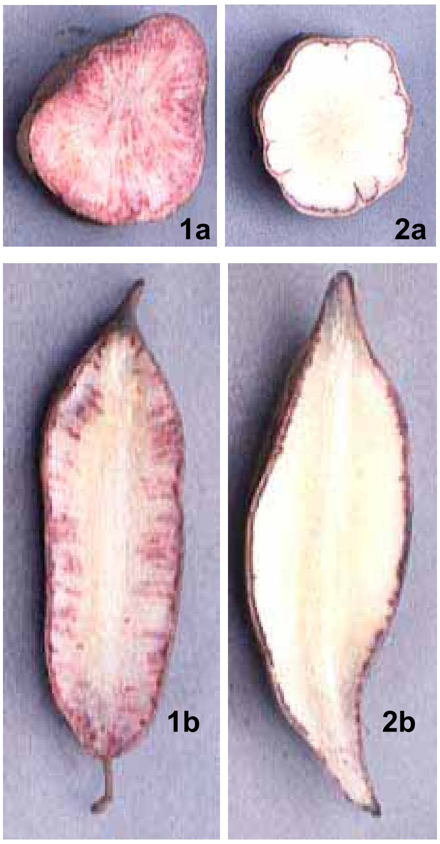

Figure 12: Secondary pigmentation in yacon storage roots. 1a = cross section of root with a radially distributed secondary pigmentation; 1b = longitudinal section of root with a radially distributed secondary pigmentation; 2a = cross section of root with a marginally distributed secondary pigmentation; 2b = longitudinal section of root with a marginally distributed secondary pigmentation.

3.4.2 Morphological Diversity in Storage Root Yield

In the majority of the accessions the root yield was very heterogeneous. Elongated as well as shortened storage roots were found almost in every accession. The length-width relation fluctuated on an average of 40 % and the individual root weight about 80 % in the accessions. In the gene bank at CIP 97 % of the accessions tended to elongated roots, while at CRIBA around 70 % presented predominantly shortened roots. At UNC in 55 % mainly shortened and in 45 % mainly elongated roots were found (Appendix E).

A number of accessions, however, had a more regular root yield pattern. The CV for weight in CLLUNC108, Y-93, Y-95 and Y-96 indicated a large variation; however, elongated roots predominated clearly in the root shape. In these accessions underdeveloped propagules seemed to be typical. There were other accessions with characteristic root types. In the accession CLLUNC-031 For example, the pear-shaped root type dominated, in CLLUNC-022 cylindrical root types predominated and in Y-089 lemon-shaped root types were mainly found (Fig. 11 and Appendix G).

A ridged root surface structure was observed in only 5 % of the accessions and concerned only scattered roots in the accession.

3.5 Duplicates of Accessions in the Germplasm Banks

Many accessions have been duplicated between the genebanks of CIP and UNC (C. Arbizu, CIP-Lima, 2002, pers. comm.). Based on the similar sites of origin and passport data it is likely that twelve CIP accessions were duplicated (Appendix D). However, the characteristics of the putative duplicates were not always very similar.

3.5.1 Refractometric Index and Root Yield

The RI varied strongly between duplicated accessions. P-1385 and CLLUNC-086, which are two genebank accessions representing the same clone, showed at CIP and at UNC relatively high RI values. Also the weight varied strongly between duplicated accessions; however, some accessions had relatively low yields at both genebanks, for example AMM-5150 and CLLUNC-084, AME-5186 and CLLUNC-083.

3.5.2 Phenotypic Characteristics of Storage Roots

A visual comparison of the storage roots allowed recognizing similar traits within the same accessions, which were grown at different sites (Fig. 13). Both AMM-5129 and CLLUNC-091 had reverse pear-shaped root types in conjunction with a bad peeling aptitude. P-1385 and CLLUNC-086 were also similar in the occurrence of cylindrical roots and a bad peeling aptitude, while AME-5186 and CLLUNC-083 were very heterogeneous similarly also and cylindrical, lemon- and reverse pear-shaped root types appeared predominantly. AKW-5075 and CLLUNC-087 seemed to be similar. The roots had a good peeling aptitude and the same root types appeared. Exceptionally in ACW-5076 and CLLUNC-090 as well as in ARB-5124, ARB 5125, CLLUNC-089 and CLLUNC-094, the colour of the root stock were similar in all duplicate pairs. The colour of the root flesh did not vary considerably within the duplicates.

The similarity of the YI of some accession duplicates was indicator for the related yield profile. Almost no deviation of the YI was determined in ACW-5076 and CLLUNC-090, AJC-5189 and CLLUNC-096, AKW-5075 and CLLUNC-087, AME-5186 and CLLUNC-083, AMM-5129 and CLLUNC-091, ARB-5027 and CLLUNC-082. With a view of the yield profiles, the repeated conspicuous distributions of weight and frequency became more concrete.

In AMM-5129 and CLLUNC-091, the slight differences appeared in the weight class ≥200, in which the weight increased in CLLUNC-091 by 10 %. The proportion of weight and frequency in the other three weight classes were relatively stable. In spite of slight differences among the yield profile of AME-5186 and CLLUNC-083 the emphasis of root frequency and weight was established in the lower weight classes (less than 150 g) by around 75 % of the total yield. In ARB-5027 and CLLUNC-082 nearly similar profiles resulted. The weight and frequency proportions decreased continuously with an increasing weight class (Fig. 14).

