UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias Químicas e Ingeniería

Sweetener of natural orgin: Proposal for development and small-scale production of a yacón-based sweetener (*Smallanthus sonchifolius)*

Trabajo de integración curricular presentado como requisito para la obtención del título de Petroquímico

Autor:

Muñoz Mejía Yamileth Jazmín

Tutor:

Areias Filipe PhD

Urcuquí, Septiembre 2020

UNIVERSIDAD YACHAY TECH

Urcuquí, 13 de noviembre de 2020

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DEDICATION

I want to dedicate this work, especially to my parents Flor and Wilson, because without them, this would not have culminated because of the patience, effort, support and, love that they have given me. Also, to my siblings Joselin and Jeffrey.

Without my family this would not have been possible, this degree project has been the culmination of one more step, of my professional training which I have achieved with great effort.

Jazmín Muñoz

ACKNOWLEDGMENT

I thank my University Yachay Tech, School of Chemical Science and Engineering to give me the opportunity to be part of their academic formation.

To thank my tutor and dear friend Filipe Miguel Areias, PhD, Professor of Yachay Tech, who with, his effort and knowledge, has managed to lead me in the best way in my degree project also, I want express my sincere and deep gratitude.

To thank my dear friend and Professor José Ángel Rivera, PhD, for the help and knowledge given for the development this project.

Jazmín Muñoz

RESUMEN

En el presente trabajo se llevó a cabo el desarrollo de una propuesta de un edulcorante natural a base de yacón, el cual es un tubérculo de la familia Asteraceae que almacena los carbohidratos en forma de fructooligosacáridos (FOS), cadenas de azúcares de 2 a 9 unidades, a diferencia de otros que lo hacen en forma de almidón. Se realizó una revisión bibliográfica de los diferentes edulcorantes naturales, su composición química, y su producción entre ellos el endulzante a base de la raíz de yacón, en el cual nos vamos a enfocar en el siguiente trabajo, se describen los beneficios en la salud con el consumo de yacón, así como también las técnicas de caracterización con TLC, HPLC, UHPLC en las cuales se registran las cantidades de FOS, y ácidos fenólicos en las diferentes partes de la planta y en diferentes formas como en extracto, jarabe, jugo tanto como de la raíz y de sus hojas. Se registró una recopilación de los compuestos existentes en pequeñas cantidades, las cuales datan en la mayoría de la revisión bibliográfica, el ácido clorogénico, ácido cafeíco y ferúlico

En la parte experimental se desarrolló un protocolo para la elaboración del edulcorante a base de yacón, el cual tuvo lugar en las instalaciones de la Universidad de Tecnología Experimental Yachay Tech, debido a la situación de pandemia se llevó a cabo parte de la experimentación de forma casera, en la cual se obtuvieron datos para el posterior desarrollo de un pequeño escalamiento de una planta productora de edulcorante natural a base de yacón. Se realizaron los cálculos pertinentes con los porcentajes obtenidos en la parte experimental.

Al finalizar el escalamiento del proceso se llevó a cabo el estudio económico para el procesamiento de 25 toneladas por mes, y 83 kg de raíz de yacón por día, trabajando 12 horas diarias, teniendo en cuenta la inversión para maquinaria necesaria, la materia prima, el personal adecuado, y demás implementos para el desarrollo de la puesta en marcha de la planta de edulcorante de yacón.

Palabras clave: Fructooligosacáridos, prebióticos.

ABSTRACT

In the present work, it was carried out the development of a proposal for a natural yacón-based sweetener, a tuber of the Asteraceae family, stores carbohydrates in the form of fructooligosaccharides (FOS), chains of sugars of 2 to 9 units, unlike others which store carbohydrates in form of starch. A bibliographic review of different natural sweeteners, its chemistry composition and its production was made in this work. The examples given in the natural sweeteners, in the present document will focus on the sweetener yacón root based. It is described the health benefits of yacón consuming, as well as the characterization techniques with TLC, HPLC, and UHPLC, in which the amounts of FOS, and phenolic acids in the different parts are recorded of the plant and in different forms such as extract, syrup, juice as well as the root and its leaves. A compilation of the existing compounds in small quantities was recorded, which date from most of the bibliographic review, chlorogenic, caffeic and ferulic acid.

In the experimental part, a protocol was developed for the elaboration of the yacón-based sweetener, which took place in the facilities of the University of Experimental Technology Yachay Tech, due to the pandemic situation, part of the experimentation was carried out homemade, in which data were obtained for the subsequent development of a small scale-up of a plant producing natural sweetener based on yacón. The pertinent calculations were made with the percentages obtained in the experimental part.

At the end of the process scaling, the economic study was carried out for the processing of 25 tons per month, and 83 kg of yacón root per day, working 12 hours a day, taking into account the investment for necessary machinery, the raw material, the personnel, and other implements for the development of the start-up of the yacón sweetener plant.

Key words: Fructooligosaccharides, prebiotic.

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CHAPTER I

1. Introduction

In Ecuador according World Health Organization (2020), diabetes is a disease that prevails in 1.7% in ages 10 to 59 years, these percentages increase at the age of 30 years old and when the person reaches 50 years old, one of each ten adults of 50 years has diabetes, due to several factors, including poor diet.

In the last 50 years, the population have adopted a production and feeding system with high calorie diets and processed food, which increase the risk of diseases such as obesity and diabetes, according scientific investigations is stated that, healthy diets and a better lifestyle would reduce the 19% to 23.6 % the premature deaths (LAVANGUARDIA, 2019).

Currently, the sugar consumption in Ecuador has decreased by 10% because of the increase of diabetes patients (Jiménez Calispa, 2019). In the world, the percentage of sweeteners consumption has grown by 0.1% each year in the last ten years, replacing common sugar with natural or artificial sweeteners (OCDE/FAO, 2017).

The increase in the percentage of diabetes and obesity population in Ecuador, has been the cause for use an alternative of sucrose in these patients. Those are the reasons that let develop a proposal for the elaboration of a natural sweetener based on yacón.

Yacón (*Smallanthus sonchifolius*) is a root own of the Andean zone, which has not been studied so much and is not used a lot. During the last years has aroused great interested in its investigation, due to this tuber is a rich source of fructooligosaccharides (FOS), which are a kind of soluble fiber with a low polymerization degree (PD), it goes from 2 to 9 units of fructose and terminal glucose (Ojansivu *et al.*, 2011; Zarate Paucarpura, 2016). Those roots have a benefit in human health and have a sweet flavor, which can be used as an alternative sweetener of sucrose in the food industry (Zarate Paucarpura, 2016).

The purpose of this investigation is the elaboration of a yacón-based sweetener, which has benefits for the human health. This sweetener is not just a sweetener also, it helps to reduce the glycemic index (GI) for people with diabetes as well the ones who want to prevent the disease. On the other hand, due to the FOS presence, non-digestible soluble fiber, act as a prebiotic which will benefit the intestinal flora, and prevent the colon cancer, moreover, it is used for combat the obesity (Caetano *et al.*, 2016). So, yacón sweetener is considered as a nutraceutical product for the healthy properties that it has.

The sweetener is developed in the laboratory with a sequence of steps such as the washing, peeling, trituration, filtration, concentration, and packaging. Those are the basic steps that will be detailed in the following pages for a better understanding.

The current manuscript presents an evaluation of yacón properties for an elaboration of sweetener and develops a protocol of yacón sweetener production in the laboratory. In this experimental part, it was developed a proposal for small industrial scaling and finally it is shown an economic analysis for the installation of a small plant yacón-sweetener production.

1.1. Problem Approach

In Ecuador, there is no production of yacón syrup as a sweetener in big scale, which is a native root of South America that doesn't have an added value. Also, the big interest in changing the province's productive matrix and the need for technology production to process raw materials internally in the country and not import processed products from abroad. Then in this work we propose the develop of a process to obtain yacón sweetener based in the objectives bellow.

1.2. Objectives

1.2.1. General Objective

To develop a process of obtention of natural sweetener yacón-based, a new alternative for the change of productive matrix in Ecuador.

1.2.2. Specific Objectives

- To specify the yacón properties for the elaboration of a sweetener rich in FOS.
- To evaluate the experimental production of a sweetener in a laboratory scale.
- To design a system to small scale for the extraction and production of a yacón sweetener based in the experimental part.
- To develop an analysis of the economic viability of the project.

CHAPTER II

2. BACKGROUND AND LITERATURE REVIEW

2.1. Sweeteners

The sweeteners are any natural or artificial substance that sweetens. Also, they are the common constitutes of foods, some of them can be considered as a food additive. Nowadays, the most popular sweetener consumed is the common sugar. Commonly, sugar comes from beet and sugar cane, a restricted disaccharide for people with diabetes, obesity, atherosclerosis, and nonalcoholic fatty liver disease problems (Giannuzzi & Molina Ortiz, 1995; Mérillon & Ramawat, 2018). These are the reasons why the pharmaceutics and food industries have been working to develop a substitute, low in calories (de Landaverde, 2014).

An ideal sweetener has to have the following characteristics, a high degree of sweetening, pleasant taste without a bitter taste, color or odor, one that solubilizes quickly, be stable, functional and economical, not toxic, and do not cause dental caries. Also, it should not be hygroscopic, and it has to be metabolized or excreted normally (Angelini *et al.*, 2018; Giannuzzi & Molina Ortiz, 1995).

2.2. Sweeteners Classification

According to Das & Chakraborty (2018), the sweeteners have been classified according to the following groups, low and high potency sweeteners, nutritive and non-nutritive sweetener and artificial and natural sweeteners, in the present document it is going to be focused in the natural ones.

2.2.1. Artificial or synthetic sweeteners

Those sweeteners are substitutes for sugar, which are artificially processed. The principal value-added is that they are low in calories and give more sweetness than common sugar. Nowadays, artificial sweeteners are used as a substitute of sugar in the food industry, for people with diabetes and obesity (de Landaverde, 2014). However, there is a debate about the risk in human health because they are a possible carcinogen, despite that they are considered as safe food additive. The sweeteners that have been approved for international organizations for its consumption are acesulfame, aspartame, cyclamate, saccharin, and sucralose (Das & Chakraborty, 2018).

2.2.2. Natural sweeteners

The natural sweeteners are named of this form, due to they come from of a natural source that can be of plants as well; it can come from animals, as is the case of honey, that comes from bees. Most natural sweeteners, such as honey and common sugar, have a high caloric value, however, there is others with low caloric value such as the stevia (de Landaverde, 2014).

Those natural alternatives of sugar involve plant saps/syrups such as maple syrup, agave nectar, syrups made from raw sugar and grains, such as molasses, barley malt, and brown rice syrup. Another natural alternative of sucrose, which have a low GI is the lucuma (*Pouteria obovata*) and yacón, which do not need any refining process. One more example is stevia and liquorice (Glycyrrhiza) however, they still not have a great application in the food industry. An additional one is the black locust (*Robinia pseudoacacia*), a tree located in the southeast of Europe. The flowers of this tree are approached for the honey production (Das & Chakraborty, 2018).

2.2.3. Examples of Natural Sweeteners

2.2.3.1. Stevia

Stevia (*Rebaudiana bertoni*), see Figure 1, is a shrub typical of South America, although it has already spread throughout the world. This species belongs to the Asteraceae family. The sweetness that is specifically extracted from its leaves depends on the different cultivation factors applied, which ones can guarantee high performance and can reduce the production cost, which can be beneficial for the agricultures. Nowadays, this sweetener is used for drinks, processed foods and personal hygiene products (Angelini *et al.*, 2018; Gasmalla *et al*., 2014).

Figure 1. Stevia *(Rebaudiana bertoni)* (Pineda, 2020).

2.2.3.1.1. Benefit Properties

Stevia has benefits in human health such as antimicrobial, anti-diarrheal, anti-tumor, anti-inflammatory, diuretic, and immunomodulatory actions. Stevia is indicated for the regulation of blood sugar and insulin; it is shown that people with diabetes type II which consumes stevia, can achieve reducing the GI in 18%; also, the stevia extract decreases oxidized LDL cholesterol and triglycerides, and lowers high blood pressure in patients with mild to moderate hypertension (Angelini *et al*., 2018; Lafelice, 2014).

The use of stevia reduces the high levels of the GI, and high blood pressure but not affect people with normal levels of glucose and pressure, so it has made its consumers have a better quality of life (Lafelice, 2014).

2.2.3.1.2. Chemical Composition

The stevia leaves have metabolites with a sweet flavor, ent-kaurene diterpenoid glycosides, which have the foremost active sweeting taste in stevioside and rebaudioside A (Gupta *et al.*, 2016). Those are low in calories and intensive sweeteners more powerful than sucrose. Also, they can replace the common sugar. It has a sweetening power of 50 to 100 times more than sucrose (Angelini *et al.*, 2018). The structure of them are shown in Figure 2.

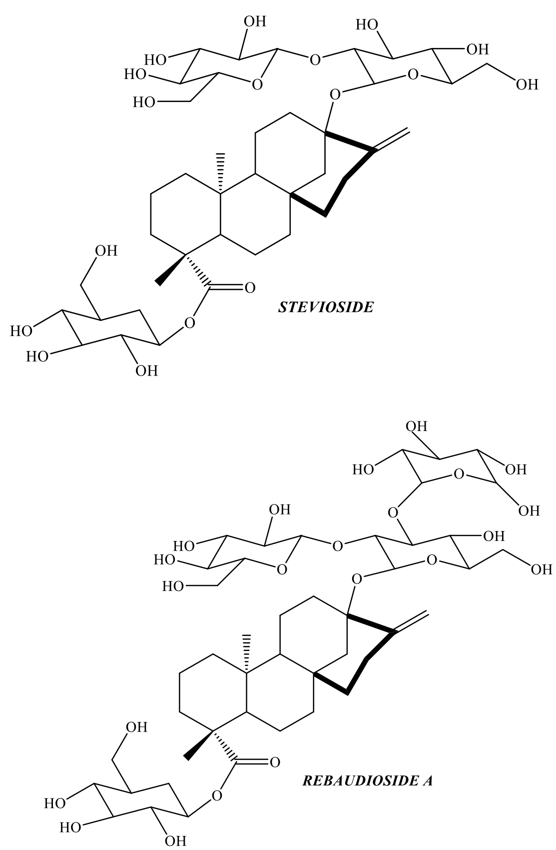

Figure 2. The sweet structures of ent-kaurene diterpenoid glycosides, stevioside and rebaudioside A (Gupta *et al.*, 2016).

