Conservación y uso de la biodiversidad de raíces y tubérculos andinos: Una década de investigación para el desarrollo (1993-2003)

8B

Yacon syrup: Principles and processing

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Chapter I

Introduction

Yacon is an underutilized and scientifically neglected root crop that is native to the Andean region. Interest in this little known crop has increased recently, since it has become known that it is the plant source with the largest content of fructooligosaccharides (FOS). FOS are a type of sugar that has a lower caloric value than other sugar types (approximately 25 to 35% of the calories of normal carbohydrates). The consumption of FOS is also known to promote better health of the intestinal tract.

Yacon syrup is a novel product, which contains up to 50% FOS, made by concentrating the juice of the tuberous storage roots of yacon. The physical and sensorial characteristics of yacon syrup are similar to those of honey, maple syrup or sugar cane syrup, and it can be consumed in a similar way but with the advantage of appealing to the health conscious consumer interested in reducing caloric intake as well as improving the quality of his or her diet. Yacon syrup can also be consumed (in moderation) by diabetics, as the consumption of FOS does not increase the amount of glucose in the blood. Market studies and sensorial evaluations have shown that the health benefits, versatility and consumer acceptance of the product indicate that yacon syrup has a strong market potential.

This manual describes a method for producing yacon syrup using a simple technology that requires modest capital investment and can be implemented in remote rural communities. By processing the product in the area where yacon is grown, some of the aggregated value of the product will remain in the community where it was cultivated. Moreover, because a sizeable portion of yacon does not satisfy the quality requirements for fresh consumption or industrial processing, it becomes necessary to transform locally the surplus unsuitable for commercialization.

Our technology depends on an evaporator, which is commonly used for the production of maple syrup. Similar processes have been around for over 100 years and their lasting effectiveness is demonstrated by their continued use in the United States and Canada. This type of evaporator can be manufactured locally and is not restricted by patents or any other form of intellectual property rights.

Other, more modern techniques are available for the concentration of liquids at low temperature. These are commonly used when processors want to preserve the aroma and chemical composition of the product (e.g. concentrated fruit juice). In the case of yacon syrup the use of this type of technology yields a product with an undesirable flavor, which can only be improved by using additives. By using the technology proposed in this manual it is not necessary to use additives to improve the flavor of the product because the effect of exposure to high temperatures during evaporation naturally enhances the flavor. Furthermore the process of evaporation does not affect the product in terms of the FOS content.

This manual is the result of a project between the Erbacher Foundation of Germany, the Swiss Agency for Development and Cooperation (SDC), the International Potato Center (CIP) and the School of Agronomy in Oxapampa, which is part of the National University Daniel Alcides Carrion (UNDAC). The objective of the project was to develop an efficient technology for yacon syrup production and to implement it in a small plant, demonstrating the viability of the method in a rural setting. At the end of 2000 the product won first place in a competition for innovation in agriculture and technology (ITA 2000). This contributed to diffusion of the concept and motivated several local companies to begin producing syrup. Peruvian yacon syrup producing companies are looking to expand into the export market.

This publication puts information discussing the technology and potential markets for yacon syrup into the public domain.The information is designed t o allow producers to set up successful yacon processing businesses, and is the cumulative result of research and experience since the beginning of the project three years ago. The manual contains descriptions of the equipment and machinery used, as well as details of the processing technology,costs involved and discussion of potential markets for the product. This same technology can also be used to produce a semi-concentrated syrup or pre-syrup, which can be transported for final processing to a larger plan t. This strategy would allow a greater level of quality control for a standardized product while offering significant savings in transportation.

It is hoped that the publication of this manual will contribute to the body of knowledge of the processing of yacon, and in this way allow for a greater commercialization of this under-utilized crop. It is hoped that this will spur the production of yacon syrup, especially in areas where the tuber is cultivated.

Chapter II

Raw material

2.1 Background

Yacon (*Smallanthus sonchifolius*) is the name commonly given to the plant and its storage root (Figures 1 and 2A). Yacon is native to the Andean region and is known to have been cultivated and consumed since pre-Inca times. Despite this, and unlike other Andean root crops such as potato and sweet potato, yacon remains relatively unexploited. Until now yacon has generally been cultivated only as a subsistence crop by Andean farmers, and more recently for sale in small provincial market towns. It is only in the last few years that the health benefits of yacon have become known and it has reached the market places of the big cities where efforts have begun to commercialize it and to experiment with processing techniques.

Taxonomically it is classified under the Asteraceae family. Other members of the Asteraceae family include chicory (*Cichorium intybus*), Jerusalem artichoke (*Helianthus tuberosus*) and dahlia (*Dahlia* sp.). The storage organs of all of these species accumulate a type of fructan

Figure 1. Yacon plants in an experimental field at the International Potato Center (CIP), La Molina, Lima, Peru.

Figure 2. Underground organs of the yacon plant. **A.** Storage roots and rhizome. **B.** Close up of a rhizome.

known as inulin, which is similar to FOS except at a high degree of polymerization.

Yacon grows well in both temperate and subtropical regions (0-24º) at altitudes between 800 and 2800 meters above sea level. Yacon is adaptable and insensitive to photoperiod or day length and can therefore also be grown in many other regions of the world. It has been successfully cultivated in several different regions with varying climates including: Brazil, Czech Republic, China, Korea, Japan, New Zealand, Russia, Taiwan and United States. The geographical distribution of yacon to greater latitudes and altitudes has been limited because of the combination of its long growing season (>180 days) and its susceptibility to frost.

The plant can grow to a height of 1.5 – 2.5 m (Figure 1). Its leaves are triangular or heart shaped and can reach a length of up to 30 cm. In Japan, Brazil and recently in Peru, the leaves have been used in the form of an infusion or tea thought to lower the level of glucose in the blood for people with diabetes. Until now this phenomenon has only been seen in laboratory animals.

In Peru, yacon can be harvested throughout the year in areas that are frost free and are well irrigated. In the high Andes only one growing season is possible and planting is done at the beginning of the rainy season. In the high jungle region of Peru planting can take place at any time of year.

The yacon root system forms fleshy rhizomes as well as tuberous roots. These rhizomes are known locally as 'cepas' and are used for the propagation of the plant. On the surface of each rhizome there are many buds or points of growth (Figure 2B). A mature rhizome can be broken into ten or twenty parts, each of which is traditionally used as seed and has between 3 and 5 growing points. There are recently developed methods of propagation that include long and short cuttings (Seminario *et al.*, 2003).

Yacon is harvested from six to twelve months after sowing. Location and altitude most affect the length of the growing season. In Peru for example, in the region of Oxapampa (1800 meters altitude) the growing season is 6 months, in the province of Sandia (2200 meters altitude) it is 8 months, while in higher altitude locations such as Cajamarca (2700 meters altitude) and Huancayo (2800 meters altitude) the growing season can be 10 months or more.

Yield per hectare for yacon is typically 20-40 t/ha. Yield is strongly affected by both location and cultivar. Good agricultural management, the application of fertilizers, and the use of high quality seed can lead to higher yields. For example: in Cajamarca, Peru, yields of 50 t/ha can be obtained, and in Sao Paulo, Brazil yields of greater than 60 t/ha have been obtained with the use of mineral fertilizers.

Yacon can be commercially cultivated in almost all parts of Peru. Until recently it was, almost exclusively farmed as a subsistence crop or for sale in rural market places. The explosion in demand for yacon in urban centers has been brought about mainly by its recent emergence as a health food with benefits for dieters and diabetics.

2.2 Description of the roots

The form and size of the tuberous storage roots are similar to some varieties of sweet potato, to the point that the two species can easily be confused at first sight (Figure 2A). Yacon roots vary in shape from spherical to lemon-shaped and inverse pear-shaped. Commonly the roots, though smooth, can have irregularities and deformities such as cracks and constrictions, and there are severely contorted roots that are difficult to peel. Some cultivars are more likely to form smooth regular roots than others.

The roots have a thin skin that is firmly attached to the flesh of the rhizome. Farmers often use the skin and flesh color to distinguish different cultivars. The color of the fleshy root can be cream, yellow or orange and in some cases can include streaks of purple. The tissue of the root is soft due to the fact that it is mainly made up of water which accounts for 90% of the fresh weight. As a result yacon roots are very fragile and are prone to breakage especially during harvesting and transportation.

The weight of each root is highly variable, even on the same plant. The weight of the roots can vary from 50 to 1000 g, but normally vary from 200 to 500 g (Polreich, 2003). Under normal conditions a single plant will produce between 2 and 3 kg of roots, but with the use of adequate irrigation, pest control and fertilizers this will most likely exceed 5 kg. In experimental trials, yields superior to 10 kg per plant have been achieved with some frequency (Amaya, 2000).

2.3 Yacon cultivars

Farmers use the color of the root and the stem to distinguish different cultivars of yacon. Four distinct types of yacon have been identified in the southern Peruvian districts of Cusco and Puno:

- white or yurac (white creamy fleshed root with a red to purple skin)
- yellow or k'ello (yellow to orange flesh with a purple root)
- speckled or ch'ecche (white creamy fleshed root with streaks of purple)

- pink or puca (reddish flesh with pink to reddish skin).