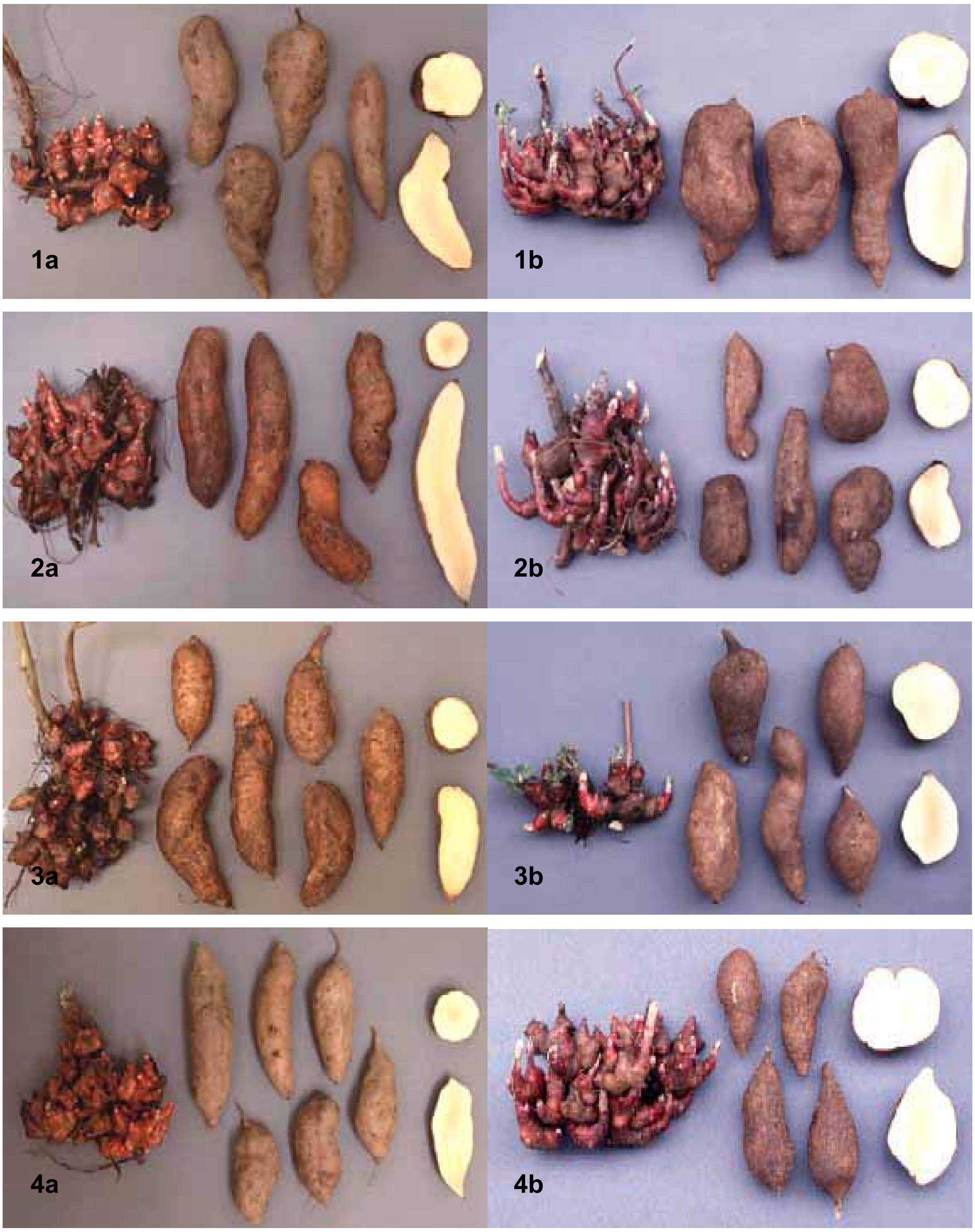

Figure 13: Accessions with similar traits in storage roots. (duplicates are indicated by the same number). 1a) AMM-5129 (CIP, 2002); 1b) CLLUNC-091 (UNC, 2002); 2a) P-1385 (CIP, 2002); 2b) CLLUNC-086 (UNC, 2002); 3a) AME-5186 (CIP, 2002); 3b) CLLUNC-083 (UNC, 2002); 4a) AKW-5075 (CIP, 2002); 4b) CLLUNC-087 (UNC, 2002).

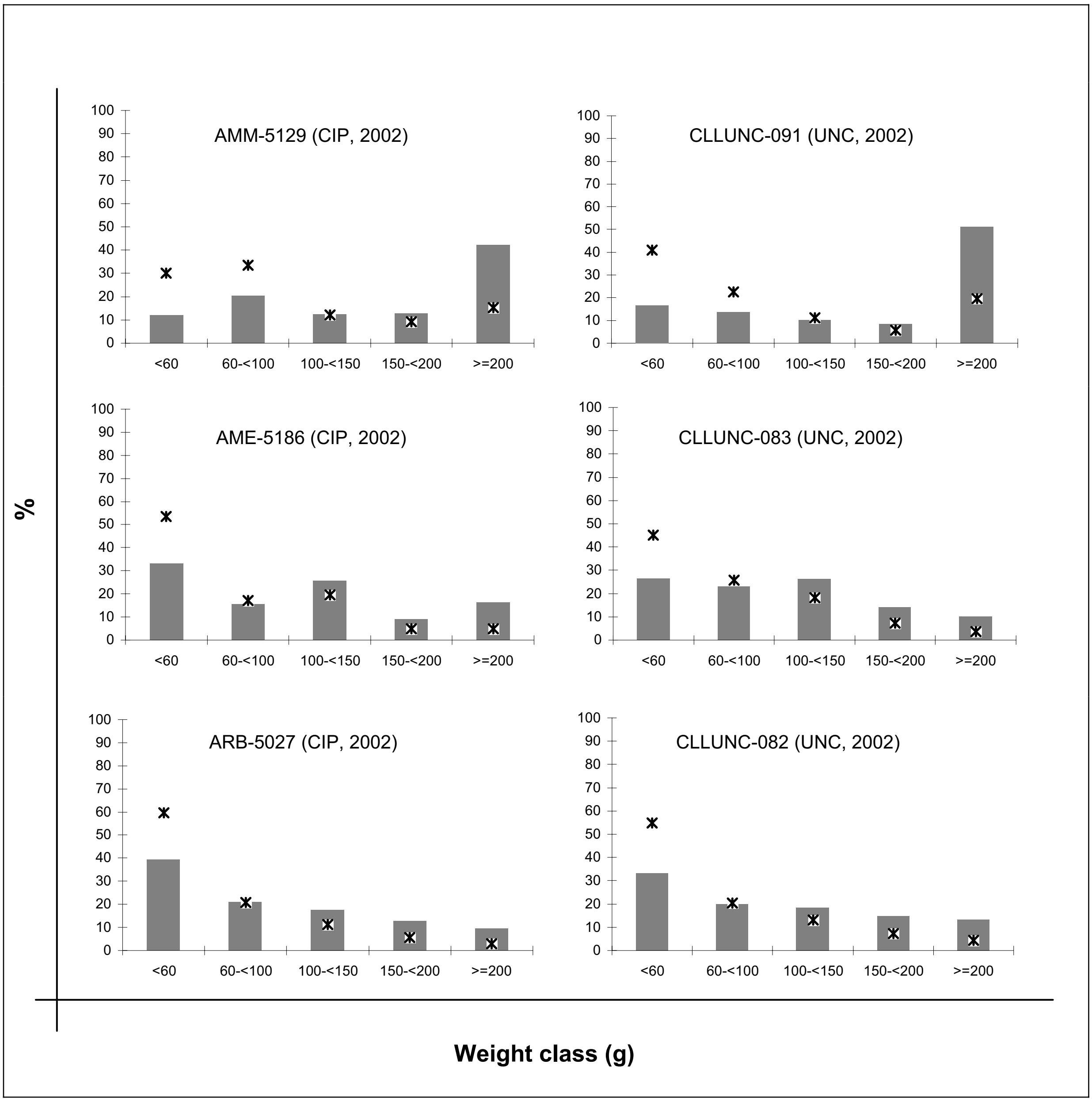

Figure 14: Yield profiles of duplicated yacon accessions. The mean root weight and the absolute number of root in each weight class per plant were transformed to relative values. The root weight is depicted in bars and the root number is presented as asterisks.

4 DISCUSSION

4.1 Reliability of Post-Harvest Characteristics

The morphological traits of the subterranean parts differed in some specimen evidently from others and perhaps could be considered as genetically determined. Within the duplicates, traits such as root type pattern, distribution of weight and frequency and colour of root stock showed to be relatively constant, while the others seemed to be influenced largely by exterior factors such as climate and agricultural management. The colour of the root flesh varied changed slightly within the roots of an accession. Therefore, it is referred to by a range of shades within the colour type.