2.2.3.1.3. Production

The stevia plant is native of Paraguay. The stevia consumption has experienced an increase of 31% in 2018. The sweetener produced from this plant has been recommended by several world organizations, as is the case with the World Health Organization of WHO. This specie in 2016 was named as endangered. However, nowadays, Paraguay is a pioneer country in its production, it produces around 3900 to 4000 tons of dry leaves, which are produced in 2370 hectares. Despite its large production, it does not supply the international market (Godoy, 2019).

The main markets for stevia worldwide are the United States, the European Union, Canada, Australia, and Japan. Being China, one of the world's largest stevia producers, produces more than half of stevia's worldwide crops (Centro de Estudios para el Desarrollo Rural Sustentable y la Soberanía Alimentaria (CEDRSSA), 2018).

2.2.3.2. Coconut Sugar

The coconut palm belongs to the Asteraceae family, and its scientific name is *Cocos nucifera L.*, from which the sap (neera) is extracted to produce coconut sugar (Borse *et al.*, 2007). It is commonly consumed in South Asia continent, in countries such as Indonesia, Philippines, India (Wrage *et al.*, 2019). Coconut sugar is a sweetener that has a lower GI than ordinary sugar or sucrose. According to Gunnar (2018), the GI of sucrose is 60, while coconut sugar in some articles determines that it is 54.

Figure 3. Coconut palm *(Cocos nucifera)* (Coco Orgánico, 2020).

2.2.3.2.1. Benefits

Coconut sugar is reported to contain nutrients and digestive agents (Borse *et al.*, 2007). Although in Gunnar (2018) reported that coconut sugar is claimed to have a lower GI than sucrose, but is not highly representative. However, coconut sugar retains small amounts of nutrients such as iron, zinc, calcium, and potassium minerals, some fatty acids, polyphenols, and antioxidants which are found in coconut palms. It is known that an element that also acts for the benefit of health is inulin, which one provides a possible decrease in the absorption of glucose in the blood (Gunnar, 2018).

2.2.3.2.2. Chemical composition

Coconut sugar according to Asghar *et al.* (2019), it has 6.91% sucrose, 3.48% fructose, 2.53% glucose. In Figure 3 it is shown the differences of sugar contents in coconut sap, sugar palm juice, and sugar cane juice.

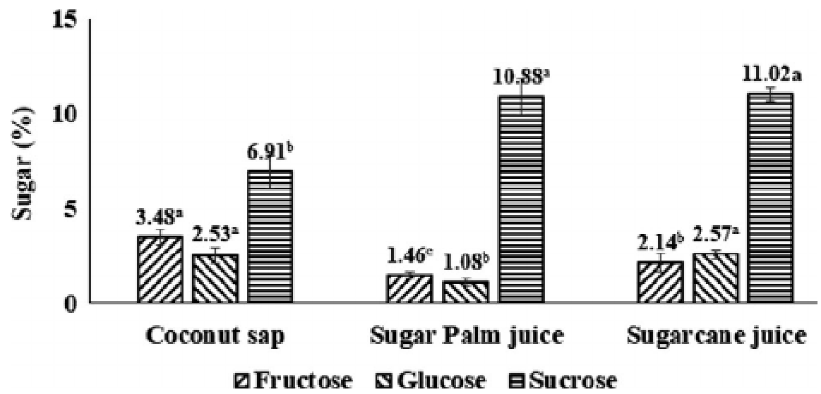

Figure 4. Coconut palm *(Cocos nucifera) (*Asghar *et al.*, 2019*).*

2.2.3.2.3. Production

It is estimated that from 2019 to 2023, there is an 8% of increase in the growth of the coconut sugar market, because the population is changing to new lifestyles and opts for a healthier one. This statistic is focused on the coconut sugar market, in the US, Europe, Japan, China, India, Southeast Asia, South America, South Africa, among others, this report is written according to the manufacturers, the region and its application. The main producers of coconut sugar worldwide are Celebes Coconut Corporation, Coco Sugar Indonesia, NOW, Foods, Nutiva (Dutton, 2020).

2.2.3.3. Inulin

Inulin is the name given to a family of complex carbohydrates (polysaccharides) (Bordas, 2019), formed by fructose units. These are not digested by the human body, due to it lacks enzymes for its degradation. Inulin is present in many vegetables, fruits and cereals. It is generally found in chicory root (*Cichorium intybus*), it can be seen in Figure 5, from which it is extracted for its commercialization also, from other sources such as dandelion root, bananas, onion, among others. Some types can provide a sweet flavor to foods; this varies from 30 to 50% when it is hydrolyzed in smaller chains of fructans.

Figure 5. Chicory *(Cichorium intybus)* (Brunel, 2020).

2.2.3.3.1. Benefits

They are widely used for add fiber in some processed foods such as yogurt, milk, bread, cookies, and ice cream. It is also used for the benefit of the digestive system. It can be used as a prebiotic since it is not digested by the human body, thus improving intestinal flora and preventing colon cancer. It also acts as a dietary fiber and helps regulate absorption glucose and fats. Also reduces LDL cholesterol levels in obese patients.

2.2.3.3.2. Chemical Composition

Inulin has the most common fructans commercialized. It is composed for 20-60 units of fructose, linked by bonds β (2→1). Generally, it is found in tubers like chicory, yacón as storage of reserve substance, and dietary fiber. It has many applications, such as in the industry of processed foods and medicine (Greg, 2008; Montenegro, 2017).

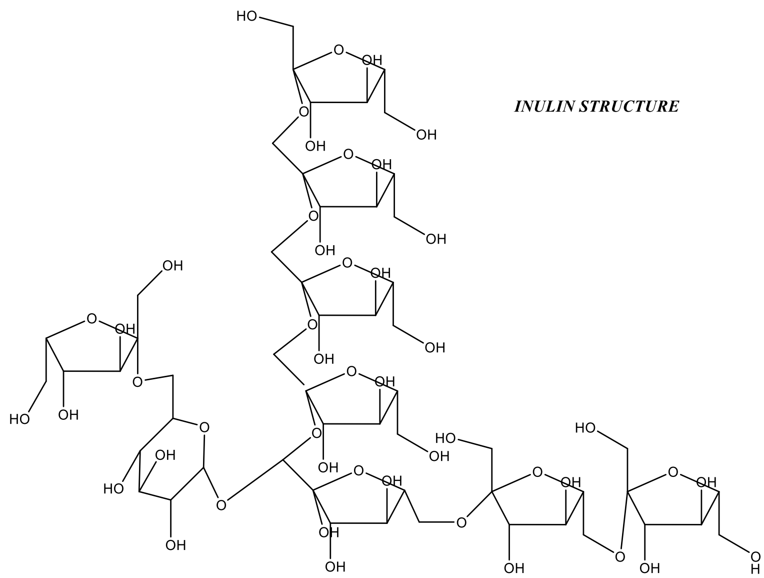

Figure 6. Inulin Chicory structure (Jacques Hernandez *et al.,* 2008).

2.2.3.3.3. Production

The vast majority of inulin production in the world is in Europe west. The principal source of the inulin extraction is chicory root, however, some investigations affirm that inulin also is in tequila agave, dandelion vernonia herbacea (Lara-Fiallos *et al.*, 2017)**.**

2.2.3.4. Agave Nectar

Agave nectar is a syrup from agave (see Figure 7). It is a plant from which is extracted from the leaves or stalks of agave, similar to aloe vera. For this production generally are applied the blue agave and the maguey agave. This syrup or better known as nectar is a powerful sweetener. This substance has been popularized for its prebiotic capacity and low GI compared to other syrups, the sugars presents are fructans called specific, agavines (Mellado-Mojica & López-Pérez, 2013). It is also used as an alternative to sucrose that uses sugar cane and other sweeteners.

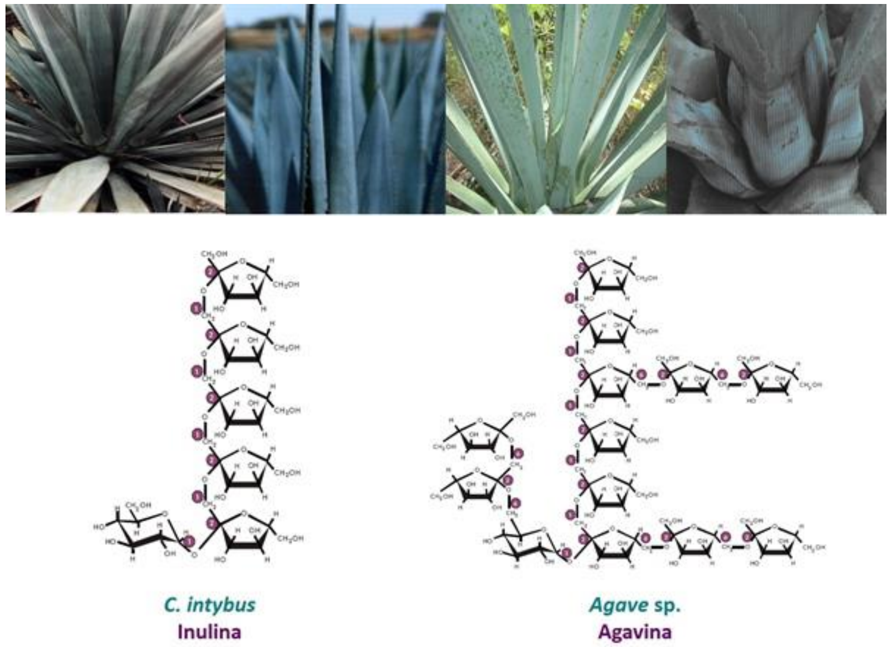

Figure 7. Agave plant, and the inulin and agavine structure (Cinvestav Conexión, 2019).

2.2.3.4.1. Benefits

It has a long duration without refrigeration. According to Hernandez Texocotitla (2018), this sweetener with natural origin, helps to reduce body weight, reduces mental deterioration, improves the appearance of the skin, and regenerates body cells. It is used as a sweetener for diabetics due to it is rich in fructose. By containing fiber, it acts as a probiotic. It tends to regulate insulin levels also, it contains vitamins (A, B_2, C) like other minerals that are essential for the body.

2.2.3.4.2. Production

It is stated for European countries such as Germany, France, Italy, and the United Kingdom and a minimum percentage to the Asian countries such as Japan and Korea. According to data from 2015, it is recorded that Mexico exported around two thousand tons of agave syrup (EL INFORMADOR, 2017).

2.3. Raw Material

2.3.1. Yacón

Smallanthus sonchifolius is a perennial plant which has sweet-tasting underground tuberous roots (see Figure 8) (Ojansivu *et al.*, 2011). It is a native species of the Andean region of South America, which grows in altitudes between 1000- 3200 meters above sea level, in temperate and subtropical areas (Caballero Méndez & Colonia Pineda, 2018; Manrique *et al.*, 2003; Pedreschi *et al.*, 2003). It is cultivated principally for the root's consumption as food in countries such as Venezuela, Colombia, Ecuador, Perú, Bolivia, and the northeast of Argentine (Salazar Conde, 2002). However, yacón has an adaptative capacity to other environmental conditions. It explains that can be cultivated in other parts of the world such as China, Japan, Brazil, the Czech Republic, Korea, New Zeeland, Russia, Taiwan and United States (Manrique *et al.*, 2003).

Around the world, this plant has different common names, and it depends on the country; for example, in Bolivia is known as aricoma and aricuma; jicama, chicama and shicama in Ecuador, and arboloco in Colombia. However, in Spanish is named yacón, which is derived from the Quéchua word "yaku" which means "watery", because its roots are constituted principally by water (Caetano *et al*., 2016).

One of the main characteristics of the yacón is that it can be consumed raw, boiled, baked, or used for making a refreshing drink. It is usually eaten raw, and the taste and texture are said to resemble a combination of apple and watermelon. This is the reason the inhabitants of the Andean continent consider this root as a fruit (Barreto Vargas, 2019; Ojansivu *et al*., 2011; Pedreschi *et al.*, 2003).

Figure 8. Plant of yacón (*Smallanthus sonchifolius*).

2.3.1.1. Taxonomy

The yacón is a plant belonging to the Asteraceae family, also, denominated Compositae, its scientific name is *Smallanthus sonchifolius*, of the Smallanthus gender. However, in the scientific literature it is also named *Polymnia sonchifolia Poepp. & Endl and Polymnia edulis Wedd* to refers to yacón. In Table 1 is described the yacón taxonomy (Seminario *et al.*, 2003).

Table 1. Taxonomy of yacón (Álvarez Cajas *et al.*, 2012).

Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Asterales
Family	Asteraceae
Gender	Smallanthus

Species	Sonchifolius
Scientific name	*Smallanthus sonchifolius* Rob
Common name	Jicama, yacón, jiquima, jiquimilla

2.3.2. Roots description

The yacón roots vary in its shape and size. Commonly it is 15-20 cm long with 10 cm thick, and its shell comes in different colors such as brown, purple, pink, and cream (Ojansivu *et al.*, 2011). The harvest time of this tuber comes to six to seven months; however, it depends on the conditions where the plant is growing (Salazar Conde, 2002). The weight of roots varies according to the agronomic techniques applied and also the environmental conditions. It comes between 2-4 kg, each root but with the use of adequate irrigation such as fertilizers and control pest it can overcome to 6 kg and also the 10 kg in fresh weight (Manrique *et al.,* 2003; Ojansivu *et al.*, 2011).