A total of seven cultivars have been found in the northern part of the country in the departments of Amazonas, Cajamarca, La Libertad, Lambayeque and Piura, three of which are the same as are found in the south (Seminario *et al.*, 2003).

Although there are differences in chemical composition (Table 1), yield and other relevant characteristics, the extent to which genetic factors (inherent to the cultivars) and environment affect the expression of these characteristics is not yet known. All this complicates attempts to identify cultivars. For this reason, although the process is not yet appropriate, it turns out to be easier and more practical make an identification of them based on the color of their roots and stems.

The diversity of yacon is much lower than that of potatoes and other Andean root and tuber crops. According to Dr. Carlos Arbizu of the International Potato Center there are probably no more than twenty varieties of yacon (personal communication, 2004).

2.4 Chemical composition

Between 85 and 90% of the fresh weight of the storage roots is water. In contrast to the majority of other edible roots, yacon does not store its carbohydrates in the form of starch but rather as FOS, fructose, glucose and sucrose. Though the percentage of the different types of sugar varies, they are of the order of magnitude of (dry basis): 40-70% FOS, 5-15% sucrose, 5-15% fructose, and <5% glucose. Proteins and lipids account for just 2.4 - 4.3% and 0.14 - 0.43% of dry weight respectively (Hermann *et al.*, 1999). Potassium accounts for an average 230 mg/100g of fresh weight. Other micronutrients occur in much lower concentrations and include calcium, phosphorous, magnesium, sodium and iron.

Table 1. Chemical composition of the main components of yacon root and data on yields of three cultivars of yacon in Cajamarca.

Variable	SAL136	AKW5075	ARB5073
Dry matter (g)[1]	136	98	115
Total carbohydrates (g)[1]	127	89	105
FOS (g)[1]	89	31	61
Free glucose (g)[1]	2.8	2.3	4.5
Free fructose (g)[1]	4.6	21.1	7.5
Free sucrose (g)[1]	12	19	14
Proteins (g)[1]	3.3	3.5	4.9
Lipids (mg)[1]	191	289	311
Fiber (g)[1]	3.6	3.5	3.7
Potassium (mg)[1]	2859	1969	1999
Yield roots (t/ha)[2]	23	84	10

[1] Source: Hermann *et al.*, 1999. The data on chemical composition were obtained from yacon planted near Quito, Ecuador. The values shown correspond to the evaluation of 1 kg of edible fresh matter.

[2] Source: Melgarejo, 1999. The data on root yields were obtained from yacon cultivars planted in Oxapampa, Pasco, Peru.

2.4.1. Fructooligosaccharides (FOS)

FOS are sugars that are found naturally in many types of plants, but never in concentrations as high as in the storage roots of yacon. FOS are chemically composed of 1 molecule of glucose connected to between 2 and 10 fructose molecules (Figure 3A). The bonds that connect the molecules of fructose are able to resist the hydrolysis of enzymes in the human digestive system and are therefore able to reach the colon without being broken down and digested by the body. It is for this reason that FOS have a low caloric value for humans (25-30% of the calories possessed by other sugars).

2.4.2. Importance of FOS

Yacon FOS are completely fermented in the colon by probiotics (Pedreschi *et al.*, 2003), a group of beneficial bacteria that forms part of the intestinal microflora. These bacteria (especially some species of the genus *Bifidus* and *Lactobacillus*) contribute to better gastrointestinal function and help to alleviate several digestive disorders. Besides, FOS are recognized as a soluble fiber which causes several favorable effects during digestion:

- an increase of intestinal peristaltic movements
- a reduction in time of intestinal transit
- an increase in the amount of water retained by the fecal matter
- an osmotic effect similar to a laxative

These effects can prevent and control constipation (Chen *et al.*, 2000).

Other favorable health effects have also been associated with the fermentation of FOS in the colon. These include:

- strengthening the immune system
- higher absorption of calcium by the body
- reduction of cholesterol level
- inhibition of the production of toxins and other carcinogenic substances in the colon.

These effects have only been demonstrated for laboratory animals, and there is a need to conduct clinical studies on humans to assess the true effects of FOS on human health (Figure 3B).

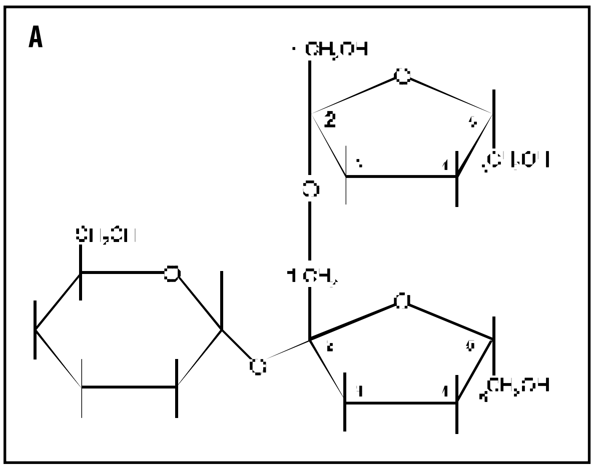
Studies have shown that the consumption of FOS does not increase the level of glucose in the blood. For this reason several companies recommend their inclusion in the diet of diabetics as a substitute for table sugar.

2.4.3. Other important chemical components

In comparison with other roots and tubers yacon contains a high level of polyphenols, which account for approximately 200 mg/100 g of fresh weight. The most abundant polyphenols are chlorogenic acid and at least four soluble phenols derived from caffeic acid. Other compounds reported with antioxidant activity are trypthophan, quercetin, ferulic acid and galic acid (Takenaka *et al*., 2003, Jirovský *et al*., 2003, Valentová & Ulrichová, 2003). Despite the high levels of polyphenols in the root, much higher levels are found in the leaves and in the stem.

Polyphenols are chemical components that have antioxidant properties. That is to say that they neutralise the oxidization caused by unstable molecules known as free radicals. Free radicals enter the body through various paths including inhalation of tobacco smoke and atmospheric pollution as well as ingestion of pesticides and certain fats. Free radicals damage cell membranes and destroy and mutate the cell's DNA, which can cause many health problems including an increased risk of cancer. Free radicals are also associated with cardiovascular disease, because they cause the oxidization of LDL cholesterol (sometimes known as good cholesterol), which leads to a thickening of the arteries.

Studies with both healthy and diabetic mice have demonstrated that the consumption of yacon tea can help reduce the level of sugar in the blood of normal and diabetic rats (Aybar *et al*., 2001). However, the chemical component responsible for this effect is not known nor is it known whether it is also found in the roots. Although common sense indicates that the FOS could have some relationship with this effect, it is not



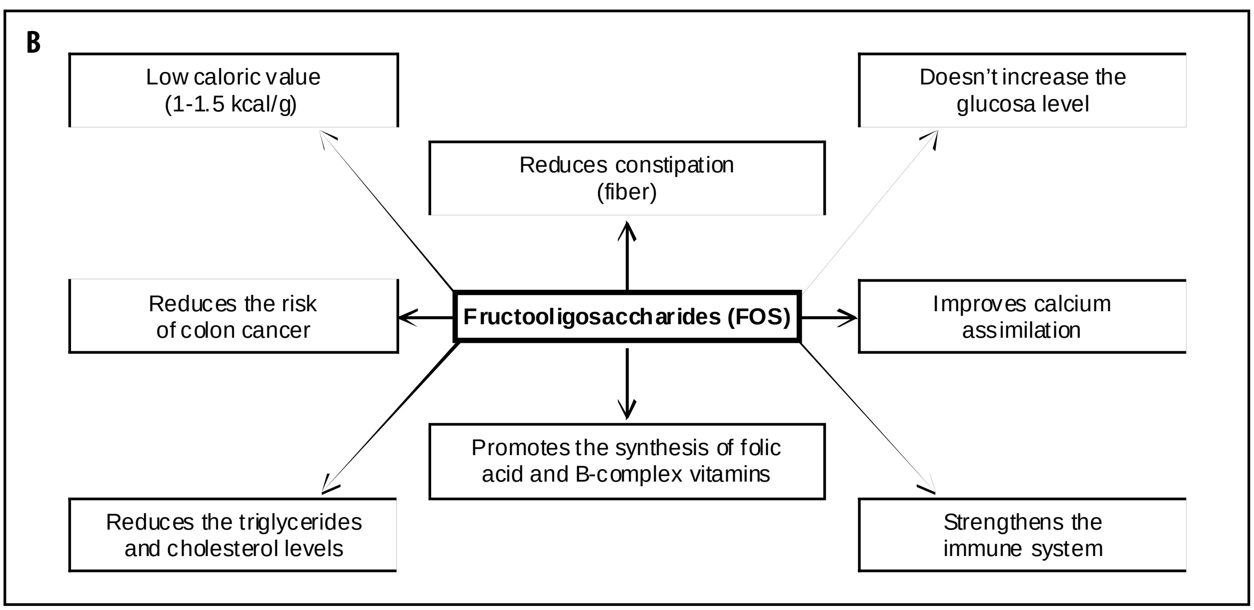


Figure 3. The fructooligosaccharides (FOS). **A.** Chemical structure of 1-kestose, the simplest FOS there is (it has just 2 molecules of fructose). The chemical structure of the rest of the FOS is similar to 1-kestose, varying only in the number of molecules of fructose that can manage to polymerize (up to 10 units). **B.** Some health effects associated with the consumption of FOS.

very likely in this case since the concentration in the leaves is very low.