Due to the lack of repetitions at the same site, the relevance of the traits could not be determined completely. Prior to this study, little was known about the ambient circumstances, the accession specific information and the condition of the germplasm in the gene banks. Even the accessions were not cultivated to produce a maximum output but to conserve gene material. In this context, the results obtained in this study can only partly assess the economic potential of an accession. Additionally it has been tested that many agronomic traits are too genetically complex to be screened for in the preliminary characterization (FAO, 1996). The complete extent of genetic variation within the genebanks could not be fully determined by only referring to the subterranean parts. Villavicencio (2002) determined a large genetic variance within 19 different groups among 31 yacon clones; when characteristics of above ground parts were included in the classification.

4.1.1 Influence of environmental Factors on Post-Harvest Traits

Due to the lack of exact information about climate and agroecology it could not be determined if the large variation of the agronomic traits within the genebank is affected by the different origins of the accessions. Due to the highly diverse microclimate in the Andean region, reconstructions about the conditions at the site of origin by interpolation of officially available data could not be carried out. Hijmans (2002) referred to the problem of low resolution of interpolated climate data. To relate climate and post-harvest characteristics it is essential to document information about the climatic and environmental conditions of the site of origin, for example like it is suggested in the descriptors of oca (*Oxalis tuberosa* Mol.) from IPGRI and CIP (2001). Further, for collecting expeditions in the future a spatially unbiased statistical sampling procedure must be used to collect a representative sample of yacon in Peru.

4.2 Physiological Traits

4.2.1 Refractometric Index

Due to the scarce gene material available for this study no statistical analysis could be carried out.

According to Graefe (2002), the genotypic variability of RI was higher within than between the accessions. The environmental interactions might have caused the variability in RI among the duplicated accessions at the two genebanks of CIP and UNC. Therefore, a direct comparison of the RIs grown at different sites could not be carried out, and the RI could not be used as a precise descriptor to differentiate accessions. Nevertheless, by comparing accessions grown under the same environmental circumstances some accessions have clearly distinct RIs. In other studies the same accessions showed prominent results in RI. Nuñez *et al*. (2001) reported that ARB-5125 had a high content of FOS, which is, immediately after harvest, highly correlated to the RI (Hermann *et al.,* 1999 and Graefe, 2002). Melgarejo (1999) reported higher RIs in accession ASL-136 and lower RIs in ARB-5185. Also in the study of Hermann *et al*. (1999) ASL-136 showed higher RIs.

Because of the great fluctuation also between roots of the same plant, it is obvious that the RI is not only affected by environmental factors. During the survey, it was observed that extreme low RIs were measured in older roots, probably due to the advanced decomposition process of the stored carbohydrates. Nieto (1991) observed that in some accessions the process of maturation was more advanced than in others. It seemed to be that the accession specific RI is affected by the speed and uniformity of which maturation is reached. While it was intended to analyze only equally conditioned roots, it was difficult to determine root only by visual selection.

Neither the root colour nor the root weight is a considerable factor for the variation in RI, however, a slight relation between weight class and RI could be observed. In this context it must be pointed to the high STD of the RI means in the weight classes.

4.2.2 Yield

Like the RIs the yield per plant fluctuated considerably within the accessions as well as between the duplicated accessions at different sites. The high variation between the duplicates can be due to the different micro climatic occurrences and soil conditions, the different age of the cultivar and different agricultural management. Within the 2.5 year old accessions in Cajamarca for example, many decomposed roots were found, while in Mariscal Castilla the condition of the roots was much better. Therefore it could not be proved if the high variation in yield within and between different accessions is determined genetically. To determine the heritability in yield, the accessions should be grown under similar environmental conditions and a monitoring over several harvest times is needed.

Similar to the RI, by comparison of the accessions within the same site some duplicates resulted in Mariscal Castilla and in Cajamarca as low yielding accessions. Melgarejo (1999) obtained high yields and root number by the accession P-1385, which came out in this study similarly with relatively high results. For the accession ASL-136, which reached the highest yield per plant and root number in the genebank at CIP, is known to normally reaching high yields (Hermann *et al*. 1998).

4.3 Morphological Traits

The subdivision of the yield into the five weight classes was preliminary, whereby the weight classes should be established within the main appearance of individual root weight, to reflect an accession specific yield profile. In profit oriented production, roots of the weight class <60g probably will not be important and more attention will be paid to the upper weight classes. The YI is still a preliminary way to assign preferences to the distinct weight classes. The importance of this value could increase if the root traits which are interesting for breeding or market objectives are clearly determined. Then the YI should be calculated based on the absolute root number.

Because of the supposed low heritability of the absolute yield and root number, it was decided to present the yield distribution in percentage, which allowed a direct comparison between the yield profiles.

Different to the study of Taboada (1998) the individual root shape was described by two parameters, shape and predominant root type pattern. Still it is discussed if elongated and shortened roots appear in the same plant or not. For example, Huaman (1991) mentioned a genetically determined variation of the root diameter and length among the analyzed accessions. M. Hermann (CIP-Lima, 2002, pers. comm.) supposed that shortened roots are formed mainly in the centre of the root stock and are surrounded by elongated roots. However, the evident differences in shape between the gene banks indicated to the influence of external factors like climate or soil conditions. During the survey besides accessions in which both shapes appeared, only elongated root formations could be documented for example in CLLUNC-108, Y-093, Y-095 and Y-096. Grau and Rea (1997) mentioned that irregularly shaped root types resulted from the contact with soil stones or the pressure of neighbouring roots. Within the analyzed material of the duplicated accessions even the irregularity seemed to be a repeating feature and was documented as bad peeling aptitude. If it was due to the pressure of neighbouring roots it could be the genetically determined growth peculiarities of the subterranean plant parts. For the processing of yacon the peeling aptitude could be an important trait for purposeful selection.

The individual root type was not an adequate criterion to differentiate the accessions in every case, rather it was dealt with as a quantitative trait, and similar to Taboada (1998) the predominant root type pattern was indicated in the database. It could be important for the farmer to know about the specific root type pattern and shape, which can influence the expenditure of harvesting. For example it is easier to harvest shortened or spherically-shaped than elongated or lemon-shaped root types.

5 CONCLUSION

This study introduces to a classification scheme to structure the post-harvest characteristics of yacon storage roots. The scheme links to a structured yacon database, designed to support the preliminary evaluation of yacon germplasm. The obtained data can be documented consistently and it is possible to enter supplementary data at a later stage into the database. The evaluation of physiological and morphological traits related to productivity and yield stability will be made easier. Due to the high variation, the set parameters can not be considered separately for identification of accessions.

Refractometric index, yield and root number might be accession specific, which were however highly variable at different growing sites. Environmental factors might be a reason for the great fluctuation. The RI was not influenced by the root weight, but seemed to be dependent on individual root age. Some accessions with characteristic individual yield profile and root type pattern were documented. Partly the same characteristics were noticed on duplicated accessions at distinct sites. However, the role of environmental variables like altitude, temperature, precipitation, radiation, soil type and physiological variables like plant age and age of individual roots on the investigated traits must be determined.

Exactly arranged assays will be essential to determine the reliability of the investigated traits and to provide information about the role of environmental and physiological factors.
The same accessions should be planted repeatedly in different altitudes and soils or should be exposed to different temperatures, precipitation or radiation densities and compared by the described parameters. To determine the root age, root formation and their influence to the RI, yacon plants could be planted in hydroponics, whereby the RI will be measured in intervals and dependent on the root position in the root stock. Also the accessions should be on trial in field experiments and the RI should be measured in certain intervals to obtain an accession specific RI gradient over time.