2.4. Benefits properties

The yacón functional properties have been recognized for a long time the folk medicine, which has been the object of clinical research (Caetano *et al.*, 2016). Recent studies inform that yacón has a health-promoting property such as the characterization of its antioxidant activity associated with the phenolic compounds. The lowering of blood glucose levels, body weight and the risk of colon cancer are related to the FOS presents in the yacón tubers, which are found in a highest concentration (Caetano *et al.*, 2016; Pedreschi *et al.*, 2003).

The FOS content found in yacón roots can modulate the human intestinal microbiota, increase glucose absorption in peripheral tissues, stimulate insulin secretion in the pancreas and modulate cellular pathways related to lipid homeostasis. So, the yacón roots, due to the functional properties, it can be used as a dietary supplement to prevent chronic diseases (Caetano *et al.,* 2016).

In Table 2 is shown the different benefits in the human health of yacón, described in the scientific literature.

Table 2. Effects of yacón consumption on human health.

Yacón source	Research, Subject Randomized, Dose and Duration	Health Properties	References
Syrup	Obese and slightly dyslipidemic pre-menopausal women. Dose: 0.14g/kg/day, for 120 days.	-Decrease in fasting serum insulin. -Decrease in body weight, waist circumference, and body mass index. -Increased defecation frequency and satiety sensation.	(Genta *et al.*, 2009)
Extract of yacón leaves	Female and male patients aged 30 to 70, with type 2 diabetes mellitus. Dose: 1g of leaves infusion + glibenclamide / 3 times per day for 90 days.	-Decreased glucose levels by 42.7%, also glycosidated hemoglobin levels from 11.12 to 8.87% and fructosamine from 33.78.	(Gordillo Rocha, 2009)
	Diabetic induced rats by hyperglycemic and streptozotocin. Dose: yacón tea at 2% instead of water for 30 days.	Increased plasma insulin, improved body weight, and plasma glucose.	(Aybar *et al.*, 2001)
Yacón Flour	Wistar male rats, Dose: (340 y 680 mg de FOS / kg body weight / day.	-Produce anti-obesity properties by inhibiting adipogenesis and improving the function of visceral adipose tissue.	(Honoré *et al.*, 2018)
	Wistar male rats. Dose:25mg of yacón flour with 7.5% FOS/kg of body weight for 8 weeks.	-Beneficial effects in the intestine and attenuates the morbidity of colon cancer.	(Grancieri *et al.*, 2017)
Dried extract of yacón roots	Wistar male rats induced by 1,2-dimethylhydrazine (DMH) for colon carcinogenesis. Dose: 0.5% and 1% dried root extract for 13 weeks.	-Reduces the number of invasive adenocarcinomas. -Can reduce the development of chemically induced colon cancer.	(De Moura *et al.*, 2012)
Yacón Powder	Sprague-Dawley male rats. Dose: 0.5% yacón powder.	-Can improve the lipid metabolism of serum, liver, and adipose tissue and affect lipid storage.	(Kim *et al.*, 2010)

2.5. Chemical Composition

Yacón is a tuber which stores its carbohydrates in the form of FOS in contrast to the majority of edible starch-storing roots (Paredes *et al.*, 2017). This tuber is composed principally by water which is in a range of 83% to 90% of the fresh weight, FOS are in a range between 50-80 g/kg, and free sugars between 18-31 g/kg (glucose 2,3-5,9%, fructose 3,9-21,1% , and sucrose 10-19%) (Caballero Méndez & Colonia Pineda, 2018).

2.5.1. Fructans

Fructans are important storage carbohydrates in many plant families. They are a group of oligosaccharides and FOS composed of fructose units connected with β (2→1) linkages, fructosyl-fructose glycosidic bonds, which frequently terminating in a glucosyl moiety (see Figure 6). Fructan molecules consist of monosaccharide units and are composed of one or as many as 70 units of fructose linked or not linked to a terminal sucrose molecule such as inulin and oligofructosyl-saccharose (oligofructose, FOS derived from inulin). Due to the aforementioned, fructans are important in human health due to the human organism have non-digestive enzymes to break down the fructans bonds making them indigestible fibers (Anadón *et al*., 2016; Greg, 2008; Mitmesser & Combs, 2017).

2.5.2. Fructooligosaccharides (FOS)

The FOS are a type of soluble fiber. Also, they are a group of fructans. They have a low PD composed by 2 to 9 units linked by β (2-1) bonds. Those are formed by a lineal chain of fructose and terminal glucose (Barreto Vargas, 2019; Pedreschi *et al.*, 2003). They are present in some fruits and vegetables such as banana, onion, garlic, asparagus, chicory, artichokes, being yacón the highest source of this lineal chains (Zarate Paucarpura, 2016).

Yacón roots have a sweet level, which can change between 30% and 100%, concerning sucrose, they have more solubility but not precipitate and neither crystalize, but it can be used in the industry as an alternative of sucrose or as dietary fiber (Barreto Vargas, 2019).

In general, FOS may decrease blood glucose levels and different health-related serum lipids in humans and animal models. They are also considered to work as prebiotics by improving the intestinal microflora balance and promoting the growth of probiotic organisms (Pedreschi *et al.*, 2003).

2.5.3. Minor compounds

Yacón is also constituted by other minor compounds, such as phenolic compounds, amino acids and additional sugars. Table 3 presents a compilation of information from scientific literature about these compounds.

Table 3. Compilation of compounds of Yacón (*Smallanthus sonchifolius*).

N°	Common name	Formula	Molecular Weight (g/mol)	Bibliography
1	Chlorogenic acid	$C_{16}H_{17}O_9$	353.0873	(Caballero Méndez & Colonia Pineda, 2018; Gomes da Silva *et al.*, 2018; Simonovska *et al.*, 2003; Takenaka *et al.*, 2003)
2	Cafeic acid	$C_9H_8O_4$	180.16	(Caballero Méndez & Colonia Pineda, 2018; Simonovska *et al.*, 2003)
3	3,4-feluric acid	$C_{10}H_{10}O_4$	194.18	(Caballero Méndez & Colonia Pineda, 2018; Simonovska *et al.*, 2003)
4	Quercetin	$C_{15}H_{10}O_7$	302.23	(Simonovska *et al.*, 2003)

5	Altaric acid coffeeoyl	n.d	n.d	(Oiga Lock y Rosario Rojas, 2005) (Oiga Lock y Rosario Rojas, 2005)
6	2,4 or 3,5-dicafeoylaltraric acid	n.d	n.d	(Oiga Lock y Rosario Rojas, 2005; Takenaka *et al.*, 2003)
7	2,5-dicafeoylaltraric acid	n.d	n.d	(Oiga Lock y Rosario Rojas, 2005; Takenaka *et al.*, 2003)
8	2,3,5 or 2,4,5-tricafeoylaltraric acid	n.d	n.d	(Gomes da Silva *et al.*, 2018; Oiga Lock y Rosario Rojas, 2005; Takenaka *et al.*, 2003)
9	6,8-dioxabicyclo octane	n.d	n.d	(Oiga Lock y Rosario Rojas, 2005)
10	4-0-cafeoyl1-2,7-anhydro-D-glyceric-(beta)-D-galacto-oct-2-ulopyranosonic acid	$C_{17}H_{17}O_{11}$	397.0771	(Gomes da Silva *et al.*, 2018; Oiga Lock y Rosario Rojas, 2005)
11	4,5-di-0-cafeoi 1-2,7-anhydro-D-glycerol-b-D-galacto-oct-2-ulopyranosic acid	$C_{26}H_{23}O_{14}$	559.1088	(Gomes da Silva *et al.*, 2018; Oiga Lock y Rosario Rojas, 2005)
12	Citric acid	$C_6H_7O_7$	191.0197	(Gomes da Silva *et al.*, 2018)
13	3-caffeoylquinic acid (Neocholologenic acid)	$C_{16}H_{17}O_9$	353.0872	(Gomes da Silva *et al.*, 2018)
14	Caffeoyl glucarate isomer 1	$C_{15}H_{15}O_{11}$	371.0614	(Gomes da Silva *et al.*, 2018)
15	Caffeoyl glucarate isomer 2	$C_{15}H_{15}O_{11}$	371.0614	(Gomes da Silva *et al.*, 2018)
16	4-O-caffeoyl-2,7-anhydro-D-glycero-beta-D-galacto-oct2-ulopyrosonic acid isomer 2	$C_{17}H_{17}O_{11}$	397.0764	(Gomes da Silva *et al.*, 2018)
17	Tryptophan	$C_{11}H_{11}N_2O_2$	203.0823	(Gomes da Silva *et al.*, 2018)
18	4-caffeoylquinic acid (Cryptocholorogenic acid)	$C_{16}H_{17}O_9$	353.0874	(Gomes da Silva *et al.*, 2018)
19	Isopropyl malic acid	$C_7H_{11}O_5$	175.0608	(Gomes da Silva *et al.*, 2018)

20	3,4-dicaffeoylquinic acid	$C_{25}H_{23}O_{12}$	515.1198	(Gomes da Silva *et al.*, 2018)
21	3,5- dicaffeoylquinic acid	$C_{25}H_{23}O_{12}$	515.1185	(Gomes da Silva *et al.*, 2018; Takenaka et al., 2003)
22	Butanediodiacetate	$C_{8}H_{13}O_{4}$	173.0809	(Gomes da Silva *et al.*, 2018)
23	Leeaoside	$C_{24}H_{39}O_{11}$	503.247	(Gomes da Silva *et al.*, 2018)
24	4,5 -dicaffeoylquinic acid/3,4-dicaffeoylquinic acid	$C_{25}H_{23}O_{12}$	515.1182	(Gomes da Silva *et al.*, 2018)

n.d (non-described in literature)

2.6. Enzymatic browning

This process is principally related with the unwanted changes of color in the vegetables and fruits. This is an important parameter for the consumer, due to when the browning happen the nutritional value reduce, for this phenomena to develop is required four different compounds, such as molecular oxygen, suitable substrates, polyphenol oxidase (PPO) and copper presence in the active center of the enzyme (Zarate Paucarpura, 2016). PPO is a name given for a group of enzymes that catalyze the oxidation of phenolic compounds, transforming it in orthoquinones, which ones produce brown or black pigments such melanin (Laurila *et al.*, 1998).

This process can occur quickly as in 30 minutes or other cases in several days, its rate depends of the concentration of active PPO, the amount of phenolic compounds, the pH, temperature, and oxygen availability. This enzyme complex works in an optimum pH range of 4 to 7 (Laurila *et al.*, 1998). According to Chamorro Rivadeneira (2016), the complex is deactivated with a low pH of 3. Also, this acidification limits the growth of series of microorganism which does not develop in this medium.

2.6.1. Enzymatic Mechanism

The oxidation is produced with an atom or atoms that donate their electrons (Garzón *et al*., 2007). This process is carried out in two stages. The early one is the enzymatic catalysis and the last one, is the non-enzymatic stage. In the first one stage of enzymatic catalysis, the PPO acts, which one const of two types of enzymes that run the following reactions (Zarate Paucarpura, 2016).

The first reaction consists of the creolase enzyme activity, which carries out the hydroxylation of the monophenols in an *ortho* position to obtain *o*-diphenols. The second reaction or catechol enzymatic activity carries out the oxidation of *o*-diphenols to its corresponding *o*-quinones (Zarate Paucarpura, 2016), the mechanism can be seen in Figure 9 .

The polyphenols compounds are natural substances that contribute to the sensory properties such as color, flavor, aroma and texture related to the sensory quality of both fresh and processed plant-based food (Zarate Paucarpura, 2016). Also, they are a fundamental part of the browning process due to the phenolic compounds are oxidized and form quinones, catalyzed by PPO enzyme. (Martínez-Valverde *et al.*, 2000). Some phenolic compounds that have been founded in the yacón roots are described in Table 3.

The non-enzymatic stage is when the *o*-quinones were formed in the first stage, are unstable and highly reactive, which react in chain with phenols, with other quinones, amino acids, or proteins to produce dark-colored compounds. They also react among themselves producing melanin (Fan *et al.*, 2005; Zarate Paucarpura, 2016).

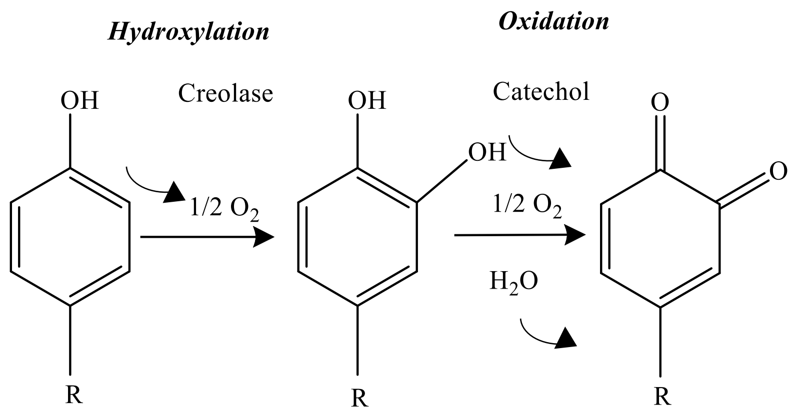

Figure 9. Reactions carry out for the (PPO) enzyme.

2.6.1.1. Antioxidants agents

The browning control is challenging in the food industry. Nowadays it is known that it is important the use of natural antioxidant and avoid the synthetic ones, because they can act against the human health. The use of good antioxidants is the key for food industrialization; there is a variety of antioxidants, and here is going to be described the most common used (Garzón *et al.*, 2007).

The correct use of antioxidants agents allows the prevention of oxidation and browning processes in the processing of yacón, due to according to Manrique *et al.* (2003), the yacón roots browning is activated in the first 10 to 15 seconds when it is in contact with oxygen, changing its yellow color to green.