2.5 Precautions for harvest and post harvest

In comparison with other roots yacon is very susceptible to physical damage both during harvest and transportation. The roots are joined to the plant via a fibrous crown that is sometimes hard to break. During harvest it is necessary to pull the roots to separate them from the rest of the plant, sometimes causing them to rupture. If the root ruptures there is a risk of microbiological contamination at the site of damage. It is much better to use a knife at the time of harvest to cut the root from the crown, thus maintaining the integrity of the root.

Roots are susceptible to damage from impacts or are often exposed to larges loads during harvest, packaging and transportation. Impact to the root should be avoided at all times. Roots should be packed into containers that support the weight that is placed on top of them. Some protection is provided by soil that adheres to the recently harvested root surface which protects it against physical damage as well as dehydration. For this reason it is recommended that the soil is not washed from the yacon until it has reached its destination.

Studies have demonstrated that soon after harvesting a rapid transformation of the composition of the sugars occurs: the FOS are hydrolyzed by an enzyme called fructan hydrolase into simple sugars (i.e. fructose, glucose and sucrose). After a week of storage at room temperature, approximately 30 – 40% of the FOS will have transformed into simple sugars (Graefe *et al.*, 2004). This process is much slower if the roots are kept at lower temperatures under refrigeration (Asami *et al.*, 1991). Storage at low temperature also reduces losses from rotting and general deterioration.

Roots can lose up to 40% of their weight in one week purely though dehydration into the atmosphere (Table 2). This represents a saving of approximately 40% in energy needed to evaporate the water from the roots to produce syrup. During this time, however, a large quantity of FOS is broken down into simple sugars.

Table 2. Effect of putting out in the sunlight(*) on the relative composition of yacon roots. The data shown (%) correspond to the average of three Peruvian yacon cultivars.

	Harvest data	Days put in the sun		
		2	4	6
Roots	100	75.2	66.7	61.7
Water	87.3	60.8	52.2	47.6
Dry matter	12.7	14.7	14.4	14.0
Total sugars	11.0	12.7	12.5	12.0
Fructooligosaccharides	7.0	7.1	6.0	5.4
Fructose	1.6	2.5	2.9	3.5
Glucose	0.3	0.5	0.5	0.7
Sucrose	2.1	2.6	3.0	2.4

Source: Graefe *et al.*, 2004.
(*) Putting in sunlight is a tradition consisting of exposing the roots to the sunlight for a few days for the purpose of making the roots sweeter for consumption.

Chapter III

Principles of processing

The technology for producing yacon syrup is simple: First juice is extracted from the root after which it is concentrated until it reaches a level of 73° Brix. The initial concentration of sugars in the root ranges from 8-12° Brix making it necessary to evaporate a significant amount of water to reach the final concentration. The ratio of water to be evaporated versus the weight of syrup produced ranges from 5:l to 8:l. Figure 4 shows the required steps for making yacon syrup.

In order to reduce the microorganism content introduced into the processing, the roots are first washed and then disinfected. First the roots are washed to remove any soil and organic matter adhering to the root surface. Then the root is disinfected to reduce remaining microorganism content and residues.

After the roots are washed and disinfected they enter the production line. The first step in the production process is to peel the roots completely. The skin contains components that negatively affect the quality of the final product, including a high content of agents that encourage oxidation of the yacon juice. It also contains resins and other substances, which give the final product a bitter flavor that is mildly spicy.

During the cutting and peeling of yacon, some cell membranes are ruptured, which causes cytoplasmic localizer enzymes (polyphenoloxidases) to come into contact with vacuolar localization substrates (phenols). The polyphenoloxidases (PPO) catalyze the oxidization of the phenols in a process known as enzymatic oxidization. The molecules produced in this process are highly reactive, and they combine with sulfhydryl or amino groups of proteins or reducer sugars, giving rise to higher-level polymers. These polymers are called melanins and have a high molecular weight and varying coloration. They are responsible for the change in color of yacon juice associated with oxidization.

In the case of yacon, oxidization occurs only a few seconds after the cells are ruptured during the juice extraction process. The color of yacon juice is originally a shade of orange very similar to cantaloupe juice. After only 10-15 seconds, however, it turns an oily dark green color. The best way to avoid the syrup turning a very dark color is to try to prevent the enzymatic oxidation from occurring. This is normally accomplished by adding an antioxidant to the juice.

The purpose of filtering is to remove the majority of insoluble solid mater from the product. Any solid matter that remains in the final product has a tendency to form sediment on the surface, which gives the product an unattractive turbid, opaque appearance. Yacon syrup is filtered for two purposes:

1. Filtration of the juice to remove all the insoluble solids.
2. Filtration of the pre-syrup to eliminate crystallized sugars that have become insoluble due to the evaporation process.

This manual recommends the use of a special evaporator that is used in the production of maple syrup. This type of evaporator concentrates liquids using evaporation in a continuous process. This reduces the amount of time that the juice is exposed to high temperatures compared to a traditional batch process, minimizing the chances of the syrup's acquiring a burnt flavor as a result of being held at high temperatures for long periods of time.

Boiling causes constituents that are the source of a distinctive unpleasant taste to be broken down. Boiling also results in a small amount of caramelization of the sugars, which helps disguise the taste of substances that have an unpleasant flavor still remaining in the final product. In this way, boiling helps give the final product a superior flavor to that possible with other concentration techniques using low temperatures (such as vacuum).

The quality of the product in terms of FOS content is maintained using maple syrup evaporators. This is because boiling has no effect on the chemical structure of FOS. FOS are only affected by temperatures in excess of 120ºC, at which point the sugars begin to break down into simpler forms (L'homme *et al*., 2003).

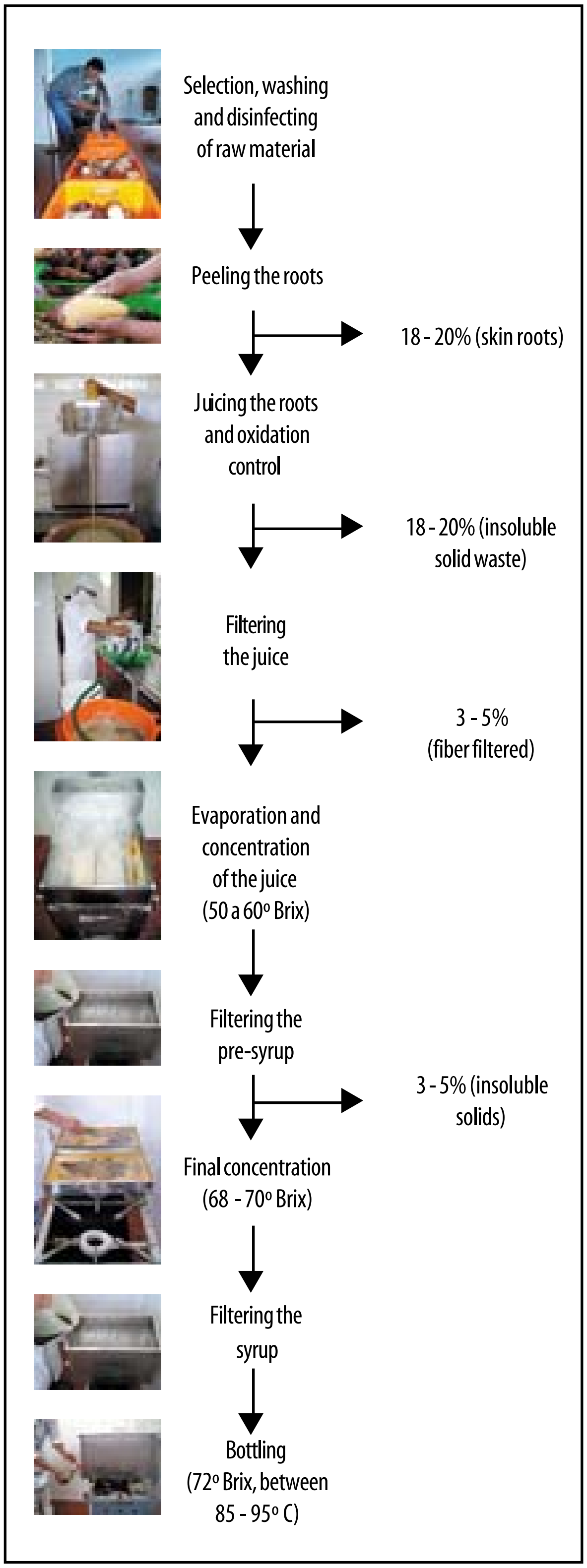


Figure 4. Flowgram of operations for the elaboration of yacon syrup.