6 SUMMARY

Yacon (*Smallanthus sonchifolius* (Poepp. & Endl.) H. Robinson) is an underused and only marginally marketed perennial Andean root crop. Recently, the interest for yacon has increased due to the dietetic properties of the yacon storage roots, especially their high content of oligofructans, also called fructo-oligosaccharides (FOS). Some institutions in Peru have started to collect and conserve gene material. Until today, the extent of the genetic diversity of yacon is unknown and a descriptive key for its characterization is needed given the high variability of phenotypic traits. At many gene banks accessions are characterized by subjective parameters, consequently, the data can hardly be compared.

The aim of the present study was to establish a classification scheme for yacon storage roots according to their physiological traits such as fresh weight (FW), root number and the refractometric index (RI) and phenotypic traits such as the colour of the root stock and root flesh, yield uniformity, predominant root-type-pattern, peeling aptitude, length-width-relation and surface structure type. In addition, representative roots and a part of the root stock were documented photographically. The data set was based on about 200 accessions, maintained at three yacon gene banks in Peru at CIP (International Potato Centre) in Mariscal Castilla, Junin; CRIBA (Regional Centre of Andean Biodiversity Research) in Ahuabamba, Cusco and UNC (National University of Cajamarca) in Cajamarca.

Immediately after harvest the FW, root number and the RI were determined. The roots were subdivided into five weight classes >60 g, 60-<100, 100-<150 g, 150-<200 g and ≥200 g, to establish a distribution of weight and frequency of each accession. The colour of the propagules and the root flesh was determined according to the colour chart from the Royal Horticultural Society, London (1995).

The FW and root number per plant varied considerably between the gene banks and also among accessions. The total FW mean amounted to 3 kg per plant, whereby the highest FW mean average of about 4.9 kg per plant was found at CRIBA. The total mean root number was 16 roots per plant. The accessions with the largest mean average root number per plant (21 roots per plant) were found at CRIBA and the accessions with the lowest mean average (12 roots per plant) at UNC.

In 50 % of all accessions RI was in the range of 7.1 – 11.7 °Brix. Lower soluble solid concentrations were found in 30 %, and higher concentrations in 20 % of all accessions.

In the gene bank at CIP the accessions with the highest mean average RI (12.3 °Brix) were found. The analysis indicated that RI and individual root weight are not related. The root yield, root number as well as RI seemed to be largely affected by cultivation and environmental factors and their genetic determination remained unclear.
About 36 % of all accessions had a yellow, 40 % a cream and 24 % a white coloured root flesh. About 4 % of the roots, all from the germplasm bank at CRIBA, showed a secondary purple pigmentation. In 15 % of all accessions the root stock colour was white, in 30 % white with red-purple and in 55 % red-purple.

Overall the results showed that only the consistent use of a well defined classification scheme comprising FW, root number, RI, colour of root stock and root flesh, yield uniformity, predominant root type pattern, peeling aptitude, length-width-relation and surface structure type will allow to differentiate between the large range of morpho-types in yacon.

To examine this further, the accessions should be grown under similar environmental conditions. Subsequent bioassay or molecular tests should be conducted in order to determine to what degree these morphological and physiological differences are genetically determined.

6 RESUMEN

Yacón (*Smallanthus sonchifolius* (Poepp. & Endl.) H. Robinson) es un cultivo perenne andino, el cual todavía esta siendo utilizado y comercializado marginalmente. El interés por éste, se ha incrementado debido a las propiedades saludables de su raíz, especialmente la gran cantidad de oligofructanos, también llamados fructo-oligosacáaridos (FOS). En Perú, algunos institutos comenzaron a colectar y conservar material genético. La extensión de la diversidad genética es aun desconocida, y descriptores para la caracterización son necesarios debido a la gran variabilidad de las características fenotípicas. En varios bancos de germoplasma, la identificación es determinada con parámetros subjetivos, por consiguiente es difícil a comparar los datos.
El objetivo de este trabajo fue a establecer un sistema para uniformizar las características de post-cosecha de la raíz de yacón, de acuerdo a sus características fisiológicas como peso fresco (PF), número de raíces y el índice refractometrico (IR) así como características fenotípicas como color de los propagulos y de la pulpa de las raíces, uniformidad del rendimiento, formas predominantes de raíces, aptitud para pelar, relación entre longitud y ancho y estructura de la superficie de la raíz. Adicional raíces representativas y un muestro de la corona fueron documentados fotográficamente. Los datos fueron basados en aproximado 200 accesiones, mantenidas en tres bancos peruanos de germoplasma de yacón: CIP (Centro Internacional de la Papa) en Mariscal Castilla-Junín; CRIBA (Centro Regional de Investigación en Biodiversidad Andina) en Ahuabamba-Cusco y UNC (Universidad Nacional de Cajamarca) en Cajamarca.

Inmediatamente después de la cosecha se determinó el PF, número de raíces e IR. El peso de las raíces fue dividido en cinco categorías: >60 g, 60-<100, 100-<150 g, 150-<200 g y ≥200 g, para establecer la distribución del peso y la frecuencia de cada accesión. El color de los propágulos y de la pulpa de las raíces fueron determinados de acuerdo a la clave de colores de la Sociedad Real de Horticultura, Londres (1995).

El PF y el número de raíces por planta variarón considerable entre los bancos de germoplasma y también entre las accesiones. El promedio total resultó en 3 kg por planta, siendo el promedio mas alto obtenido en CRIBA con 4.9 kg por planta. El promedio total del número de raíces fue de 16 raíces por planta, siendo CRIBA el banco de germoplasma que registró el promedio mas alto, con 21 raíces por planta. Las

accesiones con el promedio mas bajo (12 raíces por planta) fueron registradas en el banco de germoplasma de UNC.

El IR osciló en un rango de 7.1 – 11.7 °Brix en 50 % de las accesiones. La concentración más baja de sólido soluble fue detectada en cerca del 30 % de las raíces y la concentración más alta en 20% del total evaluado. El promedio IR del banco de germoplasma del CIP se presentó como el mas alto (12.3 °Brix).
No fueron observadas relaciones particulares entre el IR y el peso individual de la raíz. Aparentemente el rendimiento, número de las raíces como el IR fueron afectados drásticamente por factores ambientales y de cultivo que por factores debidos al genotipo. El color de la pulpa de la raíz fue en 36 % amarillo, 40 % crema y 24 % blanco. Mas que 4 % mostraron una pigmentación secundaria purpurea. En 15 % de las accesiones el color de la corona fue blanco, en 40 % crema y en 55 % rojo purpureo.

En total los resultados mostraron que solamente el uso consecuente de un esquema de la clasificación bien definido, comprendido en PF, numero de raíces, IR, color de los propagulos y de la pulpa de las raíces, uniformidad del rendimiento, formas predominantes de raíces, aptitud para pelar, relación entre longitud y ancho y estructura de la superficie permitirá la diferenciación dentro del ámbito amplio de morfotipos en yacón.

Para determinarlo exactamente es necesario que las accesiones crecen bajo de condiciones ambientales. Seguientemente, se debería examinar bio ensayos o análisis moleculares para determinar en cuanto las diferencias morfologicas y fisiologicas dependen del genotipo.