2.6.1.2. Citric Acid

This is a natural antioxidant, its principal function is the inhibition of enzymatic browning, reducing its pH and inhibiting the enzymatic activity. Also, citric acid is capable to inactive metal traces (Mastro-Durán & Borja-Padilla, 1993). Commonly is used as a food additive. It is a good conservative but have a bittering flavoring. As it is a good antioxidant, it can maintain the processed food for more time. The cost is low but can produce a residual sensorial change (Zarate Paucarpura, 2016).

2.6.1.3. Sulfites

Those are a chemical compound derived from sulfur, which is used as a food preservative and additive. The objective of add this substance is preservative properties, avoid the browning and spoilage and elimination of bacteria. Those compounds work as a reductant agent removing the oxygen from water sources that inhibit the PPO activity. However, it can be a problem when it is not controlling (Gad Consulting Services, 2014). Also, it has low cost and is effective at low concentrations, in spite of that, it have been classified as a dangerous compound for the human health, especially for asthmatic people, that is why, there is a necessity to use natural antioxidants (Sayavedra-Soto & Montgomery, 1986; Zarate Paucarpura, 2016).

2.6.1.4. L-cysteine

It is an amino acid used for preventing the browning in fruits and vegetables. It is more effective than ascorbic acid, however, it presents a negative effect on the flavor and in high concentration have an unpleasant odor, cause for its limitation in the processing food. This agent works to inhibit PPO by reducing the *o*-quinones to its precursor phenol (Garzón *et al.*, 2007; Zarate Paucarpura, 2016).

2.6.1.5. Sodium Chloride

NaCl is an antioxidant agent, with pH under 5 it can be observed an inhibitory effect dependent on pH ; however, with pH over 5 can activate the PPO, sodium chloride could inhibit the PPO as well as ascorbic acid and citric acid (Fan *et al.*, 2005).

2.6.1.6. Ascorbic acid

Ascorbic acid is one of the substances with high effectivity to prevent the enzymatic browning. Also, it is a good antioxidant due to not causing corrosive effect in the metal, which is excellent for the equipment used at the moment to produce it in high scaling (Zarate Paucarpura, 2016). Ascorbic acid doesn't have a peculiar flavor, which not change the organoleptic properties of food. So, it is using for inhibiting the PPO reducing the pH. It acts reducing the *o*-quinone produced, before it produces a chain reactions which will change the color of the fruit and vegetables and lost their organoleptic properties (Zarate Paucarpura, 2016).

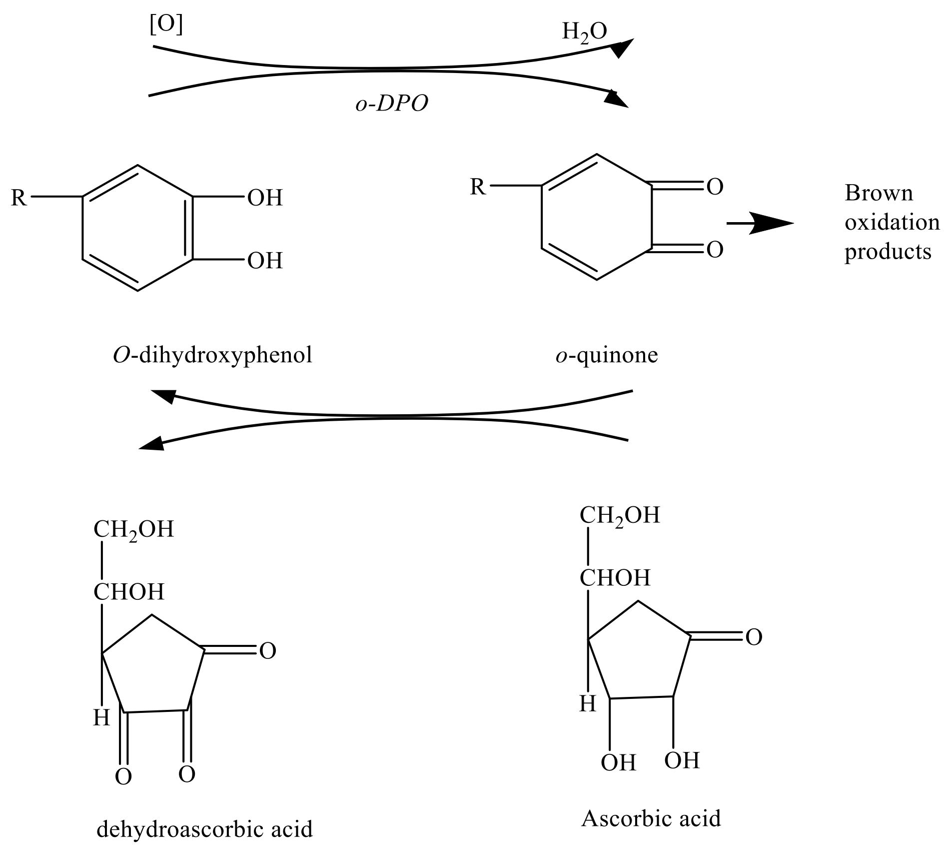

Figure 10. Reduction of ascorbic acid by the primary oxidation of *o*-quinone due to enzymatic browning (Walker, 1976).

2.7. Yacón Production

2.7.1. World Level

Nowadays, yacón root is cultivated out of The Andes, South America, according to Seminario *et al.* (2003), the migratory route of yacón has extended from Ecuador to New Zealand, where is cultivated in small scale. From New Zealand, yacón was brought to Japan, which one has done the majority of scientific investigations. Also, there are registers that yacón is cultivated in Korea, Czechoslovakia, Brazil, Paraguay, China, United States, Taiwan, Russia (Ministry of Foreing Affairds (CBI), 2016; Seminario *et al*., 2003).

2.7.2. Regional Level

The yacón is an original root of the Andean Region, South America, and has been cultivated in Venezuela, Colombia, Ecuador, Chile northeast of Argentine, and Perú (Seminario *et al*., 2003). According Ministry of Foreing Affairds (CBI) (2016), Perú is one of the countries the most export yacón to Europe. It is the supplier in high percent, between 2011 and 2015 the exportation has increased in 106 %.

Table 4. Peruvian yacón exportation (kg) (Oficina Comercial de Perú en Miami, 2012).

Country	2007	2008	2009	2010	2011
US	10163.16	20872.04	16957.37	32034.27	52635.36
UK	2027.83	2087.87	1983.22	3163.65	2164.48
Australia	634.2	444	251.91	262.69	1147.78
Chile	212	318	346.42	334.73	738.13
Germany	809.68	802.24	2616.52	972.63	691.51
New Zealand	8.58	0.86	0	0	556
Netherlands	629.45	1094.25	696.78	1231.13	500.77
France	584.83	1702.31	720.85	783.53	371.08
Canada	1757.75	1185.66	166.87	315.34	326.34

Czech Republic	29.81	238.24	44.73	292.93	185.84
Sweden	0	0	78.29	119.01	166.27
Norway	0	0	46.78	374.19	106.52
Argentina	0	26.09	0	25.5	99.57
Spain	31.3	0	205.38	54.37	71.42
South Africa	0	20	0	109.25	54.19
Subtotal	1688859	28791.56	24115.12	40073.22	59815.26
Rest	1495.57	1764.66	976.93	553.95	170.29
TOTAL	18384.16	30556.22	25092.05	40627.17	59985.55

2.7.3. Local-level

In Ecuador, it has been reported that yacón is cultivated in the Ecuadorian mountains in provinces such as Carchi, Imbabura, Pichincha, Cotopaxi, Tungurahua, Bolívar, Chimborazo, Azogues, Cañar, and Loja, being Loja the province with more production. According to reports in Ecuador the most useful part of the plant is the roots, and usually, the production is used for self-consumption (Montenegro, 2017; Seminario *et al.*, 2003).

2.8. Economic Market

Yacón is a plant, which is easy to cultivate. According to Castillo Palomino (2014), its performance is from 10 to 100 tons/ha, and it depends on the production place. In Perú is marketed as a syrup, juice, tea, marmalade, and chips. However, persons with high economic status prefer a more elaborated yacón product as capsules, syrup than persons with low financial condition, which prefer products without added value, they use the root directly as a food. Table 5 indicates the international production of yacón.

Table 5. International production of yacón (Castillo Palomino, 2014).

Country	Ton/ha	Year
Brasil: Sao Paulo, Capao Bonito	100	1996

Brasil: Sao Paulo, Batucatu	54	2002
Perú: Cajamarca, Baños del Inca	52	1997
Perú: Cajamarca, Hualqui	51	2001
Japón: Ibaraki	49	1989
Perú: Pasco Oxapampa	48	1999
Perú: Cajamarca, Los eucaliptos	31	1983
Ecuador: Quito, Santa Catalina	29	1999
Corea: Chanju	28	2001
Perú: Cuzco, Ahuabamba	28	1997

Table 6. Yacón roots prices in Perú, Ecuador, and Brazil.

Country	Quantity (kg)	Average Price
Perú	1	$ 1,45
Ecuador	1	$ 1,00
Brazil	1	$ 4,50

The prices in Table 6, have been stablished of markets of each country of the present year 2020.

Table 7. One-ounce price of different sweeteners in amazon in US market, the present year 2020, and according to the added value that each one has.

	Powder Oz	Syrup Oz fl	Extract	Capsules
Yacón	$ 3,03	$ 2,13	$ 11,48	$ 18,46
Stevia	$ 3,64	-	$ 5,40	-
Inulin powder	$1,16	-	-	-
Coconut sugar	$0,41	-	-	-
Agave nectar	-	$0,40	-	-

It is important to clarify that those analyses are made with prices founded on the website of the United States market. It is an estimated that values can vary for different parameters such as the purity, the quantity, and also the origin as if it is organic or not.

Yacón is a sweetener not known as well the others but is the one that has a higher economic value in the US market. Also, in Table 8, shows that yacón sweetener has a higher sweetness than common sugar (Oficina Comercial de Perú en Miami, 2012).

Table 8. The necessary quantity of several sweeteners to have similar sweetness of tablespoon of common sugar (Oficina Comercial de Perú en Miami, 2012).

Sweeteners	Quantity (tablespoon)
Honey	½
Syrup or agave nectar	1 ¼
Inulin powder	1
Yacón syrup	¾
Stevia Drops	6 drops
Coconut sugar	2/3

2.9. Quality control methods

The quality control is an important stage during the productive process, it guarantees the final product meet the stablished objectives. Also, it is an important stage due to this process serves to reduce the likelihood of placing faulty products on the market (Orellana Nirian, 1981).

2.9.1. Physical, chemical and microbiologic methods.

Exist a series of methods of quality and control the ones considered the most used according Fernandez (2014), are the determination of its pH, its transparency, flavor, odor, color, viscosity, density, strange bodies, volume and °Brix.

One the other hand, the microbiology analysis are important too, and the most common used are total aerobic count, yeast and fungus count, determination of Escherichia coli, Salmonella and Pseudomonas (Fernandez, 2014).

2.9.2. Analytical methods.

For the sweetener obtention it is important to know which compounds are in the yacón to ensure the quality of final product. Also, to have a register if a problem appears during the elaboration process. In the present work is going to be described some important analytical methods.

. **Thin Layer Chromatography (TLC)-** it is an analytical technique and its objective is the analysis of a mixture of components, its technique can be of great help because it can quantitatively indicate the existing compounds in the syrup in an easy and quickly way (Angerell *et al.,* 2020). Also, it is helpful to observe if there is a possible contamination. It would be useful for sugars such as sucrose, fructose and others.

. **High-performance liquid chromatography (HPLC)-** this is a technique which separate compounds, occurs based on the interaction of the system with the mobile phase and the stationary phase. This technique can be very useful in quality control because it shows the amount of possible existing compounds. In general, this technique is sensitive to analytes or large molecules with sizes of 5 microns (Dhandapani, 2018).

. Ultra-high-performance liquid chromatography (UHPLC)- it is a technology based on the principle that a smaller particle size leads to higher efficiency, faster separations with higher resolution and sensitivity. This technique detects smaller compounds with a size of 2 microns, it would be very useful for quality control by detecting molecules that were not detected in the HPLC technique (Dhandapani, 2018).

Different experimental conditions for TLC, HPLC and UHPL techniques have been found in the literature, which can be seen in Tables 9 and 10, to characterize the compounds found in the yacón plant found in Table 3

Table 9. TLC technique to determine sugars and phenolic acids present in yacón plant.

Technique	Mobile Phase	TLC staining solution	Isolated compound	Stationary Phase	Bibliography
TLC^{LE}	n-hexane–ethyl acetate–formic acid (20:20:1, v/v/v) ethylacetate–water–formic acid (85:15:10, v/v/v)	n.d	caffeic and ferulic acid chlorogenic acid.	Silica gel	(Simonovska *et al.*, 2003)
TLC^{RE}	$CH_3(CH_2)_2OH$-H_2O (6:1) which were stained using orcinol-H_2SO_4 reagent, at 100 ◦C for 5 min	n.d	Glucose Fructose FOS	Silica gel	(Paredes *et al.*, 2017)
TLC^{RE}	Butanol, isopropanol, water and acetic acid (7:5:4:2)	Aniline, diphenylamine, phosphoric acid and acetone (1:1:5:50)	Inulin	Silica gel	(Benítez-Cortés *et al.*, 2015; Montenegro, 2017)

TLC^{RE}	Butanol, methanol, acetic acid water (5:2.5:1:2 v/v)	Ethanol, anisaldehyde, sulfuric acid (9:0,5:0,5)	Fructose glucose sucrose Inulin	Silica gel	(Parra Montes de Oca, 2014)
TLC^{FE}	Acetonitrile, isopropanol, water (12:4:6 v/v)	diphenylamine, aniline in phosphoric acid.	Fructose glucose sucrose Inulin	Silica gel	(Domitila, 2015)
TLC^{RE}	Chloroform, acetic acid, water (3:3.5:0.5 v/v)	diphenylamine, aniline in acetone. (1gr diph, 1mL anil in 100mL acet) this mixture with orthophosphoric acid 85% (10/1 v/v)	Fructose glucose sucrose Raffinose	Silica gel	(Farag, 1978)
TLC	n-butanol, isopropanol, water (3:12:4 v/v)	Anisaldehyde	malto or isomalto-oligosaccharides	Silica gel	(Kanaya *et al.*, 1978)

n.d (non-described in literature)

Table 10. HPLC and UHPLC techniques for determine the compounds are in different forms of yacón.