Chapter IV

Description of the process

4.1. Selection of raw materials

Unfortunately the laboratory tests required to establish the level of FOS in the product are both labor intensive and expensive. For this reason a method for indirectly estimating the content of FOS from the refractive index or degrees Brix has been developed by the authors. This method, which is fast, simple and cheap, permit us to select among various plots of yacon, those which have the highest FOS content.

A refractometer is a device for measuring the refractive index, which is normally expressed on a scale known as Brix. The Brix scale was created to correspond to the percentage of soluble sugars in a solution (glucose, fructose and sucrose). In the case of yacon, FOS represent the largest component of sugar in the juice. Given that there is a high correlation ($r > 0.8$) between degrees Brix and the content of FOS in yacon juice (Hermann *et al*., 1999), degrees Brix can be used to compare the relative content of FOS between two or more lots of yacon. The biggest advantage of this method is that results are obtained immediately with a portable refractometer, which is relatively inexpensive and easy to use. The details of this method are illustrated in Figure 5.

For better selection of raw materials, the above test can be complemented with a taste test. The simple sugars found in yacon (sucrose, fructose and glucose) are four times sweeter than FOS. This means that if the roots taste less sweet, there is a greater probability that they have a high content of FOS. With this in mind, selecting the crop (lot) for processing that contains the highest concentration of FOS can be made by selecting crops with a high Brix level and the least sweet flavor.

4.2. Washing and disinfecting the raw material

Washing should be done using plenty of water, rubbing the roots against one another and with the use of a scrubbing brush which will easily remove the soil that adheres to the surface of the root. After washing, the roots should be submerged in a solution of sodium hypochloride and water with a concentration of 200 ppm. This reduces the microorganism content which is still present on the yacon surface. Sodium hypochloride is one of the most effective, economical and easy to use disinfectants available. A solution of sodium hypochloride at a concentration of 200 ppm can be made by mixing 4 ml of commercial bleach with each liter of water (the majority of bleaches contain 5% sodium hypochloride).

4.3 Peeling the roots

The roots are peeled manually using a conventional handheld swivel potato peeler (Figures 6A and 6B). It is recommended that after the roots have been peeled, they be submerged in clean water to reduce oxidation (Figures 6C and 6D). With this system a person can peel between 20 and 25 kg of yacon roots per hour with a loss of approximately 20% of the initial weight of the roots.

The concentration of sugars found in the root increases from the center to surface (Figure 7) of the root. For this reason, care must be taken not to remove an excessive amount of flesh when peeling since this is where the

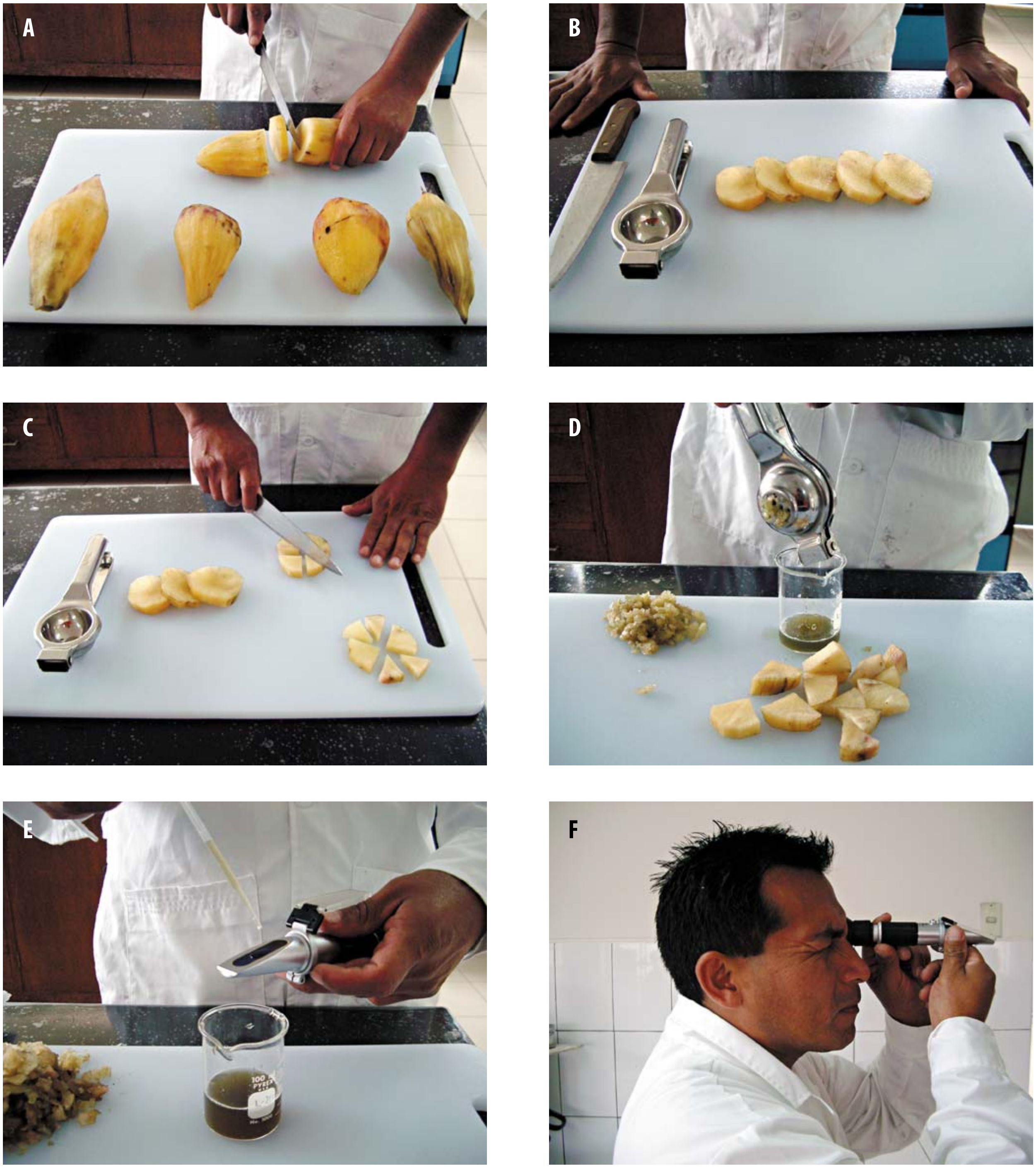


Figure 5. A quick simple method for estimating the sugar content of a lot of yacon roots. **A.** Randomly select a minimum of five yacon roots and peel them. **B.** Cut a central slice 1 cm thick from each root selected. **C.** Divide each slice into several pieces. **D.** Remove the juice with the help of a lime squeezer. **E.** Place a couple of drops of the juice on the prism of a portable refractometer. **F.** Take the reading. The value measured (in °Brix) is an estimate of the percentage of total sugars in the juice and have a high correlation with the FOS content.

Figure 6. Peeling. **A.** Different models of domestic peelers which can be used to peel yacon roots. **B.** Details of a simple ergonomic model. **C.** Two women in the middle of peeling in the APYEDO processing plant (Association of Producers of Ecological Yacon and Derivatives of Oxapampa (APYEDO)), Pasco, Peru. **D.** Right after peeling, the roots are submerged in cold water to prevent their turning dark.

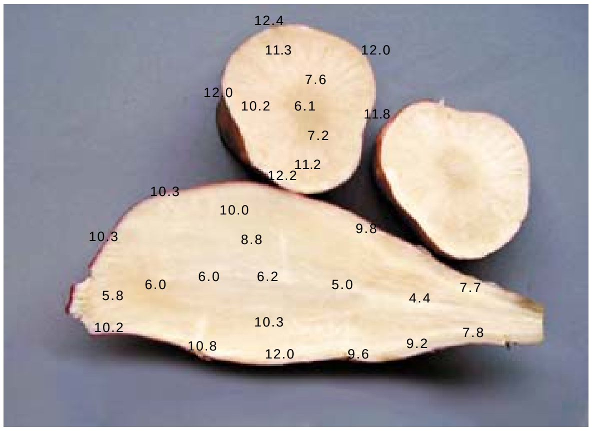


Figure 7. Distribution of sugars (° Brix) in yacon root. Observe that there is a gradient of growing concentration from the internal part toward the external part.

highest concentration of sugars is found. On the other hand, the skin contains the highest concentration of substances that are catalysts for the oxidation of the juice, which must be completely removed.

In preliminary tests conducted at the International Potato Center (CIP), it was found that the skin could easily be removed after being exposed to high-pressure steam in a domestic pressure cooker. The skin is released in a clean fashion, without wastage of the flesh, resulting in a significant saving of raw material in comparison with conventional peeling methods. A cost benefit analysis should be conducted in this area before considering investment in an industrial autoclave. An additional advantage of peeling using high-pressure steam is that it can help to deactivate the enzymes responsible for enzymatic oxidation.