6 ZUSAMMENFASSUNG

Yacon (*Smallanthus sonchifolius* (Poepp. & Endl.) H. Robinson) ist eine wenig genutzte und marginal vermarktete perenne Wurzelknolle aus den Anden. Durch die kalorienarmen Inhaltsstoffe der Speicherwurzeln, insbesondere einem hohen Anteil an Oligofructose, auch Fructooligosacchsride genannt (FOS), hat das Interesse an Yacon in der letzten Zeit stark zugenommen. In Peru haben einige Institutionen damit begonnen Genmaterial zu sammeln und zu konservieren. Bis heute ist das Ausmaß an genetischer Vielfalt unbekannt und wegen der hohen Variabilität der phänotypischen Merkmale wird ein Bestimmungsschlüssel benötigt. An vielen Genbanken geschieht die Charakterisierung der Herkünfte durch subjektiv festgelegte Parameter, folglich können die Daten schwerlich miteinander verglichen werden.

Das Ziel dieser Arbeit war die Entwicklung eines Klassifizierungsschemas für Speicherwurzeln des Yacon, bezüglich der physiologischen Charakteristika wie Frischgewicht (FG), Wurzelanzahl und refraktometrischer Index (RI), als auch der phänotypischen Charakteristika wie Farbe der unterirdischen Sprossteile und des Wurzelfleisches, Gleichmäßigkeit in der Ertragsbildung, vorwiegende Zusammensetzung der Wurzeltypen, Schäleigenschaft, Länge-Breite Verhältnis und Oberflächenbeschaffenheit der Wurzeln. Zusätzlich wurden repräsentative Wurzeln mit einem Stück des unterirdischen Sprossteils fotografisch dokumentiert. Die Daten wurden von über 200 Herkünften erhoben, welche von drei Genbanken in Peru, dem CIP (Internationales Kartoffelforschungszentrum) in Mariscal Castilla, Junin; CRIBA (Regionales Zentrum zur Erforschung der Andinen Biodiversität) in Ahuabamba, Cusco und der UNC (Nationaluniversität Cajamarca) in Cajamarca, zur Verfügung gestellt wurden.

Unmittelbar nach der Ernte wurden das FG, die Wurzelanzahl und der RI bestimmt. Die Wurzeln wurden in fünf Gewichtsklassen (>60 g, 60-<100, 100-<150 g, 150-<200 g und ≥200 g) aufgeteilt, um die Gewichts- und Häufigkeitsverteilung in jeder Herkunft zu ermitteln. Um die Farbe der unterirdischen Sprossteile und des Wurzelfleisches zu beurteilen, wurde der Farbencode der Royal Horticultural Society, London (1995) benutzt.

Das FG und die Wurzelanzahl pro Pflanze variierten beträchtlich zwischen den Genbanken als auch innerhalb der Herkünfte. Der Gesamtdurchschnitt des FG betrug 3 kg pro Pflanze. Pro Genbank wurde der höchste Durchschnitt (ca. 4.9 kg pro Pflanze) bei den Herkünften des CRIBA festgestellt. Der Gesamtdurchschnitt der Wurzelanzahl betrug 16 Wurzeln pro Pflanze. Die Herkünfte mit der höchsten durchschnittlichen Wurzelanzahl (21 Wurzeln pro Pflanze) wurden am CRIBA ermittelt, währen an der UNC durchschnittlich nur 12 Wurzeln pro Pflanze gebildet wurden.

Bei 50 % der Herkünfte wurde ein durchschnittlicher RI in einem Bereich von 7.1 – 11.7 °Brix gemessen. Durchschnittlich niedriger liegende RIs wurden bei 30 % ermittelt, während bei 20 % die durchschnittlichen RIs höher als bei allen anderen waren. Ein insgesamt deutlich höherer Durchschnitt wurde in den Herkünften des CIP festgestellt (12.3 °Brix). Aufgrund der Analysen konnten keine speziellen Zusammenhänge zwischen individuellen Wurzelgewicht und RI nachgewiesen werden. Wurzelertrag und -nummer sowie RI schienen stark durch umweltbedingte und anbautechnische Faktoren beeinflusst worden zu sein, wobei die genetische Veranlagung unklar blieb.

36 % der Herkünfte besaß eine gelbe, 40 % eine cremefarbene and 24 % eine weiße Wurzelfleischfarbe. 4 % zeigte außerdem noch eine sekundäre Pigmentierung. Die unterirdischen Sprossteile waren bei 15 % der Herkünfte weiß, bei 30 % weiß mit purpurroten Stellen und bei 55 % purpurrot gefärbt.

Insgesamt zeigten die Ergebnisse, dass nur durch einen konsequenten Gebrauch eines klar definierten Klassifizierungsschemas eine Differenzierung innerhalb der großen Spanne von Morphotypen in Yacon erfolgen kann. Dabei sollten folgende Charakteristika mit eingeschlossen werden: FG, Wurzelanzahl, RI, Farbe der unterirdischen Sprossteile und des Wurzelfleisches, Gleichmäßigkeit in der Ertragesbildung, vorwiegende Zusammensetzung der Wurzeltypen, Schäleigenschaft, Länge-Breite Verhältnis und Oberflächenbeschaffenheit der Wurzeln.

Um dies genauer untersuchen zu können, sollten die Herkünfte unter gleichen Umweltbedingungen angepflanzt werden. Bioassays oder Molekularanalysen sollten durchgeführt werden, um den Grad der genetischen Veranlagung morphologischer und physiologischer Unterschiede zu untersuchen.

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APPENDICES

Appendix A:	Provisional descriptors for yacon, proposed by Arbizu *et al*. (2001).
Appendix B:	Data of the climatic conditions during 2000 at the gene banks of the CIP in Mariscal Castilla, the CRIBA in Ahuabamba and the UNC in Cajamarca.
Appendix C:	Calculation of the yield uniformity by the CVs of the length-width relation and the individual root weight.
Appendix D:	Passport data and post-harvest characteristics of duplicated accessions
Appendix E:	Passport data and post-harvest characteristics (CD-ROM)
Appendix F:	Yield profiles (CD-ROM)
Appendix G:	Photo archive of storage roots (CD-ROM)

Appendix A: Provisional descriptors for yacon, proposed by Arbizu *et al.* (2001).

1. Predominant colour of the stems
1a. green / 1b. green-yellow
2. dark green
3. green with purple
4. red with purple

2. Distribution of the secondary stem pigmentation
0. absent
1. nodes
2. internodes
3. nodes and internodes

3. Ramification of the stems
0. absent
1. predominant apical
2. within the complete stem

4. Colour of the foliage
1. green
2. dark green

5. Colour of the leaf surface
1. green
2. green with purple pigmentation

6. Colour of the leaf veins
1. green
2. red-purple over principle leaf veins distributed
3. red-purple over principle and secondary leaf veins distributed

7. Overlapping of the leaf wings
0. absent
1. present

8. Leaf shape
1. triangular
2. triangular hastate
3. roped

9. Shape of the leaf base
1. truncated
2. hastate
3. roped

10. Shape of the leaf top
1. acute
2. blunt

11. Shape of the leaf border
1. pinnacled
2. sowed
3. double sowed

12. Habit of the inflorescence
0. absent
1. sparse
2. moderate
3. frequent

13. Colour of the ray flowers
1. dark yellow
2. orange-yellow

14. Shape of the ray flowers
1. ovate
2. elongated
3. elliptic

15. Teeth number of the ray flowers
0. absent
1. 2-toothed
2. 3-toothed

16. Seed production
0. absent
1. present

17. Colour of the storage root bark
1. white
2. orange
3. red-purple

18. Colour of the storage root flesh
1. yellow-white
2. yellow-white with secondary purple pigmentation
3. bright yellow?
4. orange

19. Hendidures in the storage roots
0. absent
1. present

20. Colour of the root stock
1. white (155 A – D)
2. white with red-purple
3. red-purple (60 B)

Appendix B: Data of the climatic conditions during 2000 at the gene banks of the CIP in Mariscal Castilla, the CRIBA in Ahuabamba and the UNC in Cajamarca.