Technique	Column	Dimensions	Mobile Phase	Gradient	Flow Rate (mL/ min)	Tempe rature (°C)	Detection (nm)	Injec tion (µl)	Bibliography
$HPLC^{LR}/MS$	Luna C-18	150 mm x 4.6 mm, 3µm	Solvent (A) Acetonitrile in water, 10 % (v/v),acetic acid 0.05% Solvent (B) Acetonitrile in water 0.05%	100% A--(0.0) 100% B--(39.0) 100% B--(40.0) 100%A--(41.0) 100% A--(46.0) 100%A--(47.0)	0.5 0.5 1 1 1 0.5	200	366nm	10 µl	(Simonovska *et al.*, 2003)
$RP-HPLC^{LE}$	Luna C-18	250mm x2 mm	Solvent (A): $CH_3CN-H_2O-CH_3COOH$. Solvent (B): H_2O-CH_3COOH (99.5:0.5)	5--75 % A in B	0.2	n.d	190-500 nm	n.d	(Simonovska et al., 2003)
$HPLC^{LE}$	XDB-C-18	150 mm x 4.6 mm, 5µm	Water-phosphoric acid and acetonitrile in water (100:0.5)	n.d	1	n.d	n.d	n.d	(Zheng *et al.*, 2009)
$HPLC^{E}$	Luna NH2	n.d	Acetonitrile: water (75:25)	Isocratic separation	1	50	n.d DETE	10 µl	(Domitila, 2015)
$HPLC^{E}$	Varian	39 mm x 300 mm	Acetonitrile: water (84:16)	n.d	1,5	n.d	n.d	30 µl	(Ávila Núñez *et al.*, 2012)
$HPLC^{RE}$	Cosmosil 5C18-MS	15cm x 4.6 nm	n.d	Methanol (5—33.5%) in 5% acetic acid	1	n.d	200-600 nm		

$UHPLC^S$	UHPLC BEH	150 mm x 2.1 mm, 1.7 µm	Solvent (A) water with 0.1% formic acid. Solvent (B) acetonitrile with 0.1% formic acid	2–95% B-- (0-15) 100% B--(15.1-17) 2% B--(17.1-19.1)	0.4	40	n.d	5 µl	(Gomes da Silva *et al*., 2018)
$UHPLC^{LE}$-UV-HRMS	CSH C-18	150 mm x 2.1 mm, 1.7 µm	Solvent (A) water with 0.2% formic acid. Solvent (B) acetonitrile with 0.1% formic acid	3-20% B-- (0-15) 20-95% B--(15-40) 95--3% B--(40-43) 3% B--(43-45)	n.d	40	190 & 400	5 µl	(Padilla-González *et al*., 2019)
UHPLC-IR	ACQUITY UPLC BEH	150 mm x 2.1 mm, 1.7 µm	Solvent (A) Acetone: water (77:23 v/v), with 0.05 treptilamine (p/v)	(Rosana *et al*., 2017)	0.15	85	n.d	2 µl	(Rosana *et al*., 2017)

n.d (non-described in literature)

L	Leaves
R	Roots
S	Syrup
F	Flour
E	Extract

CHAPTER III

3. EXPERIMENTAL PART: DESIGN OF AN EXTRACTION PROCESS FOR THE OBTENTION OF YACÓN-BASED SWEETENER.

3.1. Reagents and equipment

3.1.1. Reagents

Reagents used in the present work.

- Ascorbic acid (99,0 % Sigma-Aldrich)
- Commercial sodium hypochlorite
- Distilled water (NOVA Laboratorios)

3.1.2. Equipment

- Balance Cobos precision HR-150A (COBOS precision, Spain)
- BUCHI Rotavapor R-210 (BUCHI Labortechnik, Switzerland)
- Portable Refractometer RHB0-80 (China)
- Bante MS300 hot plate magnetic stirrer (BANTE instruments, EEUU)

3.2. Principles and fundamentals of the process to obtain yacón sweetener

The fundament to develop this process is to extract the juice of yacón roots, concentrate it and make a natural sweetener with FOS, which has an important role in human health, as is mentioned in Table 2. Diagram 1 shows a summary sequence of the sweetener process.

This process has different operations, which must be carried out in a specific order. The selection of raw material is the beginning of the process, the objective of the selection is choosing the samples with a high FOS content; according to Manrique *et al.*(2003) this selection should be with a lot of samples with the high value of °Brix and between this lots, select the samples which have a less sweet flavor due to if is so sweet means exist more free sugars and less FOS.

Another operation of this process is the washing and disinfection, as this is a food production process, must be aseptic. According to (Coronado Panta, 2013), the principal objective is eliminating the farmland that yacón roots have, also the microorganism that could be attached. The peeled consist of eliminating the shell of yacón for the pulp be used. After that, the next steps, yacón roots are chopped, and they are subdued to scalding process (Coronado Panta, 2013). This operation is important due to it controls the browning, for the acting of PPO, which catalyzes the oxidation of phenols to quinones. This process is known as enzymatic oxidation, this can be visualized with a color change in the pulp and also in the juice, it is transformed from yellow juice to a dark green color, (see in Figure 11) (Zarate Paucarpura, 2016).

Trituration and filtration are important steps in the process. Due to there, the juice that is going to be in the process is extracted and filtered to remove solid waste and obtain a syrup with better quality (Coronado Panta, 2013). The concentration is a process of water elimination, and the partial degradation of compounds presents in the juice that does not have a savouriness. The high temperatures used in this operation do not affect the FOS degradation due to, the depolymerization of FOS appear when the temperature has exceeded 120°C. Then the sweetener is obtained with high quality. Finally, the packaging is the last operation for its commercialization and consumption.

Figure 11. The oxidizing character of polyphenol oxidase in time function.

3.3. Experimental yacón sweetener production in laboratory

In this part is described the laboratory protocol followed for the yacón-based sweetener obtention, see (Diagram 1).

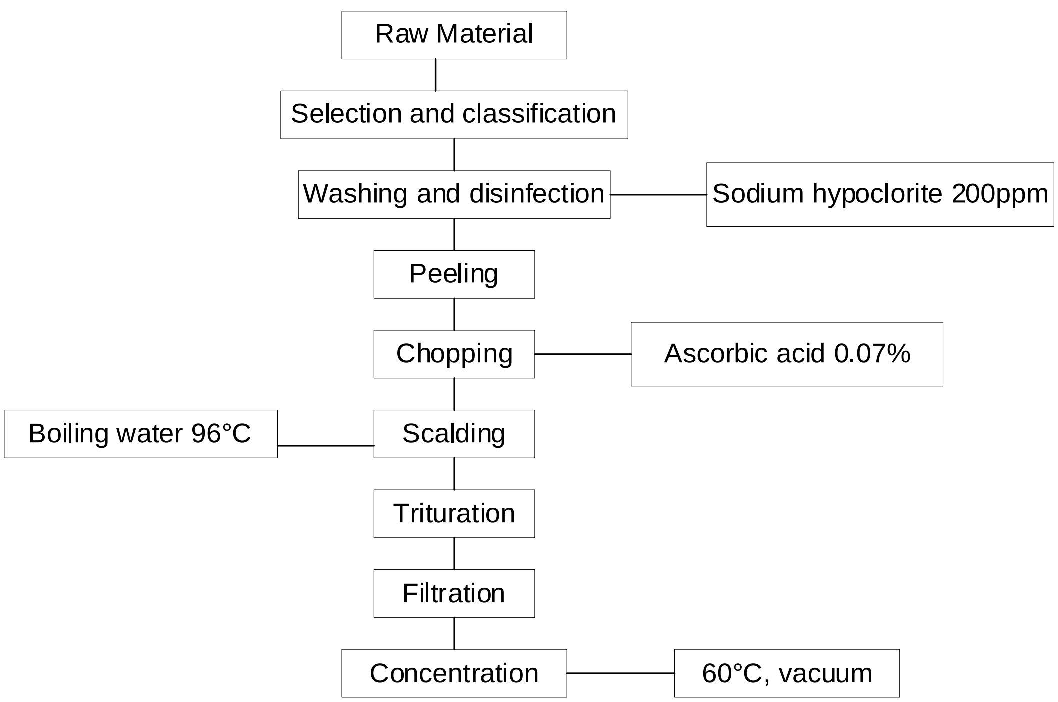

Diagram 1. Experimental design of elaboration of yacón sweetener in the laboratory.

3.4. Experimental process description

The experimental process was carried out in the Yachay Tech installations, there was a bibliographic review, and it was taken into account the following conditions for design a protocol that adapts to our circumstances.

3.4.1. Conditions for the yacón treatment for its processing.

Yacón, being a perishable food, tends to suffer organoleptic changes such as oxidizing very quickly, leading to enzymatic browning in the roots, that is why it must be subjected to conditioning conditions to keep the yacón roots, and have a quality processed final product. A compilation of these conditions can be found in Tables 11, 12, 13.

Table 11. Conditions for eliminating the farmland and microorganisms attached in the root.

Reactive	Proportions	Time (min)	Bibliography
Sodium hypochlorite	200 ppm	4	(Chamorro Rivadeneira, 2016)
	2%	-	(Coronado Panta, 2013)
	200 ppm	-	(Manrique *et al.*, 2003)
	200 ppm	-	(Juárez Castillo, 2015)
	100 uL/L	-	(Garzón-García *et al.*, 2018)

Sodium hypochlorite is known as a disinfectant and it is commonly used for water treatment, odor control, and chemical synthesis. This compound is very corrosive to many materials because it is a potential oxidant. The stability of sodium hypochlorite depends on a series of factors such as its concentration, pH, temperature and impurities of other metals (Jaeger & Van Buren, 2010).

In the present work, the use of sodium hypochlorite is in low concentrations, 200 ppm. According to the FAO agricultural services bulletin those concentration are in the range established for its use in fruits, legumes, and food for human consumption for disinfection (López, 2003).

On the other hand, the greater amount of sodium hypochlorite would remain on the surface of the yacón shell, which then enters to the peeling process in which more than 95% of sodium hypochlorite residues would be eliminated, this continues to the process of inhibition of the enzymatic browning of PPO that is carried out with ascorbic acid, which is a good antioxidant and can neutralize any potential oxidant (Zarate Paucarpura, 2016).

According Land (2005), the use of ascorbic acid is a chemical method used to neutralize sodium hypochlorite so, 2.5 parts of ascorbic acid neutralizes a part of chlorine. To avoid possible sodium hypochlorite contamination at the end of the process, excess ascorbic acid is added to reactor 1 to inhibit enzymatic browning and to neutralize possible sodium hypochlorite residues.

It is also important to take into account that sodium hypochlorite can cause corrosion in the equipment. The process carried out works in low concentrations but there is the possibility of having pitting corrosion which according to (Jaeger & Van Buren, 2010) to avoid the equipment corrosion commonly is used equipment coatings with fiber reinforced plastic or epoxy paint those methods have given good results in storage tanks of sodium hypochlorite at high concentrations.

Table 12. Conditions for the pretreatment to avoid the browning roots.

Reactive	**Proportions**	**T °C**	**Bibliography**
Ascorbic Acid	0.15 g/kg root	-	(Manrique *et al.*, 2003)
	0.07%	-	(Coronado Panta, 2013)
	5 g/L	1	(Castro *et al.*, 2016)

	0.15/kg zumo		(Huiman Arroyo & Luna Jerí, 2014)
Citric Acid	2.4 w/v	8	(Gomes da Silva *et al.*, 2018)
	2%	-	(Huiman Arroyo & Luna Jerí, 2014)
	0.03%		(Chamorro Rivadeneira, 2016)

Table 13. Conditions for scalding process.

	Temperature °C	**Time [min]**	**Bibliography**
Hot Water	92	-	(Coronado Panta, 2013)
	70	4	(Chamorro Rivadeneira, 2016)
	80-90	4.51	(Zarate Paucarpura, 2016)

3.4.2. Selection and classification of raw material

Selection of raw material is important because the yacón roots have to be fresh due to if they are a long time without refrigeration and with sun presence, they can lose their properties and have more free sugars than FOS.

3.4.3. Washing and disinfection

The washing process is done with abundant water to eliminate the farmland attached to the surface root. The disinfection was done with a sodium hypochlorite 200 ppm to eliminate the microorganism that can be present in the shell.

3.4.4. Peeling

The peeling was manual with a stainless-steel knife. In this operation exist a loss, the 20% of the weight of initial roots.

3.4.5. Chopping

The roots are reduced in its size. It is cut in cubes of 3 cm^2; in this step is important to avoid the browning of the yacón roots with an ascorbic acid solution in 0.07 %, used as an antioxidant for the juice color not change from yellow to green.

3.4.6. Scalding

This is an important operation due the cubes of the last step are submitted to boiling water 96°C. The objective of this is to have a good cleaning of the product; also, it provokes the deactivation of PPO, which causes browning in the yacón.

3.4.7. Trituration

This is an important step due to here, the juice is extracted by a home extractor, which reduced the particle size.

3.4.8. Filtration

It was made with a canvas filter of coffee for waste particle retention.

3.4.9. Concentration

This process was made in a laboratory, using a rotavapor with vacuum with a temperature of 60°C.