Some varieties of yacon are not affected by the use of high-pressure steam for peeling. In these cases a method for peeling using a brushing machine has been designed at CIP (Butler & Rivera, 2004). The machine consists of a cylinder lined inside with resistant hard-bristled nylon brushes. This cylinder turns around a central axis and the roots are slowly peeled by mechanical friction against the brushes. The machine removes the resinous outer peel, but leaves the fleshy inner peel intact, leaving a high quantity of undesirable components in the yacon. To eliminate the flavor of these chemical compounds in the final product, any of the following strategies can be employed:

1) Trials are being conducted using additives to try to reduce the effect of these components in the flavor of the final product. Excellent additives are ascorbic acid and camu camu pulp (*Myrciaria dubia*), a fruit which grows in the Amazon, recognized as the richest natural source of ascorbic acid. The advantage of this method is that a significant saving is obtained over conventional peeling methods with losses of <1% of the raw material.

2) To eliminate the inner layer of the peel by chemical means. The roots are submerged for 20 seconds in a 3% caustic soda solution in a boiling state, then washed with an abundant amount of water and finally submerged in a 2% citric acid solution to neutralize the effect of the soda. Although the peeling method is effective, it still remains for future evaluation to determine if potentially toxic levels of caustic soda residues manage to remain in the final product.

4.4. Juicing the roots and oxidation control

A machine has been proposed similar to the one typically used for making carrot juice, for use in the process of yacon juice extraction. This machine consists of a revolving abrasive disk, which shreds the yacon and allows for the immediate separation of the juice from the solid waste (see section 6.1). This type of juicer is common and can be manufactured by most workshops without major difficulty. Tests should be carried out with the machine to ensure that the maximum amount of juice is removed from the solid matter. Typically 20% of the weight of the yacon is lost during the juicing process. In reality 80% of the solid waste is liquid that was not separated from the solids during juicing.

The advantage of a juicer that uses an abrasive disk as described above is that the juice is extracted very quickly before oxidation has time to occur, so an antioxidant can be added immediately to halt the process of oxidation. This is in contrast to other machines, such as pulpers and presses, where the juice is not quickly separated from the solid waste, thus allowing intense and irreversible oxidation to occur.

There are two options for reducing the amount of oxidation:

The first option is to use a thermal treatment on the recently extracted juice. For this a large receptor is used to collect the juice immediately after extraction. The temperature inside the receptor should be kept above 60ºC so that the polyphenoloxidase enzymes will be deactivated (the majority of enzymes permanently lose their activity at temperatures superior to this). Oxidation is therefore controlled by deactivating the enzymes responsible for the oxidation before it has time to occur.

The other option is to collect the juice in a receptor containing an antioxidant (Figure 8A). In this way the juice comes into immediate contact with an antioxidant which prevents oxidation from occurring. In tests conducted by the authors it was found that the use of 4 ml of lime juice (*Citrus aurantifolia* var. Sutil) for each liter of yacon juice can control the oxidation of the majority of yacon cultivars. Better results are obtained with the use of ascorbic acid (0.15 g for each kg of yacon root).

To gain a more complete antioxidant effect ascorbic acid can be combined with citric acid. One side effect of using citric acid is that it increases the acidity of the final processed product. This can help to inhibit the development of microorganisms in the bottled product. This also poses a problem because increased acidity greatly increases the rate at which FOS convert into simple sugars. For example, a product with pH = 4 will convert approximately 25% of its FOS into simple sugars after 6 months of storage, in contrast a product with pH = 3 will depolymerize approximately 45% in the same time period. For this reason care should be taken to ensure any citric acid used will not reduce the pH to less than 4.

4.5. Filtering the juice

The juice obtained from the extractor still contains small amounts of insoluble solids that should be eliminated before evaporation begins. If the juice is not filtered at this point, then the process of filtering the syrup is slow and labor intensive. The process of filtration involves forcing the juice through a porous membrane to separate the insoluble solid matter from the juice. This process can be carried out using a press filter (Figure 8B).

One simple, cheap alternative to a press filter is to use a fine mesh where the juice passes though the mesh by gravity. It is important,that the meshes used are made from a suitable material (such as stainless steel) and are constructed in compliance with the standards for food processing hygiene . The mesh pore size should not exceed a diameter of 100 μm.

4.6. Evaporation and concentration of the juice

The purpose of the evaporator is to increase the concentration of soluble solids (principally sugars) to the point where it reaches 70° Brix. In practice this level

Figure 8. Extraction and filtration of yacon juice. **A.** As the juice is extracted, it comes in contact with a solution of lime juice for the purpose of helping prevent its turning dark. **B.** The juice is immediately filt ered in a press filter.

of concentration is very difficult to achieve using a maple syrup evaporator so the juice is only concentrated to pre-syrup stage at a concentration of 50-60° Brix.

It is important that the process is continuous so that the syrup does not get a burned flavor. To achieve this, it is necessary to obtain a gradient of concentration during the evaporation process (Figure 9). The three parts of this process: receptor tank, evaporator and furnace, must be coordinated with care. What follows is a description of each of these components and their importance to the process.

The receptor tank:

This is the tank where the juice is stored temporarily after filtration, before being fed into the evaporator. The receptor tank has an exit valve that allows the user to control the flow of juice to the evaporator (Figure 9A). The control and regulation of this valve is crucial to maintaining a gradient of concentration in the evaporator. At the beginning the rate at which the juice enters the evaporator should be equal to the rate of evaporation of water, this should be maintained until the gradient of evaporation in the evaporator has been established (Figure 9B). This can be achieved by ensuring that the depth of juice at the point where the juice enters the evaporator should remain constant (approximately 3 cm).

The evaporator:

The evaporator is the device in which the water is evaporated from the juice. The evaporator consists of a tray separated by dividing barriers to create channels for the juice to flow along. The juice enters the evaporator at one extreme end and flows through the channels until it reaches the opposite corner where it leaves the evaporator as a pre-syrup (Figure 9). The juice that enters the evaporator replaces the volume of water that has been evaporated (Figure 10A) and is of a constant depth throughout the evaporator (this is so that the syrup does not burn). As the process stabilizes the concentration gradient is established in the evaporator from 10° Brix (average value of yacon juice) to 50-60° Brix (the maximum level attainable in the evaporator).

When the concentration gradient is established, the drainage valve should be opened to remove the pre-syrup from the evaporator (Figure 10B). At the same time the exit valve from the receptor should be opened further to compensate for the syrup that is being drained off. This operation should be repeated at regular intervals, frequent enough to prevent burning of the pre-syrup in

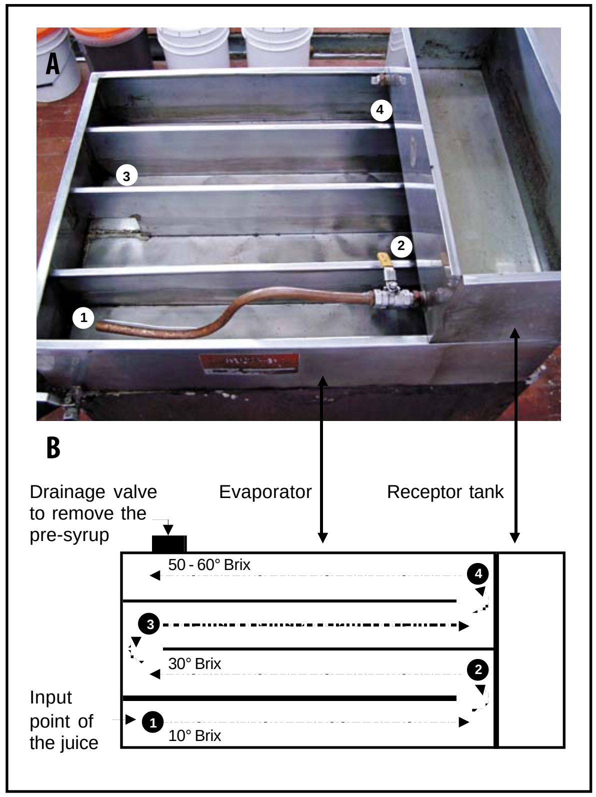


Figure 9. Evaporator design. **A.** The evaporation ray is divided by several internal channels which help increase evaporation efficiency. The reception tank has a valve to regulate the volume of the juice entering the evaporation tray. **B.** The yacon juice enters the tray, usually with 8 to 12° Brix (depending on the refractometric index of the roots) and, flowing to the other end of the evaporator, the concentration will increase to between 50 and 60° Brix.

the evaporator, but not too often, in order to maintain the concentration gradient. The use of the refractometer to test the syrup near the outlet can help to determine the time interval.

The furnace:

Depending on the location of the processing plant (i.e. rural or urban) and the availability of different types of fuels, an appropriate furnace can be selected. Furnaces can be designed to burn wood (Figure 10C), oil, propane or natural gas. In the case of propane- or oil-burning furnaces an even heat distribution is achieved, which promotes the correct operation of the evaporator. Caution should be used when using wood-burning furnaces so that a uniform temperature distribution is maintained.