	Precipitation (mm)			Temperature (°C)		
Month	CIP*1)	CRIBA*2)	UNC*3)	CIP*1)	CRIBA*2)	UNC*3)
Jan.	149.6	179.0	69.3	15.7	18.6	15.2
Feb.	149.4	175.2	85.5	15.9	18.5	15.0
Mar.	149.0	167.6	91.2	15.5	18.7	15.1
Apr.	78.0	85.5	61.0	15.6	18.2	15.1
May.	46.5	49.0	23.0	14.9	17.4	15.0
Jun.	18.9	37.0	0	14.2	16.2	14.5
Jul.	28.2	40.5	0	13.9	16.1	14.2
Aug.	31.2	52.0	0	14.6	17.1	14.7
Sep.	66.0	67.4	25.0	15.5	18.3	14.8
Oct.	96.0	90.0	69.4	16.0	18.9	14.9
Nov.	87.9	110.6	66.2	16.6	19.4	15.2
Dec.	134.6	146.5	60.0	16.1	18.9	15.2
Total / Average	**1035**	**1200**	**550**	**15.4**	**18**	**14.9**

*1) Source from the CIP, Lima (2000); *2) Source from L. Lizarraga (pers. comm., 2001), CRIBA, Ahuabamba; *3) Source from the meteorological station A. Weberbauer, UNC-Senamhi, 2000; *5).

Appendix C: Calculation of the yield uniformity by the CVs of the length-width relation and the individual root weight.

Accession	**Length-width relation** < 0.5 = elongated => 0.5 shortened	**CV (%)**	**Mean root weight (g)**	**CV (%)**	**Uniformity** = CV (shape) * CV (weight) / 100
ACW-5076	0.35	40	110.2	78	31
AJC-5189	0.3	18	113.0	59	11
AKW-5075	0.32	22	78.5	41	9
AME-5186	0.37	25	80.6	57	14
AMM-5129	0.35	24	124.8	85	20
AMM-5135	0.28	20	78.5	53	10
AMM-5136	0.39	7	92.0	49	4
AMM-5150	0.31	39	103.9	48	19
AMM-5163	0.34	19	99.5	51	10
ARB-5027	0.27	12	75.9	48	6
ARB-5073	0.32	33	93.3	43	14
ARB-5124	0.24	19	133.7	53	10
ARB-5125	0.3	21	111.6	48	10
ARB-5184	0.32	27	98.5	54	15
ARB-5185	0.33	25	117.6	70	18
ARB-5382	0.3	11	110.3	58	6
ARB-5537	0.33	27	67.1	37	10
ARB-5563	0.28	31	92.4	44	14
ARB-5564	0.34	29	90.2	37	11
ASL-136	0.26	24	110.8	56	13
CLLUNC-001	0.7	83	170.5	109	90
CLLUNC-002	0.39	11	128.2	100	11
CLLUNC-003	0.39	36	130.4	113	40
CLLUNC-004	0.58	44	113.9	60	27
CLLUNC-005	0.39	41	122.2	62	25
CLLUNC-006	0.47	25	109.0	95	24
CLLUNC-007	0.37	35	88.5	66	23
CLLUNC-008	0.51	62	91.9	52	32
CLLUNC-009	0.4	34	75.4	61	21
CLLUNC-010	0.49	60	114.7	49	30
CLLUNC-011	0.38	27	138.0	67	18
CLLUNC-012	0.66	31	80.1	62	19
CLLUNC-014	0.46	34	106.4	69	24
CLLUNC-015	0.39	42	101.4	71	30
CLLUNC-016	0.42	36	103.1	62	23
CLLUNC-017	0.47	27	94.1	52	14
CLLUNC-021	0.45	26	99.1	43	11
CLLUNC-022	0.27	20	94.6	64	13
CLLUNC-023	0.37	39	124.0	62	24
CLLUNC-025	0.58	51	166.7	69	35
CLLUNC-026	0.49	37	117.1	63	23
CLLUNC-027	0.43	41	155.8	63	26
CLLUNC-028	0.35	22	113.6	65	14

Appendix C continued

Accession	**Mean shape** < 0.5 = elongated => 0.5 shortened	**CV (%)**	**Mean root weight (g)**	**CV (%)**	**Uniformity** = CV (shape) * CV (weight) / 100
CLLUNC-029	0.34	44	124.3	48	21
CLLUNC-030	0.33	27	102.0	59	16
CLLUNC-031	0.54	14	94.7	49	7
CLLUNC-034	0.6	34	127.0	54	18
CLLUNC-036	0.53	29	154.9	49	14
CLLUNC-037	0.6	39	98.7	63	25
CLLUNC-038	0.41	25	101.4	62	15
CLLUNC-039	0.54	15	127.6	76	11
CLLUNC-040	0.55	21	133.3	83	18
CLLUNC-041	0.54	32	151.7	99	31
CLLUNC-042	0.56	24	123.5	90	21
CLLUNC-043	0.59	17	112.6	80	13
CLLUNC-045	0.44	32	105.8	65	21
CLLUNC-046	0.58	16	191.6	78	13
CLLUNC-047	0.65	35	95.9	80	28
CLLUNC-048	0.57	49	87.4	49	24
CLLUNC-049	0.43	35	135.0	67	23
CLLUNC-050	0.33	30	122.8	57	17
CLLUNC-052	0.45	20	99.3	70	14
CLLUNC-053	0.38	24	144.7	72	18
CLLUNC-054	0.61	50	85.6	49	25
CLLUNC-055	0.54	35	120.9	72	25
CLLUNC-056	0.32	26	123.3	65	17
CLLUNC-057	0.3	24	96.8	44	11
CLLUNC-058	0.53	43	123.3	81	34
CLLUNC-059	0.3	36	102.9	73	26
CLLUNC-060	0.62	44	87.4	60	26
CLLUNC-061	0.44	21	141.2	55	12
CLLUNC-062	0.5	49	90.3	79	39
CLLUNC-063	0.4	18	130.1	59	10
CLLUNC-065	0.44	19	94.2	41	8
CLLUNC-067	0.65	31	83.1	85	26
CLLUNC-068	0.59	21	113.5	68	14
CLLUNC-069	0.24	12	140.6	82	9
CLLUNC-070	0.49	42	111.9	64	27
CLLUNC-071	0.41	25	127.0	60	15
CLLUNC-072	0.64	54	213.1	77	42
CLLUNC-073	0.37	62	105.3	65	40
CLLUNC-075	0.46	25	97.4	54	13
CLLUNC-077	0.59	27	86.6	57	15
CLLUNC-079	0.59	71	179.0	118	83
CLLUNC-081	0.71	24	98.7	64	15
CLLUNC-082	0.46	27	82.3	46	12
CLLUNC-083	0.47	36	84.9	41	15
CLLUNC-084	0.5	41	88.9	53	22
CLLUNC-086	0.5	34	89.9	51	17
CLLUNC-087	0.49	26	88.6	63	17
CLLUNC-088	0.38	32	85.0	59	19