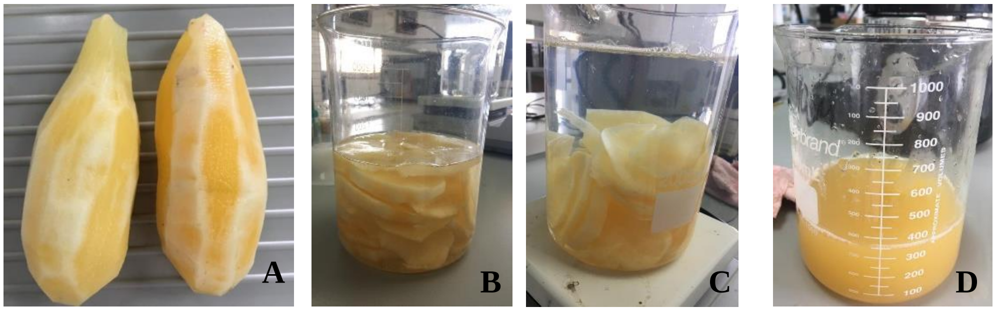

Figure 12. A) Peeled yacón, B) chopped yacón with ascorbic acid and C) yacón with boiling water D) juice yacón extraction.

Figure 13. Concentrated of yacón at vacuum and 60°C.

3.5. Design of small industrial scaling for the obtention of a yacón sweetener

In the present section, it has been developed the projection of a small industrial process with the results of experimental design carried out in the Yachay Tech installations. The calculation basis has been established according to the Ecuador yacón production including the weather, altitude and the superficial area of Muñoz's farm to meet the established process times, and specifications required for getting the yacón sweetener.

The process has been established with the production according to the yields per hectare founded in bibliography, as shown in the Table 5. Ecuador has had a reference to a production of 29 tons/ha. According to this yield, it has established the subsequent parameters, which are described in Table 14.

Table 14. Parameters considered as the basis of calculation.

	tons/ha	**kg/ha**	**Processing kg/12 working hours**
Monthly production	25	25000	83.3
Daily processing	1	1000	83.3

The raw material was obtained from Ibarra city, in Imbabura province, in the Andean zone from the north of Ecuador. Diagram 2, shows the possible industrial process of yacón-based sweetener with its respective calculus, also it was constructed with the results of experimental part developed in the laboratory.

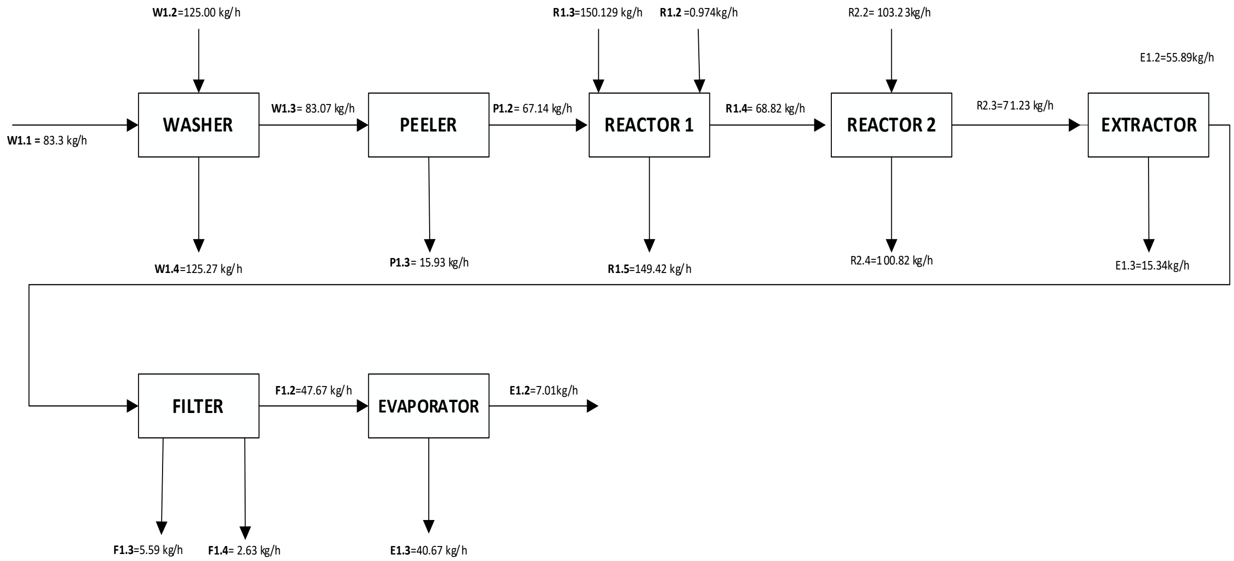

Diagram 2. Block diagram for yacón sweetener obtention.

The Diagram 2 is composed by production lines of each unit operations. Table 15 shows the prefix of each one and its meaning to have a better the reading and understanding.

Table 15. Production lines in semi-industrial process.

Prefix	**Name**
W1.1 (MrY)	Yacón raw material
W.1.2 (Mw)	Water
W.1.3 (MwY)	Washed yacón
W.1.4. (Mdw)	Dirty water
P1.1(MwY)	Washed yacón
P1.2(MpY)	Peeled yacón
P1.3(MrsY)	Yacón residue shell
R1.1 (MpY)	Peeled yacón
R1.2 (MAc. Asc)	Ascorbic acid
R1.3 (Mw)	Water
R2.1 (MYt)	Yacón with ascorbic acid
R2.2 (Mbw)	Boiling water

R2.3 (Yde)	Yacón with enzymes disactivated
R2.4 (Mbwr)	Boiling water residues
E1.1 (Yde)	Yacón with enzymes disactivated
E1.2 (Myj)	Yacón juice with small particles
E1.3 (Myb)	Bagasse
F1.1 (Myj)	Yacón juice with small particles
F1.2 (Myjf)	Yacón Juice filtered
F1.3 (Mbp)	Bagasse particles
F1.4 (Mlp)	Lost extraction process
Ev1.1 (Myjf)	Yacón Juice filtered
Ev1.2 (Mys)	Yacón Syrup
Ev1.3 (Mew)	Water evaporated

3.5.1. Material Balance

This process is one of the most important part of engineering process; here it is developed calculus the inputs and outputs that occur in each unit operation. Also, it is the basis of the analysis of a chemical process. This section describes the calculation of unit operations in the syrup yacón elaboration process. Table 16 shows the percentages obtained in the experimental part which were used for the previous elaboration of material balance calculus.

Table 16. Variables take into account for the yacón syrup processing.

Variables	Value	Units	Bibliography
Dirty in yacón	0.3218	%	Experimental
Relation water/yacón	1.5	%	Experimental
Yacón Shell	19.17	%	Experimental
Water retention in reactor 1	2.5	%	Experimental
Water retention in reactor 2	3.5	%	Experimental
Bagasse	21.53	%	Experimental
Small particles in juice	10	%	Experimental
Water evaporation/ juice	85.30	%	Experimental
Water evaporation / root	92.05	%	Experimental

Lost in the extraction process	0.046	%	Experimental
Yacón mass density	1.1117	g/cm3	Experimental
Average total phenolic amount	0.89	%	(Lachman *et al*., 2007)
Average total quinone amount.	0.89	%	(Lachman *et al*., 2007)
Rate reaction (ascorbic acid and quinone)	0.79	dm3/mol*s	(Isaacs & Van Eldik, 1997)
Quinone molecular weight	108.095	g/mol	(Centro Nacional de Información Biotecnológica, 2020a)
Ascorbic acid molecular weight	176.12	g/mol	(Centro Nacional de Información Biotecnológica, 2020b)
Water density	1	g/cm3	(Centro Nacional de Información Biotecnológica, 2020c)

The results of previous material balance calculations of each unit operation are shown in Table 17.

Table 17. General Material Balance of yacón syrup processing.

WASHER		**PEELER**		**REACTOR 1**	
Stream	**Balance (kg/h)**	**Stream**	**Balance (kg/h)**	**Stream**	**Balance (kg/h)**
W1.1 (MrY)	83.3	P1.1(MwY	83.07	R1.1 (MpY)	67.14
W.1.2 (Mw)	125.00	P1.2(MpY)	67.14	R1.2 (MAc. Asc)	0.974
W.1.3 (MwY)	83.08	P1.3(MrsY)	15.93	R1.3 (Mw)	150.13
W.1.4. (Mdw)	125.27			R1.4 (MYt)	68.82
				R1.5 (MrAc.Asc)	149.42
REACTOR 2		**EXTRACTOR**		**FILTER**	
Stream	**Balance (kg/h)**	**Stream**	**Balance (kg/h)**	**Stream**	**Balance (kg/h)**
R2.1 (MYt)	68.82	E1.1 (Yde	71.23	F1.1 (Myj)	55.89
R2.2 (Mbw)	102.23	E1.2 (Myj)	55.89	F1.2 (Myjf)	47.67
R2.3 (Yde)	71.23	E1.3 (Myb)	15.34	F1.3 (Mbp)	5.59
R2.4 (Mbwr)	100.82			F1.4 (Mlp)	2.63

EVAPORATOR	
Stream	**Balance (kg/h)**
Ev1.1 (Myjf)	47.67
Ev1.2 (Mys)	7.01
Ev1.3 (Mew)	40.67

WASHING PROCESS

In this unit operation is going to carry out the washing of raw material and elimination of farmland waste as is shown in Figure 14 and Diagram 3. It was used water/yacón in a proportion of 1.5/1 according to the experimental part, this data is similar with the found in bibliography according to Barreto Vargas (2019) which show that the proportions are 1.4/1, also in this unit, is carried out the disinfection process which, allows to avoid contamination by microorganisms, this process has a content of sodium hypochlorite at a concentration of 200 ppm, this concentration was taken and experimented according to Coronado Panta (2013) in Table 11.

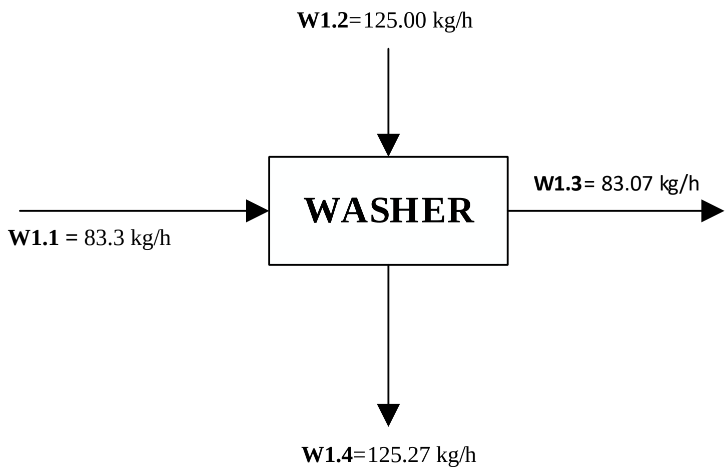

Diagram 3. Diagram of washing mechanism.

Figure 14. A. Dirty yacón and B washed and disinfected yacón.

PEELING PROCESS

In this unit operation is carried out the peeled system (see Diagram 4, and Figure 15). This process is after the washing process of raw material. According to Manrique *et al.* (2003), the loss of yacón shell is around 20 %, and according to the experienced developed in the laboratory, the amount of shell, residues are about 19.17 %, a value which was take into account in the following material balance.

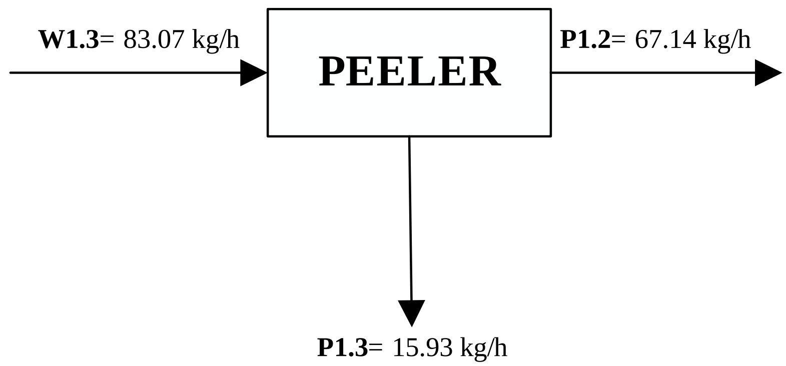

Diagram 4. Diagram of peeling mechanism.

Figure 15. Peeled yacón.

REACTOR 1

The yacón peeled root enter to the first reactor which is shown in Diagram 5, in which is going to occur the reaction to avoid the root browning for the following process. Here was taken into account the rate reaction between ascorbic acid and quinones and the amount of phenolic acids that the root contains. Also, it was calculated the reactor volume, which is important for the process design. The number of phenolic compounds is the quantity that will be transformed into *o*-quinones, which will give the different organoleptic characteristics. According to Lachman *et al*. (2007), this quantity is 0.89%, which was used in the material balance calculation. On the other hand, with the calculation of % *o*-quinones and the stoichiometry developed was calculated the ascorbic acid quantity that will be used for avoid the browning of yacón.

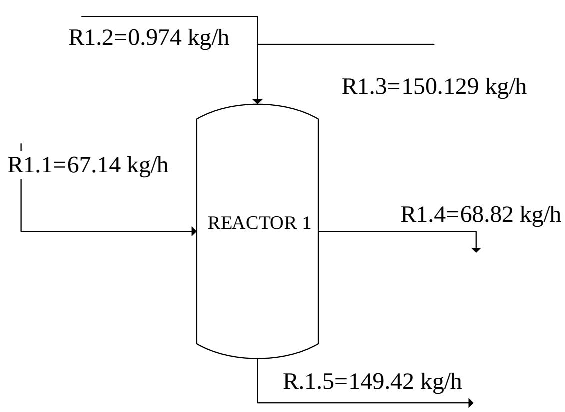

Diagram 5. Diagram of reactor 1 mechanism.

Calculation of reactor volume

In this calculation was taken into account the volume relationship yacón/water, also the volume of ascorbic acid. Giving as a result a batch reactor with 211.17 L.