The use of hard wood is preferable to softer woods, which tend to give off more intense energy while burning. In the mountains, eucalyptus (*Eucalyptus*

Figure 10. Different stages of processing. **A.** Evaporation of yacon juice. **B.** Obtaining the pre-syrup (50 to 60° Brix). **C.** Feeding blocks of firewood into the furnace. **D.** Filtering. **E.** Concentration of the pre-syrup in small trays to between 68 and 70° Brix. **F.** Final concentration of syrup (72 a 74° Brix) and bottling.

globulus and *E. tereticornis*) is widely grown and is of excellent quality for use as firewood. In the jungle regions, the pacae tree, particularly the Inga edulis, a species that is found in abundance in the Amazon, is commonly used as firewood. Any wood that is used should be seasoned long enough to allow it to dry fully. Small pieces of wood should be uniformly placed in the furnace in order to achieve an intense, well distributed heat inside the furnace. This is important, since only with an intense, uniform heat can the concentration gradient can be maintained. Wood should also be replenished in the furnace at the rate it is burned, so that the intensity of the heat remains more or less constant.

4.7. Filtering the pre-syrup

During the evaporation process, foam forms on the surface of the syrup and sugars begin to crystallize. These should be filtered out of the pre-syrup after leaving the evaporator. Either a press filter or a fine mesh filter with pores not exceeding 100 μm can be used for filtration (Figure 10D).

4.8. Final concentration

The pre-syrup (50-60° Brix) needs to be further concentrated to form the final syrup (72-73° Brix). This is done in finishing pans that are much smaller than the evaporator (Figure 10E). This reduces the amount of time that the syrup is exposed to heat, therefore reducing risk of burning and excessive caramelization. It is a simple finishing process where the pre-syrup is introduced into the finishing pans, which are placed over a heat source. The syrup is then boiled until it reaches a concentration between 68 and 70° Brix. The heat source can take the form of a domestic propane stove.

4.9. Filtering the syrup

The syrup should undergo a final filtration to eliminate crystallized sugars that formed during the finishing process. It is important that the concentration of the syrup does not exceed 70° Brix since it is likely to increase by 1 or 2° Brix as it cools. This filtration can be carried out using a fine mesh filter with pores not exceeding 100 μm diameter (Figure 10D).

4.10. Bottling

This process requires the use of a stainless steel dispensing tank (Figure 10F). The tank has a valve where the syrup exits the tank and enters the flask. Before bottling, the temperature in the tank must be above 85°C and the concentration of the syrup must be 72° Brix. These measures help to reduce the chance of microorganisms developing in the bottled produce.

The 60 μm filter can easily be placed and removed from the top of the dispensing tank. This way the dispensing tank has the double function of performing the final filtration and dispensing the syrup into the flasks (Figures 10B and 10F).

Chapter V

The syrup

Yacon syrup has a very distinctive yet pleasant flavor. Consequently it is very difficult to make a direct comparison with similar products. Preliminary tasting trials have demonstrated that the level of acceptance is very high. Yacon syrup, as presented in this manual has the following characteristics.

- Concentration of soluble solids equal to 73 ± 1° Brix
- Density is 1.350 g/ml
- pH between 4.2 – 5.8. Care should be taken to ensure that the pH level does not fall below 4, or else the FOS begin to break down into simple sugars during storage.

5.1. Coefficients of production

The conversion from roots to syrup varies in efficiency from 7-10%, which is to say that to obtain 1 kg of syrup, between 10 and 15 kg of washed yacon roots are required. The soluble solids content of the raw material is the factor that most affects the conversion efficiency of the syrup. For example, to obtain 1 kg of syrup, 6 liters of yacon juice are required if it has a concentration of 12° Brix, but 9 liters are required if it has a concentration of 8° Brix (Figure 11). The use of large, uniformly shaped roots, which are easy to peel and have less waste from peeling, also affects the technical coefficients. Finally the insoluble solids can be pressed to extract any remaining juice that can be added to the production. Moisture accounts for approximately 80% of the weight of insoluble solids collected at the juicer.

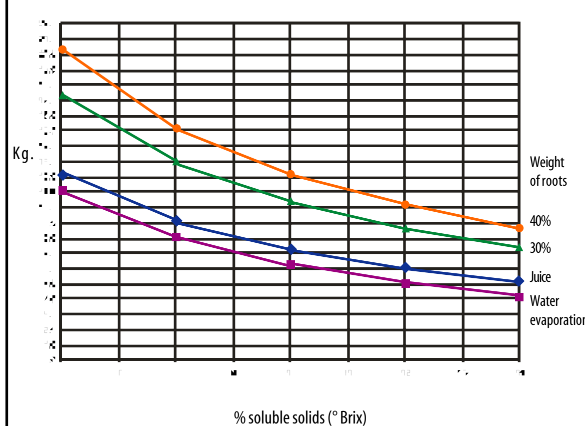


Figure 11. Conversion factors for producing 1 kg of syrup (73° Brix) in function of the initial contents of soluble solids in the yacon juice. Orange and green lines: weight of roots with different levels of wastage (40 and 30% respectively). Blue line: volume of juice. Purple line: quantity of water requiring evaporation. **Observations. 1.** The waste includes the loss of raw materials in the peeling, bagasse and filtration. **2.** The density of the juice is 1 kg/l and of the syrup 1.35 kg/l. **3.** The weight of the roots refers to the unpeeled roots.

5.2. Chemical composition

Carbohydrates account for 65-70% of yacon syrup and water accounts for approximately 25%. Proteins account for between 1 and 2% and fat accounts for > 0.1% of fresh weight. Potassium is the only micronutrient found at significant levels and accounts for approximately 1%. FOS can be considered as a soluble fiber (Coussement, 1999) therefore the FOS level in the syrup can also represent the level of fiber.

The concentration of carbohydrates in the raw material can vary widely (see section 2.3 and 2.4). For this reason, the concentration of FOS can vary greatly in the syrup. Table 3 shows the concentration of FOS in syrup produced from two varieties of yacon: AMM5163 and Hualqui. From the table it can be seen that the concentration of FOS varies from 50% for AMM5163 to

Table 3. Differences in chemical composition (%), the caloric content (kcal/100g syrup), and the pH in two lots of syrup elaborated with two cultivars of yacon: CCLUNC118 (Hualqui cultivar) and AMM5163.

Variable	CLLUNC118 (Hualqui)	AMM5163
Total ash	2.9	2.3
Fat	0.1	0.0
Moisture	25.5	22.0
Crude protein	1.3	1.0
FOS (= soluble fiber)	10.9	47.6
Free glucose	15.5	2.6
Free fructose	25.4	7.9
Free sucrose	12.2	20.0
Caloric content (kcal)	265	164
pH	5.0	5.4

as low as 10% for Hualqui. This illustrates the enormous variation in FOS content that can exist.

5.3. Caloric content

In general terms, the caloric content of carbohydrates is 4 kcal/g. FOS, being a special type of carbohydrate, has a caloric content of between 1 and 1.5 kcal/g (Roberfroid, 1999). A major problem in determining the caloric content of products containing FOS is that most laboratories do not have a method of quantifying FOS content and distinguishing them from other carbohydrates. This causes most laboratories to overestimate the caloric content of yacon syrup.

The caloric content of yacon can vary from 1.64 kcal/g to 2.65 kcal/g. This wide range is directly related to the FOS content of the syrup. Figure 12 shows the relationship of FOS content to the caloric content of yacon syrup.

5.4. Shelf life

For syrup that is bottled without preservatives and with an acidity of pH = 5 the shelf life can be quite long either with or without refrigeration (Figure 13). Preliminary tests at the International Potato Center show that after twelve months of storage, the syrup does not spoil, and its chemical composition changes very little.

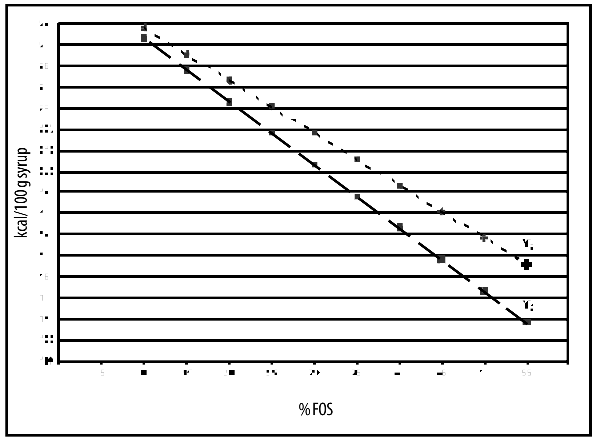


Figure 12. Expected lines of regression (Y_1 and Y_2) for the caloric value of 100 grams of yacon syrup in function of the FOS contents. For Y1 and Y2 is considered the value of 1.0 kcal and 1.5 kcal for each gram of FOS, respectively.
Assumptions:
1. Calorie content: G, F, S = 4 kcal/g, proteins = 4 kcal/g, fat = 9 kcal/g.
2. A constant concentration of 1.2 g of protein and 0.05 g of fat for each 100 grams of syrup is always assumed.
3. The percentage of simple sugars (G, F and S) is the result of subtracting the percentage of FOS from 72 (total soluble solids in the syrup).
FOS = fructooligosaccharides, F = fructose, G = glucose, S = sucrose.