Appendix C continued

Accession	**Mean shape** < 0.5 = elongated => 0.5 shortened	**CV (%)**	**Mean root weight (g)**	**CV (%)**	**Uniformity** = CV (shape) * CV (weight) / 100
CLLUNC-089	0.47	33	101.6	58	19
CLLUNC-090	0.52	49	101.1	63	31
CLLUNC-091	0.43	21	124.3	73	16
CLLUNC-092	0.44	26	89.5	70	18
CLLUNC-094	0.42	28	103.0	77	22
CLLUNC-095	0.41	48	65.2	45	22
CLLUNC-096	0.45	31	131.2	64	20
CLLUNC-102	0.35	27	144.7	72	20
CLLUNC-105	0.45	16	112.2	61	10
CLLUNC-106	0.38	33	112.3	66	22
CLLUNC-118	0.47	15	171.5	56	9
CYDPA-07001	0.34	17	82.4	45	8
CYDPA-07002	0.23	18	74.4	52	9
CYDPA-07003	0.38	41	66.4	25	10
CYDPA-07004	0.42	19	70.7	28	5
CYDPA-07005	0.38	32	97.5	45	15
CYDPA-07006	0.42	59	105.6	53	31
CYDPA-07007	0.38	21	88.5	45	10
CYDPA-07008	0.26	18	87.9	37	7
CYDPA-07009	0.29	29	84.0	46	13
CYDPA-07010	0.38	29	103.0	48	14
CYDPA-07011	0.54	30	62.0	27	8
GOM-130	0.36	37	86.8	42	15
P-1184	0.34	26	118.5	67	17
P-1385	0.25	20	109.0	50	10
Y-001	0.42	36	103.5	54	20
Y-003	0.61	37	143.7	54	20
Y-004	0.48	22	257.2	81	18
Y-005	0.39	22	133.0	67	15
Y-007	0.48	19	91.3	51	10
Y-008	0.41	21	164.2	73	15
Y-009	0.61	27	145.2	65	18
Y-010	0.58	20	197.0	70	14
Y-011	0.68	27	149.1	75	20
Y-012	0.5	22	181.5	86	19
Y-013	0.64	31	149.6	68	21
Y-014	0.53	17	145.3	60	10
Y-015	0.55	29	166.4	52	15
Y-016	0.54	41	152.9	81	33
Y-017	0.41	20	121.7	51	10
Y-020	0.51	53	242.8	65	35
Y-021	0.52	21	244.4	64	13
Y-023	0.82	25	269.3	95	23
Y-024	0.41	13	199.9	73	10
Y-025	0.44	30	208.1	57	17
Y-026	0.52	22	140.2	62	13
Y-028	0.6	26	185.7	73	19

Appendix C continued

Accession	**Mean shape** < 0.5 = elongated => 0.5 shortened	**CV (%)**	**Mean root weight (g)**	**CV (%)**	**Uniformity** = CV (shape) * CV (weight) / 100
Y-030	0.38	14	196.0	56	8
Y-031	0.65	45	239.4	94	42
Y-032	0.53	16	226.6	71	11
Y-033	0.44	12	230.6	90	11
Y-034	0.43	31	219.0	78	24
Y-037	0.41	12	205.3	65	8
Y-038	0.57	18	179.5	67	12
Y-039	0.56	8	158.2	57	5
Y-040	0.53	46	182.6	67	31
Y-041	0.66	36	196.6	72	26
Y-042	0.49	27	183.3	66	17
Y-044	0.52	19	187.2	76	14
Y-046	0.75	22	206.2	62	14
Y-049	0.52	15	225.5	58	8
Y-052	0.65	20	172.7	98	20
Y-053	0.7	13	184.9	64	9
Y-055	0.62	23	210.1	69	16
Y-056	0.7	31	179.9	73	22
Y-059	0.44	24	148.2	69	17
Y-060	0.53	21	189.7	75	16
Y-061	0.49	29	173.6	58	17
Y-062	0.75	27	178.7	68	18
Y-063	0.67	38	207.2	92	35
Y-065	0.66	26	205.2	67	18
Y-067	0.47	14	256.2	95	13
Y-071	0.46	19	232.3	72	13
Y-072	0.41	17	233.2	88	15
Y-075	0.4	16	211.9	84	13
Y-077	0.43	26	238.4	62	16
Y-078	0.45	14	188.9	69	10
Y-081	0.31	31	279.0	101	31
Y-084	0.5	24	229.3	71	17
Y-086	0.39	43	208.5	57	25
Y-087	0.52	31	162.3	68	21
Y-088	0.46	18	220.9	61	11
Y-089	0.35	15	274.4	63	10
Y-090	0.41	21	202.7	69	14
Y-100	0.48	25	170.5	60	15
Y-103	0.5	35	156.5	67	23
Y-104	0.49	14	226.9	99	14
Y-106	0.51	19	153.3	66	13
Y-107	0.53	20	154.3	66	13
Y-108	0.49	39	163.0	74	29
0.46	**0.14**	**29**	**138.5**	**122.4**	**65**

Appendix D: Passport data and post-harvest characteristics of duplicated accessions.