REACTOR 2

Here have been taken into account, firstly, the reactor volume and the temperature of the water that have to be under 70 °C for the PPO enzyme deactivation. The experimental values were in a range of 80-90°C taken into account according to Zarate Paucarpura (2016). It was taken into account the volume of reactor 1. The process works in high temperatures, that is why is used a jacketed reactor to preserve the heat see Diagram 6 and Figure 16. Also, it was taken into account according to the experimental procedure the water retention after the pretreatment process was 6.02 %.

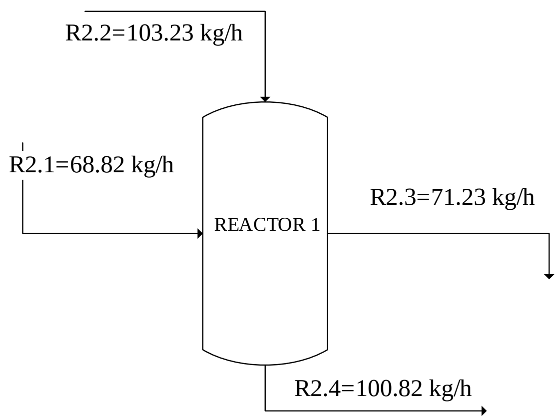

Diagram 6. Diagram of reactor in scalding process.

Figure 16. Scalding process of yacón.

EXTRACTION PROCESS

In this process is carried out the process of juice extraction as is shown in Diagram 7, the percentage of juice according to the experimental part was 78.46% in relation to the input of peeled yacón pretreatment. Its color was yellow, and its appearance cloudy.

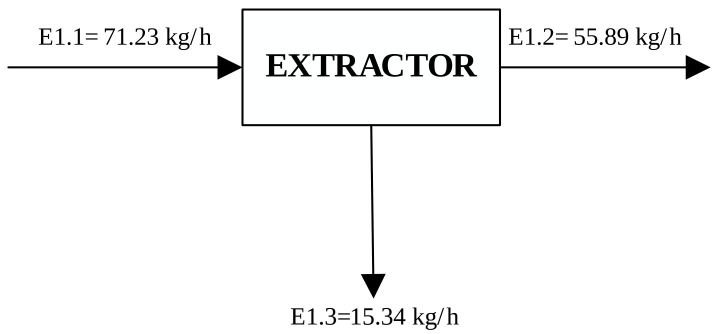

Diagram 7. Diagram of extractor mechanism.

FILTRATION PROCESS

This operation was considered, the residues of the juice filtration in the experimental part were around 10.02 % of residues. The process is carried out as is shown in Diagram 8 and Figure 17.

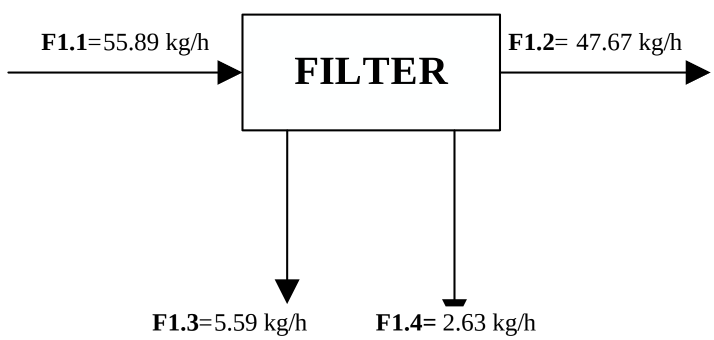

Diagram 8. Diagram of filtration mechanism

Figure 17. Filtration process of yacón juice.

CONCENTRATION PROCESS

In this unit operation, the objective according to Manrique *et al.* (2003), was that the juice has to be concentrated until 70°Brix, Diagram 9 shows how is carried out this process. This were measure with a refractometer, and was obtained the yacón syrup, here was elaborated a concentration curve, presented in Figure 19. The water percentage in respect to yacón peeled the experimental part was 92.42%, and according to Caballero Méndez & Colonia Pineda, (2018), it is around 80-90 % of water, which is similar to the experimental part. The performance of yacón syrup, which contains a concentration of FOS, is 10.44 %. Finally according to data reported in Seminario *et al.*, (2003), root to syrup conversion efficiency is around 12:1 (root weight:syrup weight), the value that represents the 8 % which match with the data obtained in the experimental part that is around 10 % of (root weight: syrup weight), which represents a relation approximately of 10:1, which is not far from the bibliographic data.

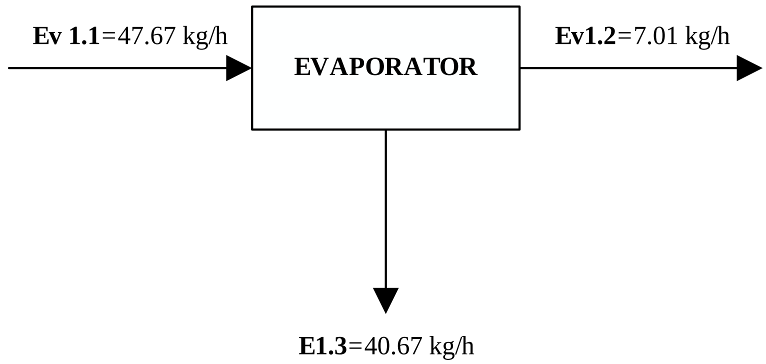

Diagram 9. Diagram of evaporation mechanism.

Figure 18. Yacón syrup.

Figure 19 shows a curve of concentration of yacón juice in time, it shows that for achieve 70 °Brix takes around 45 minutes.

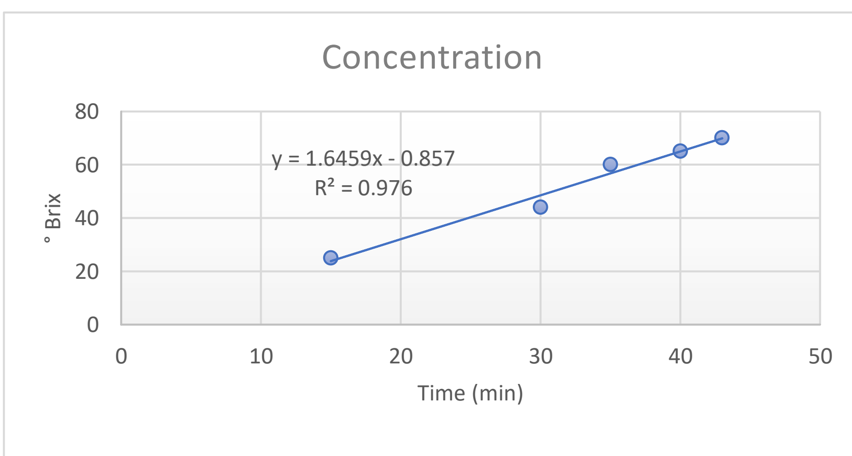

Figure 19. Curve of concentration of yacón juice in time.

CHAPTER IV

4. FINANCIAL EVALUATION FOR THE CONCEPTUAL IMPLEMENTATION OF A YACÓN SYRUP PROCESSING PLANT.

This chapter describes the economic analyses of implementation of the semi-industrial plant of yacón sweetener.

4.1. Investment

An economic study of the initial investment was carried out, in which the fixed assets were taken into account, those describe the machinery, equipment, and material goods (see Annex 6). Regarding deferred assets, the expenses for the incorporation of the company and advertising expenses are included (see Annex 6). The working capital, which is the monetary amount that the company must have to maintain a business. Thus, having an initial investment of $ 90089.63, which will be financed half by contributions from partners and the other half a bank loan at 8% interest. The total initial investment is detailed in Table 19.

In Table 18 it is shown the necessary equipment for using in the yacón syrup process, which described its quantity and prices. These values are taken into account in Table 19 as part of Fixed Assets.

Table 18. Equipment investment.

Article	Quantity	Unit price	Total price
Balance	1	56	78
Washer	1	900	1260
Peeler	1	2780	3892

Reactor	1	1800	2520
Jacketed Reactor	1	2,000	2800
Extractor	1	1300	1820
Filter	1	50	70
Evaporator	1	500	700
Storage Tank	1	300	420
Packer	1	850	1190
TOTAL	10		14750

The necessary equipment was taken into account according the necessities of a semi-industrial plant, the total price was calculated with an increase of 0.40 % of its price because of the import inversion.

Table 19. Total Initial Investment.

TOTAL INVESTMENT	
Details	**Value**
Fixed Assets	75239.63
Deferred Assets	4,850
Work Capital	10000.00
TOTAL	**90089.63**
FINANCING	
Partner 1	22522.408
Partner 2	22522.408
Bank Credit	45044.82
TOTAL	**90089.63**

4.2. Demand

Two cities in the country were taken into account to sell the product, those are the Ibarra city, where it is grown and processed, and the capital, Quito, those are the main cities in the north of the country. To calculate the demand for the sweetener, different variables were taken into account: the current demand for sweeteners in Ecuador, social class, percentage of the population with diseases such as diabetes, and the per capita sweeteners consumption, thus giving an approximate number of potential customers with 5-year projection (see Table 20). The total calculations are in the Annex 7.

Table 20. Demand indicator in two cities of the country.

Years	**2021**	**2022**	**2023**	**2024**	**2025**
Yacón sweetener (kg)	72894	76568.21	80419.36	84456.10	88687.10

As it was established in Table 14, it was processed 25 tons per year and 83.3 kg per hour, in 12 hours per day, in two periods, for which the following results were obtained given that the plant will produce the same quantity during the first five years, these results are shown in Table 21.

Table 21. Annual production of raw material and yacón processed.

	2021	**2022**	**2023**	**2024**	**2025**
Total raw material processed (kg)	300000	300000	300000	300000	300000
Total syrup processed (kg)	25220	25220	25220	25220	25220
Total bottle production (250mL)	90745	90745	90745	90745	90745

4.3. Price

The price for each presentation of the sweetener was calculated according to the prices of this natural sweeteners in the market, as well as according to the cost of production of each bottle of yacón sweetener. A 5-year projection was made according to the variations of Consumer's Price Index (CPI) that indicate on April 2020 had an increase of 4.27% (INEC, 2020). The price established for the final consumer is $ 5 for 250 mL. Considering that the sale is going to be made to suppliers. Table 22 shows the variation in prices according the CPI during the first five years.

Table 22. Projection prices of yacón syrup to the first five years.

Years	**2021**	**2022**	**2023**	**2024**	**2025**
Unit Price ($)	3.75	3.90	4.05	4.20	4.35

4.4. Income Projection

The monetary income to be obtained annually is calculated according to the demand and the sale price of the final product.

Income projection = sale price of the product x demand

Table 23. Income projection during the first five years.

Years	**2021**	**2022**	**2023**	**2024**	**2025**
Incomes ($)	340292.7	353904.4	367516.1	381127.81	394739.52

4.5. Production Costs

These costs are necessary to carry out the sweetener production in our case, how much does it cost to produce a 250 mL bottle of yacón sweetener. These include raw material costs, wages, and direct and indirect costs.

Raw material costs have to be with the direct inputs necessary to carry out the production of the sweetener.

Table 24. Raw material cost in the first Year.

Raw Material	Price $ /kg	Quantity kg/year	Total
Yacón roots	0.4	300000	120000
Sodium hypochlorite	0.54	900	486
Ascorbic acid	7	3504.84	24533.85
TOTAL			145019.35

In this section, the number of personnel was taken into account according to the size of the company, with this it has been considered to have 11 employees with different roles in the company, as well as their salary is according to the salaries in the country, to the position that each individual has. In Table 26 is shown the first annual salaries, and Table 27 shows the salaries during the following years.

Table 25. Labor costs during the first Year.

Company staff first Year									
Area	**Position**	**N°**	**Salary**						**Annual**
			Sub total	**XIII**	**XIV**	**Vaca tion**	**Employer contribution**	**Total**	
Production	Production manager	1	800	66.67	33.42	33.33	69.57	1002.98	12035.78
	Workers	4	450	37.50	33.42	18.75	39.13	2315.19	27782.26
	Cleaning staff	1	450	37.50	33.42	18.75	39.13	578.80	6945.57
	Logistic staff	1	450	37.50	33.42	18.75	39.13	578.80	6945.57
Administrative	General Manager	1	1000	83.33	33.42	41.67	86.96	1245.37	14944.48
	Accountant	1	450	37.50	33.42	18.75	39.13	578.80	6945.57
	Security Guard	1	450	37.50	33.42	18.75	39.13	578.80	6945.57
	Seller	1	450	37.50	33.42	18.75	39.13	578.80	6945.57
SUBTOTAL		11	4500.00	375.00	267.33	187.50	391.30	7457.53	89490.35

Table 26. Total Annual labor costs for the next five years.

2021	2022	2023	2024	2025
Direct Labor Costs				
53709.17	56254.28	58926.65	63897.24	66951.76
Administrative Salary				
35781.17	37490.03	39284.33	43052.37	45124.79
Total Labor Costs				
89490.35	93744.32	98210.98	106949.61	112076.54

Salaries as the years go by, they increase because each year with the country's political reforms and according to PIB, they generally increasing by 0.05 % each year.

4.6. Cash Flow

In this flow, the income and expenses that will be present in the execution of the project are detailed. In this, we can see the gains and losses that can appear.