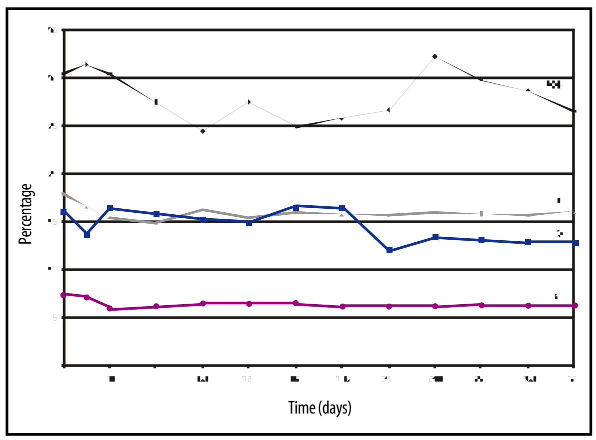


Figure 13. Content of sugars (FOS, glucose, sucrose and fructose) in yacon syrup during storage at room temperature (25° C) for eleven months. The variation observed in the valves showed is due to the method of analysis used.

5.5. Uses, modes of consumption and properties

Yacon syrup can be used as a sweetener for a variety of products including fruit salads, juices, hot beverages and deserts, among others. Yacon syrup has very similar characteristics to other products such as honey, cane sugar syrup or molasses (known in Spanish as miel de chancaca), and maple syrup, and can be considered as a hypocaloric substitute for these products (Table 4).

Few studies have been carried out on the specific effects of yacon syrup on human health. There is much scientific literature available, however, on the effects of FOS on human health (Andersson *et al.*, 1999). Based on studies on the effects of FOS on human health, the likely properties of yacon syrup can be summarized:

1. Yacon syrup is naturally low in calories (40-50% fewer calories than honey), and so can be considered suitable for dieters and people who are overweight or obese.
2. Consumption of yacon can promote better health of the gastrointestinal tract. FOS have a bifidogenic effect, which is to say the consumption of FOS causes a proliferation of *Bifidobacteria*, a group of beneficial bacteria in the colon. These bacteria are associated with many physiological processes leading to better health of the gastrointestinal tract.
3. Oral bacteria that cause dental cavities are not able to metabolize FOS. For this reason the consumption of FOS is better for oral health than similar products, reducing the risk of cavities.
4. Physiologically FOS behave like soluble fiber which helps maintain regular bowel movements, so yacon syrup could be employed to prevent constipation.
5. Some studies have suggested that the consumption of FOS can help the body absorb calcium, folic acid, and B-complex vitamins. It has also been shown that FOS can help to reduce cholesterol and triglycerides in the blood, reduce the risk of colon cancer and fortify the immune system.
6. Several studies have shown that the consumption of FOS does not increase the level of sugar in the blood. This is also true for people with Type 2 Diabetes. (Alles *et al.*, 1999). However yacon syrup also contains other sugars, although in lower levels that FOS, which rapidly increase the glucose in the blood. Clinical studies should therefore be carries out to evaluate appropriate consumption level for diabetics.
7. Several years ago the concept of nutraceutical food started in Europe, referring to any food that, irrespective of its nutritional values, has beneficial effects on the health of the consumer. Yacon syrup would be a good candidate for this list of products.

Table 4. Caloric value of yacon syrup in comparison with similar products on the market.

Product	Brix (°)	kcal/100g of product
Yacon syrup	73	164 – 265
Maple syrup	66	252
Honey	82	304

The majority of properties listed above are only speculative and have not necessarily been studied exhaustively. Future clinical trials should be carried out on humans to confirm the effects of yacon syrup on human health. This manual is primarily dedicated to the dissemination of an efficient technology for the processing of yacon syrup in the public domain. However, it is also important to consider the uses and benefits of the product for human health. This is intended to avoid patents or other forms of intellectual property rights being asserted for yacon syrup and associated processing technology.

5.6. Quantity of consumption

It is known that excessive consumption of FOS causes flatulence and diarrhea. The majority of scientific studies show that consumption levels less than 20 g/day do not cause these undesirable side effects. As a general guide it is suggested that general consumption should not exceed 0.3 and 0.4 g per kilogram of body weight for women and men respectively. Doses greater than 20 g/day can cause flatulence and doses superior to 50 g/day can cause diarrhea.

The recommended daily consumption without great risk of any side affects of yacon syrup is 40 g/day. This assumes that FOS represent 50% of the chemical composition of the yacon syrup, for cases where FOS are found in lower levels, a higher consumption can be tolerated without any consequences. For this reason it would be useful to specify the FOS content on the product label. Several companies have begun to manufacture and commercialize yacon syrup in Peru (Figure 14), few of these display the FOS content on the label.

In one study undertaken at Peru's Cayetano Heredia University, it was reported that yacon syrup had a very low postprandial glycemic effect on people with Type 2 diabetes. This suggests that yacon syrup can be consumed by people with type 2 diabetes since it little affects the level of glucose in the blood (Seclén *et al.*, 2005). Though these results are promising, it is necessary to carry out additional tests to establish suitable dosage levels over an extended period of time.

Figure 14. Some brands of yacon syrup are commercialized in the Lima market.

In reviewing the literature for the preparation of this manual, no references or documents were found regarding toxic effects associated with the consumption of FOS. There is therefore no reason to believe that the consumption of yacon can lead to allergic or toxic reactions. On the contrary, yacon has been consumed, occasionally in large quantities, for centuries in the high Andean Mountains and there have never been any references made to toxic, allergic, or any other unusual reaction associated with yacon (Seminario *et al.*, 2003).

Chapter VI

Equipment

6.1. Juicer

The following points could be useful for the design of a of a semi-industrial juicer (Figure 15A).

Motor

For the motor to be able to operate continuously for several hours it must have a minimum power rating of 2 HP. The motor should be able to rotate a t a rate of 7000 rpm to enable the abrasive disk and perforated cone to effectively separate the juice from the insoluble solid matter. A machine of lower specifications is also likely to have a shortened life.

Abrasive disk

This circular disk has small sharp edges embossed onto its flat surface (Figures 15B and 15C). The disk, which is made of stainless steel, is turned at high rotational velocity by the motor shredding the raw material in the process. The higher speeds of rotation increase the efficiency of the process of separation of juice from insoluble solid matt er.

Perforated cone

This is a cone-shaped laminate made with perforated stainless steel (Figures 15B and 15C). The perforated cone acts as an internal filter separating the juice from the insoluble solid waste. In order to achieve a good level of filtration, minimizing the quantity of insoluble solid particles in the juice, the perforations in the cone should be as small as possible (about the diameter of a pin point). The perforations should b e located densely throughout the cone.

Channels for the juice, roots and waste

The peeled and disinfected roots usually enter through an opening in the top of the juicer. The diamet er of the opening should be large enough accommodate whole yacon roots. The machine has two exit channels, one for the outflow of juice and the other for the insoluble solid waste. The exit channel should be designed in an open fashion to allow for the total evacuation of solid mat er, ther efore allowing the machine to op erate continuously without its needing to be disassembled for the removal of solid waste. The exit channel for the juice should be designed so that a hose can be attached, guiding the juice to a receptor (Figures 15A and 15C).

6.2. Press filter

This consists of a system of plates stacked on top of each other, each separat ed from the other by a sheet of filter paper or cloth (Figures 15D and 15E). Pressure is used to force the yacon juice through the plates. The solids that are present in the juice are caught in the filter papers between the plates. In this way the juice is filtered, greatly reducing the number of particles suspended in it, which will give it a more translucent appearance.

As an alternativ e to the pr ess filter, a simple mesh filter can be employed. In this system the juice passes through the mesh with the aid of gravity into a tank (Figure 15F). The disadvantage of this system is that it is slow, working without the aid of a pump to force the juice through the filter. A mesh with pores not exceeding 100 µm diameter should be used to filter juice and another mesh <100 µm to filter the syrup.