Duplicate set	1		2		3		4		5	
Collection#	**ACW-5076**	**CLLUNC-090**	**AJC-5189**	**CLLUNC-096**	**AKW-5075**	**CLLUNC-087**	**AME-5186**	**CLLUNC-083**	**AMM-5129**	**CLLUNC-091**
Location	Bambamarca	Bambamarca	Frutillo	Frutillo	Caucau	Caucau	Chiquián	Chiquián	Cochahuayin	Cochahuayin
District	Bambamarca	Bambamarca	Bambamarca	Bambamarca	Namora	Namora	Chiquián	Chiquián	Yungay	Yungay
Province	Hualgayoc	Hualgayoc	Hualgayoc	Hualgayoc	Cajamarca	Cajamarca	Bolognesi	Bolognesi	Yungay	Yungay
Department	Cajamarca	Cajamarca	Cajamarca	Cajamarca	Cajamarca	Cajamarca	Ancash	Ancash	Ancash	Ancash
Country	Peru	Peru	Peru	Peru	Peru	Peru	Peru	Peru	Peru	Peru
Altitude	2500	2500	2500	2600	2600	2600	3300	3300	2500	2500
Latitude	-6.667	-6.667	-6.667	-6.667	-7.202	-7.202	-10.150	-10.150	-9.134	-9.134
Longitude	-78.500	-78.500	-78.500	-78.500	-78.269	-78.269	-77.184	-77.184	-77.734	-77.734
CultivarName	Yacon	Yacon	Yacon	Yacon	Yacon	Yacon	Yacon blanco	Yacon blanco	Yacon	Yacon
SourceType	22		22		22		22		22	
CollectionDate	19910730		19930315		19910715		19930113		19921019	
Collector	Juan Cruzado		Juan Cruzado		Kasuo Watanabe		Magaly Espejo		Marcial Méndez	
Institution	CIP	UNC	CIP	UNC	CIP	UNC	CIP	UNC	CIP	UNC
BiologicalState	300		300		300		300		300	
RI	13.6	7.7	15.2	9.0	12.5	9.8	10.0	10.3	15.3	10.6
LCL_0.95	12.5	6.4	14.0	7.5	11.1	8.4	9.0	9.1	14.1	9.0
UCL_0.95	14.8	8.9	16.4	10.5	13.9	11.2	11.0	11.5	16.6	12.1
Yield	3.6	1.4	3.2	2.1	2.2	1.0	2.2	1.2	1.4	2.2
YI	6.1	2.9	6.9	4.3	5.2	2.3	5.2	2.7	2.7	4.3
Root#	33	13	28	16	28	12	27	14	11	18
Uniformity	0	0	0	0	1	0	0	0	0	0
PeelingAptitude	1	1	1	0	1	1	0	0	0	0
Shape	2	1	2	1	2	1	2	1	2	2
RootSurfaceStructure	0	0	0	0	0	0	0	0	0	0
PredominatedPattern	1	2 / 1	5 / 2	3 / 5	5 / 1 / 2 / 3	3 / 2	5 / 1 / 2	5 / 1 / 2	2 / 3	2 / 1
Colour	2	3	2	3	2	2	1	2	1	2
Sec.Pigmentation	0	0	0	0	0	0	0	0	0	0
ColourPropagules	3	1	3	3	3	3	3	3	3	3

Appendix D continued

Duplicate set	**6**		**7**		**8**		**9**		
Collection#	**AMM-5150**	**CLLUNC-084**	**AMM-5163**	**CLLUNC-092**	**ARB-5027**	**CLLUNC-082**	**ARB-5124**	**CLLUNC-089**	**CLLUNC-094**
Location	Arwaypampa	Arwaypampa	Llipta	Llipta	Tintín	Tintín	José Galvez	José Galvez	José Galvez
District	Carhuaz	Carhuaz	Shilla	Shilla	Laraos	Laraos	José Galvez	José Galvez	José Galvez
Province	Carhuaz	Carhuaz	Carhuaz	Carhuaz	Yauyos	Yauyos	Celendin	Celendín	Celendín
Department	Ancash	Ancash	Ancash	Ancash	Lima	Lima	Cajamarca	Cajamarca	Cajamarca
Country	Peru	Peru	Peru	Peru	Peru	Peru	Peru	Peru	Peru
Altitude	2700	2700	3400	3400	3200	3200	2600	2600	2600
Latitude	-9.270	-9.270	-9.217	-9.217	-12.330	-12.330	-6.917	-6.917	-6.917
Longitude	-77.634	-77.634	-77.617	-77.617	-75.750	-75.750	-78.117	-78.117	-78.117
CultivarName	Yacon	Yacon	Yacon	Yacon	Yacon	Yacon	Yacon blanco	Llacón	Llacón
SourceType	22		22		22		22		
CollectionDate	19921020		19921021		19910504		19921018		
Collector	Marcial Méndez		Marcial Méndez		Carlos Arbizu		Carlos Arbizu		
Institution	CIP	UNC	CIP	UNC	CIP	UNC	CIP	UNC	UNC
BiologicalState	300		300		300		300		
RI	12.4	13.3	14.1	10.2	10.7	13.0	14.1	9.4	10.1
LCL_0.95	11.5	11.3	13.2	8.7	10.0	11.8	13.1	8.5	9.0
UCL_0.95	13.3	15.3	15.1	11.7	11.4	14.2	15.1	10.3	11.2
Yield	1.9	0.7	1.6	1.4	2.7	1.4	2.0	1.6	1.9
YI	4.3	1.5	3.8	2.9	6.1	3.2	3.8	3.6	3.8
Root#	18	8	16	15	35	17	15	16	19
Uniformity	0	0	1	0	1	0	1	0	0
PeelingAptitude	1	1	1	0	0	1	0	0	0
Shape	2	1	2	2	2	1	2	1	2
RootSurfaceStructure	1	0	0	0	0	0	0	0	0
PredominatedPattern	5 / 2	1 / 3 / 5	5 / 1	3 / 2 / 5	2 / 5	5 / 2 / 1	5 / 1	1 / 2 / 5	5 / 1 / 2
Colour	1	2	2	3	1	2	3	2	3
Sec.Pigmentation	0	0	0	0	0	0	0	0	0
ColourRootstock	3	3	3	3	3	3	3	1	1

Appendix D continued

Duplicate set	10			11			12	
Collection#	**ARB-5125**	**CLLUNC-089**	**CLLUNC-094**	**ASL-136**	**CLLUNC-032**	**CLLUNC-095**	**P-1385**	**CLLUNC-086**
Location	José Galvez	José Galvez	José Galvez	Chota	Chota	Chota	Roncopata	Roncopata
District	José Galvez	José Galvez	José Galvez	Chota	Chota	Chota	Santa Maria de Chicmo	Santa Maria de Chicmo
Province	Celendin	Celendín	Celendín	Chota	Chota	Chota	Andahuaylas	Andahuaylas
Department	Cajamarca	Cajamarca	Cajamarca	Cajamarca	Cajamarca	Cajamarca	Apurimac	Apurimac
Country	Peru	Peru	Peru	Peru	Peru	Peru	Peru	Peru
Altitude	2600	2600	2600	2900	2388	2900	2750	2750
Latitude	-6.917	-6.917	-6.917	-6.550	-6.557	-6.550	-13.650	-13.650
Longitude	-78.117	-78.117	-78.117	-78.650	-78.650	-78.650	-73.480	-73.484
CultivarName	Yacon naranja	Llacón	Llacón	Yacon	Llacón	Yacon	YaKumpi	Yacumpi
SourceType	22			22			22	
CollectionDate	19921018			19920610	19930720		19850820	
Collector	Carlos Arbizu			Alberto Salas	Juan Seminario		Carlos Arbizu	
Institution	CIP	UNC	UNC	CIP	UNC	UNC	CIP	UNC
BiologicalState	300			300	300		300	
RI	14.7	9.4	10.1	14.5		9.0	14.1	12.2
LCL_0.95	13.9	8.5	9.0	13.6		7.7	13.4	10.4
UCL_0.95	15.5	10.3	11.2	15.2		10.3	14.9	14.0
Yield	3.3	1.6	1.9	4.6		1.1	3.0	1.1
YI	7.4	3.6	3.8	9.7		2.4	6.6	2.5
Root#	30	16	19	42		16	28	12
Uniformity	1	0	0	0		0	1	0
PeelingAptitude	0	0	0	1		0	0	0
Shape	2	1	2	2		2	2	1
RootSurfaceStructure	0	0	0	0		0	0	0
PredominatedPattern	5 / 3	1 / 2 / 5	5 / 1 / 2	1 / 5		1 / 3 / 5	5	5 / 2 / 3
Colour	3	2	3	2		3	2	3
Sec.Pigmentation	0	0	0	0		0	0	0
ColourPropagules	3	1	1	3		1	3	3

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