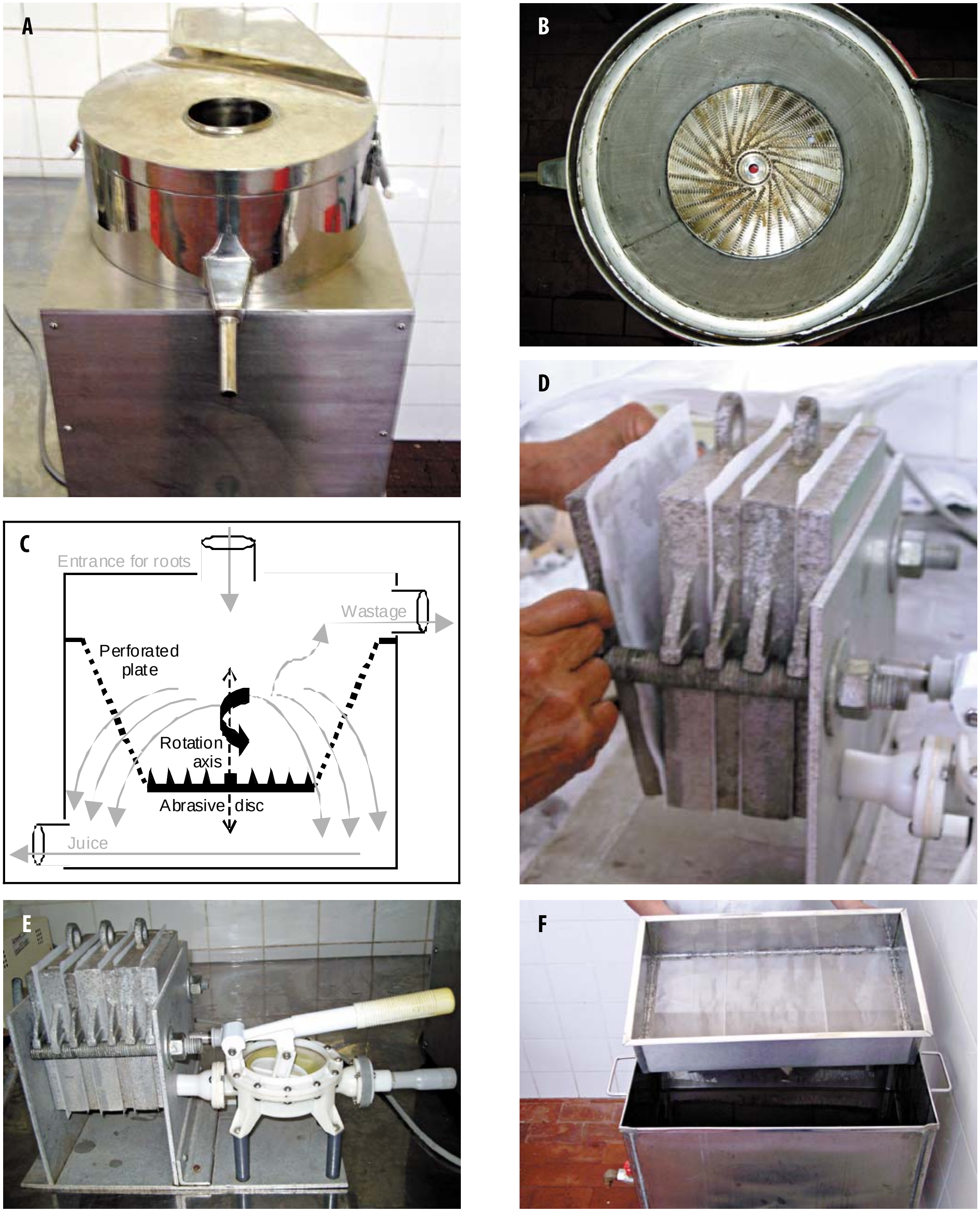


Figure 15. Some equipment utilized for processing the syrup. **A.** Juice extractor (note that the diameter of the opening of the feeding conduit is sufficiently wide for a whole large yacon root). **B.** Detail of perforated plate and abrasive disc of the juice extractor. **C.** Building plan of the perforated plate and abrasive disc (frontal view of lengthwise cut). **D.** Preparation of press filter **E.** Details of a press filter operated with mechanical pressure pump. **F.** Filtration tray and dispenser tank.

6.3. Dispenser

This is the device used to store the syrup and dispense it into the bottles. This consists of a reservoir equipped with a thermometer and a drainage valve. The thermometer is to help control the temperature of the syrup inside the dispensing tank. The drainage valve allows the flasks to be filled with syrup at between 86 and 96°C. A mesh with 100 µm pore diameter can be placed over the dispensing tank to filter the syrup before it enters (syrup should be at 68 - 70° Brix) the tank (Figure 10D and 10F).

6.4. Evaporator

This is a central item of equipment, which has already been described in detail in section 4.6 and Figure 16.

The evaporator and dispensing tank are made entirely of stainless steel. The dividers separating the channels in the evaporator are also made of stainless steel and are soldered into place with lead free solder. To avoid excessive heat loss and to maximize efficiency, the furnace should be made of a heat resistant material and should be lined on the inside with high temperature firebricks and refractive cement. This type of equipment can be imported, or it can be constructed in a local workshop. The following are useful Internet addresses for companies which sell maple syrup evaporators:

www.webathena.com/leader/site/
www.bascommaple.com/index.html
http://martinsmapleform.com/index.cfm

Further information about evaporators can be obtained from the book *North American Maple Syrup Producers Manual.* (1996). Bulletin 856 (Koelling and Heiligmann (eds.), Cleveland: Ohio State University Extension.

Figure 16. Evaporator. **A.** Complete view of evaporator: furnace, evaporation tray, reception tank and chimney. **B.** The evaporator in operation.

Chapter VII

Conclusions

Yacon is a root, traditionally consumed as a fresh fruit. It has not been widely cultivated as a commercial crop for several reasons.

a. Yacon is perishable and its nutritional content degrades significantly while in post harvest storage.
b. Significant losses from roots that are either too large or too small for sale.
c. High transportation costs of raw materials (90% of the weight of fresh yacon is in the form of water).
d. High costs associated with damage to the roots during transit.

Production of yacon syrup will help to overcome some of the problems above, associated with the cultivation of yacon. These include:

a. The syrup can be stored for several months without significant reduction in the nutritional quality of the product.
b. Waste from roots that cannot be processed due to size is minimal.
c. Transportation costs can be reduced by up to 90% because the syrup contains much less water than the roots.
d. There is no wastage associated with transportation.
e. Processing yacon into syrup generates jobs.
f. Production of yacon syrup generates aggregated value for the product in or close to the location where the yacon was grown.
g. Creates a new way of consuming yacon.

This manual presents a simple, easy to implement technology (Appendix) for the production of yacon syrup. Many of the processes within this technology can be improved. These include:

a. Manual peeling of the roots is an inefficient process, causing the loss of approximately 20% of the root weight. Peeling also requires a large amount of labor.
b. The juicer eliminates insoluble solid waste that contains a large amount of yacon juice (approximately 80% of the weight of insoluble solid waste is yacon juice).
c. Different types of fuel (coal, oil and natural gas) can be used to provide the heat necessary for the evaporator. Firewood is scarce in many places and its use often contributes to environmental degradation. Efficient technologies using clean fuels exist mainly for large-scale processors, which are rarely located close to the area of cultivation of yacon. It is important that yacon is produced in the area where it is grown not only because of losses and costs associated with transportation of the raw material, but also to promote a better image of yacon syrup and potentially provide entrance into the fair trade market.

Yacon syrup is a product that could be well positioned in the market of natural low calorie sweeteners. Preliminary tasting trials have indicated that there is potentially a large market for this product. Yacon syrup could also be well positioned as a nutraceutical product since legislation in several countries recognizes the bifidogenic effects of FOS and the beneficial effects of this on human digestive health (Coussement, 1999). There are many other promising effects of yacon syrup, which could potentially be beneficial to human health. These effects need to be exhaustively researched. If further beneficial effects are definitively established, they will provide further marketing opportunities for yacon syrup.

Recent scientific studies suggest that yacon might have properties that can be used in the treatment of diabetes. Studies have shown that the consumption of yacon roots reduces the amount of sugar in the blood of clinically healthy people (Mayta *et al*., 2003) and also people with type 2 diabetes (Seclén *et al*., 2004). These results are consistent with earlier studies on laboratory animals with induced diabetes (Galindo and Paredes, 2002; Rodríguez and Soplopuco, 2004). Though these are preliminary studies, they open the doorway for further research into whether yacon syrup is a beneficial product for diabetics.

Chapter VIII

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Appendix

Cost analysis (in S/.) for a yacon syrup processing plant with a 30 kg per day capacity. Referential costs to December 2001 (1 US$ = S/. 3.4).

Fixed costs

	Initial cost	Useful life	Cost per year
1. Infrastructure			
Construction, simple	3000	10	300
Services (water, light, others)	1200	1	1200
2. Machinery			
1 Evaporator	3400	5	680
1 Filtration tank	748	10	75
2 Refractometers	1190	5	238
2 Juice extractors	9860	3	3287
1 Gas stove	204	5	41
1 Current stabilizer	680	5	136
Other (pails, trays, peelers, etc.)	680	2	340
Total annual fixed costs			**6297**
Fixed costs per day of production*			**25.2**

* Considering 250 days of production per year.

Variable costs (for one day of production)

	Quantity	Unit cost	Cost for 30 kg of syrup
1. Raw materials (kg)			
Yacon roots	420	0.3	126
Limes	10	4	40
Firewood	30	30	30
2. Labor (day of labor)			
Washing	1	15	15
Peeling	3	15	45
Juice extraction and evaporation	2	15	30
Packaging	1	15	15
3. Packing and transport			
400 g Bottles	75	0.6	45
Shipping (Provinces-Lima)	1	30	30
Total variable costs per day of production			**376**

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