Table 27. Final Cash Flow

DETAILS	PROJECT HORIZONT					
	PRE-OP	2021	2022	2023	2024	2025
INCOMES						
Operational						
Syrup bottles		340293	349367.2	362978.9	376590.6	390202.28
Non-operational						
Working Capital	10000	0	0	0	0	0
TOTAL INCOMES	10000	340293	349367.2	362978.9	376590.6	390202.28
EXPENSES						

Operational						
Supplier payment		172130	172130.1	172130.1	172130.1	172130.09
Basic Services		5907.47	5957.53	6017.61	6089.70	6176.21
Direct Labor Costs		53709.2	56254.28	58926.65	63897.24	66951.76
Administration salaries		35781.2	37490.03	39284.33	43052.37	45124.79
Advertising expenses		850	850	850	850	850
Insurance and machinery maintenance		3730	3810	3898	3994.8	4101.28
Depreciation		1527.02	1527.02	1527.02	0	0
Non-operational						
Credit payment		21025.6	21025.58	21025.58	0	0
Income tax payment		9199.92	11130.57	14344.14	16509.81	18566.59
Office expending		720	756	793.8	833.49	875.16
Administration expenses		150	150	150	150	150
TOTAL EXPENSES	0	304730.42	312215.42	320081.53	308641.81	316060.19
NET CASH FLOW	-90089.63	35562.26	41688.98	47434.58	72486	78679.33
INICIAL BALANCE	0	-90089.63	-54527.37	-12838.39	34596.19	107082.19
FINAL BALANCE	-90089.63	-54527.37	-12838.39	34596.19	107082.19	185761.52

4.7. Financial Evaluation

When a business project is starting, it is important to consider both its viability and its profitability. This can be obtained with the IRR and NPV formulas, regardless of the area or product applied.

4.7.1. Net Present Value (NPV)

These acronyms correspond to the Net Present Value; it is a financial indicator that it is used to determine the viability of a project. If after measuring the flows of future income and expenses, and discounting the initial investment, an economic benefit or profit is obtained; the project is viable. This indicator also offers us the opportunity to determine the price of the company, project or business, if it is going to be sold. For the project to be viable, the NPV value must be greater than 0 (greater than the initial investment) (Morales Velayos, 2017). Those values can be seen in Table 27.

4.7.2. Internal Rate of Return (IRR)

IRR is the acronym that corresponds to the Internal Rate of Return. Its function is to give us known the rate at which the initial investment of the business will be recovered. The higher the IRR, it means that the project will be more profitable, (see Table 27) (Sevilla, 2019).

4.7.3. Benefit/ Cost (B/C)

This is a benefit/cost ratio; this indicator compares the cost and benefit to define its viability. For this to be viable, this value must be greater than 1, which means that the project is feasible, (see Table 27) (ESAN, 2017).

Table 28. Values of NPV, IRR, B/C

Indicator	Value	Units
NPV	192821.25	$
IRR	44.10	%
B/C	1.10	

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Yacón is a root that is not very popular in Andean zone of Ecuador and is known by the name jícama, it is commonly consumed as fresh fruit by indigenous people.

Yacón syrup can have a great acceptance in the country because the benefits have been proven not only as a sweetener, also, for the health, such as preventing colon cancer, and especially for people who have diseases such as diabetes, obesity among others. Yacón syrup can be a promise to improve the quality of life of people who consume it.

The roots used in the experimentation to obtain syrup have a high yield because it was obtained a relation of (10:1) of syrup concerning to the peeled roots, which is near with the mentioned in (Manrique *et al.*, 2003) that is (12:1). As well as the percentage of water contained in the roots was 90% results similar to reported by Paredes *et al.*, (2017).

The scaling was carried out according to the data obtained in the experimentation developed in the laboratory. Considering that the production of yacón starts at 25 tons per hectare per month, 83 kg of roots will be processed per hour during 12 hours of the day, it can be seen that the processes carried out in the laboratory is less efficient than at the industrial processed, due to it generates a greater amount of losses. In the manual peeling process around 19.17 % of the fresh root was lost. There are also losses in the extractor because a considerable amount of juice remains in the bagasse. Those losses can be reduced with the appropriate machinery.

The economic analysis was carried out to observe its profitability; this study was carried out for a demand of two cities because they are located in the north of the country, Ibarra, the town where it is processed, and Quito, the capital of Ecuador and one of the most populated cities in the country. These two cities were selected due to the costs involved in transporting the products to the rest of the country during the initial stage. According this analysis, the demand was determined with the minimum number of potential consumers.

The production of yacón syrup brings great advantages in some areas because it generates work, gives added value to the roots, and diversifies the ways of consuming this endemic root.

5.2. Recommendations

It is recommended studies to use the residues to give it added value, bagasse as chips, and the extract of yacón leaves because they have phenolic compounds that can help reduce glucose levels.

Studies can carry out an increase in the production of yacón syrup, as well as its raw material production, and therefore its demand.

It is recommended to carry out an economic study for a future exportation because prices are higher in the international market.

To create a parallel vacuum line to obtain transparent syrup could be a good option to have two types of presentations.

Implement quality standards and environmental control.

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ANNEXES

Annex 1. Protocol to follow in lab.

1. Weigh yacón roots.
2. Wash with 200 ppm sodium hypochlorite water.
3. Peel the shell from the root.
4. Chop the roots into small cubes.
5. Prepare a 0.007% solution of ascorbic acid.
6. Immerse the root cubes in ascorbic acid for 3 minutes.
7. Immerse the roots in 96 ° C water for 3 minutes.
8. Extract the juice.
9. Filter the juice.
10. Concentrate on the rotary evaporator to 70 ° Brix.

Annex 2.Calculus of yacón root density.

Figure 20. Yacón roots for its density calculation

Table 29. Parameters for the yacón density calculation.

Experimental data laboratory		
Yacón weight	61	g
*height	3.8	cm
*weight	3.8	cm
*depth	3.8	cm
Yacón volume	54.872	cm3

$$\rho_{yacón} = \frac{m}{V}$$

$$\rho_{yacón} = \frac{61\ g}{54.872\ cm^3} = 1.111\ \frac{g}{cm3}$$

Annex 3. Behavior of ascorbic acid over time.

Table 30. Behavior of ascorbic acid in yacón roots over time

YACÓN SAMPLE	Browning time (min)	Treatment time with ascorbic acid (min)	Scalding time (min)
1	0	30	3
2	30	30	3
3	60	30	3

Table 31. Experimental process to prove the enzymatic browning

YACÓN SAMPLE	Browning time (min)	Treatment time with ascorbic acid (min)	Scalding time (min)
2			
3			

Annex 4.Stoichiometric calculations to know the amount of ascorbic acid to avoid enzymatic browning.

Reaction

$$\boldsymbol{Quinones + Ascorbic\ acid \rightarrow Dehydroascorbic\ acid + hydroquinone}$$

$$1\ C_6H_4O_2 + 1\ C_6H_8O_6 \rightarrow 1\ C_6H_6O_6 + 1C_6H_6O_2$$

Table 32. Molecular weight of C,H,O

Reactants	Products
C=12	C=12
H=12	H=12
O=12	O=8

Table 33. Molecular weight of some compounds presents in the reaction between yacón and ascorbic acid.

Compounds	Molecular weight (g/mol)
Quinones	108.095
Ascorbic acid	176.12
Dehydroascorbic acid	174.108
Hydroquinone	110.11

Annex 5. Calculus for the reactor volume.

Table 34. Variables for the reactor size calculation.

REACTOR 1			
Variables			
TPA	**Average total phenolic amount**	0.89	%
TQA	**Average total quinone amount(A)**	0.89	%
rA	**Rate reaction (ascorbic acid and quinones)**	0.79	dm3/mol*s
w/y	**Relationship (water/yacón)**	1.5	
X	**molar conversion**	0.95	
	Total input mass flow rate	67.139	kg/h
		67138.57	g/h
P	**Yacón mass density**	1.1117	g/cm3
		0.0011	kg/cm3
	Total volumetric flow rate	60393.90	cm3/h
	Volumetric flow rate A	537.51	cm3/h
Qmw	**Quinone molecular weight**	108.095	g/mol

pW	**Water**	1	g/cm3
Ac.as	**Ascorbic Acid molecular weight**	176.12	g/mol
a/q	**Mass relation ascorbic acid and quinone**	1.6293	

$$input\ mass\ to\ reactor\ 1 = \ 67138.57\ g$$

$$mass\ relation\ (a/q) = \frac{(g)ascorbic\ acid}{(g)quinones} = \frac{176.12}{108.095} = 1.6293$$

$$input\ mass\ to\ react\ (g) = peeled\ yacón(g) * quinones\ (\%)$$

$$input\ mass\ to\ react\ (g) = \ 67138.57\ g * 0.89\ \% = 597.53g$$

$$(g)ascorbic\ acid\ need = input\ mass\ to\ react\ (g) * mass\ relation\ (a/q)$$

$$(g)ascorbic\ acid\ needed\ for\ inhibition = 597.53\ g * 1.62 = 973.38g$$

For achieve the concentration of bibliography and the used in laboratory proofs

Table 35. Quantities of ascorbic acid and water to obtain the correct concentration.

Laboratory scale		
Ascorbic acid (g)	Water (mL)	Concentration [p/v]
4.28	600	0.007
Semi-industrial scale		
973.8	150129.25	0.007

In spite of not birth with the relation (water/yacón) = 1.5, birth the specification of inhibit the total amount of quinones birthing the [] stablished, the final relation (water/yacón) = 2.23

Reactor volume calculation.

Table 36. Summary of Reactor volume.

Reactor volume		
Yacón roots	60.40	L
Water	150.13	L
Ascorbic acid	0.65	L
Reactor volume	211.20	L
Excess		

Annex 6. Calculus for economic chapter.

Detailed calculation of Table 19 Fixed assessments

Table 37. Summary of Construction facilities.

Construction Facilities				
Area	**Building**	**Quantity**	**Unit price**	**Total**
Production	Factory	1	10000	10000
Administration	Administration	1	15000	15000
Laboratory	Laboratory	1	10000	10000
Land	Land	1	15000	15000
TOTAL			50000	50000

Table 38. Furniture and equipment.

Furniture and equipment			
Articles	**Quantity**	**Unit Price**	**Total**
Office desks	3	400	1200
Cabinets	3	200	600
Executive chairs	3	150	450
Meeting table	1	1000	1000
Board	1	90	90
Counter Reception	1	500	500
Meeting chairs	10	100	1000
Waiting room chairs	3	80	240
Complementary items	5	271.85	1359.23
TOTAL		2791.85	6439.23

Table 39. Computer equipment

Computer Equipment			
Article	**Quantity**	**Unite price**	**Total**
Computer	3	1000	3000
Printers	3	150	450
TOTAL		1150	3450

Table 40. Office equipment

Office equipment			
Article	**Quantity**	**Unit price**	**Total**
Phone	3	200	600
TOTAL		200	600

Detailed calculation of Deferred Assets

Table 41. Sales Expenses.

Sales Expenses				
Concept	**Specification**	**Quantity**	**Unit Price**	**Total Price**
Publicidad	Social Media	1	300	300
	Radio	1	200	200
	Magazines and Newspapers	1	200	200
	Flyers	5000	0.03	150
TOTAL			700	850

Detailed calculation of Credit Bank

Table 42. Amortization table with fixed fee.

AMORTIZATION TABLE WITH FIXED FEE					
Amount	44659.82				
Term / Months	36				
Annual Interest	20				
Monthly Interest	0.02000				
Monthly fee	1752.13				
Quota Year	**Initial Balance**	**Fixed fee**	**Interest**	**Capital Payment**	**Final Balance**
0					44659.82
1	44659.82	1752.13	893.20	858.94	43800.88
2	43800.88	1752.13	876.02	876.11	42924.77
3	42924.77	1752.13	858.50	893.64	42031.13
4	42031.13	1752.13	840.62	911.51	41119.62
5	41119.62	1752.13	822.39	929.74	40189.88
6	40189.88	1752.13	803.80	948.33	39241.55
7	39241.55	1752.13	784.83	967.30	38274.24
8	38274.24	1752.13	765.48	986.65	37287.60
9	37287.60	1752.13	745.75	1006.38	36281.22
10	36281.22	1752.13	725.62	1026.51	35254.71
11	35254.71	1752.13	705.09	1047.04	34207.67

12	34207.67	1752.13	684.15	1067.98	33139.69
13	33139.69	1752.13	662.79	1089.34	32050.36
14	32050.36	1752.13	641.01	1111.12	30939.23
15	30939.23	1752.13	618.78	1133.35	29805.88
16	29805.88	1752.13	596.12	1156.01	28649.87
17	28649.87	1752.13	573.00	1179.13	27470.73
18	27470.73	1752.13	549.41	1202.72	26268.02
19	26268.02	1752.13	525.36	1226.77	25041.25
20	25041.25	1752.13	500.82	1251.31	23789.94
21	23789.94	1752.13	475.80	1276.33	22513.61
22	22513.61	1752.13	450.27	1301.86	21211.75
23	21211.75	1752.13	424.23	1327.90	19883.85
24	19883.85	1752.13	397.68	1354.46	18529.39
25	18529.39	1752.13	370.59	1381.54	17147.85
26	17147.85	1752.13	342.96	1409.17	15738.67
27	15738.67	1752.13	314.77	1437.36	14301.32
28	14301.32	1752.13	286.03	1466.11	12835.21
29	12835.21	1752.13	256.70	1495.43	11339.78
30	11339.78	1752.13	226.80	1525.34	9814.45
31	9814.45	1752.13	196.29	1555.84	8258.60
32	8258.60	1752.13	165.17	1586.96	6671.64
33	6671.64	1752.13	133.43	1618.70	5052.94
34	5052.94	1752.13	101.06	1651.07	3401.87
35	3401.87	1752.13	68.04	1684.09	1717.78
36	1717.78	1752.13	34.36	1717.78	0.00
TOTAL		**63076.75**	**18416.94**	**44659.82**	

Annex 7. Calculus of Cash Flow.

Determination of demand in Ibarra and Quito.

Table 43. Determination of demand in Ibarra city.

IBARRA DEMAND					
Estimation of the total number of clients	**2021**	**2022**	**2023**	**2024**	**2025**
Population	163690	170237.6	177047.10	184128.99	191494.15
Not extreme poverty (%)	97.1	97.1	97.1	97.1	97.1
Subtotal 1	158942.99	165300.71	171912.74	178789.25	185940.82
Age between 10-59 years (%)	64.1	64.1	64.1	64.1	64.1
Subtotal 2 (Universe Population)	101882.46	105957.75	110196.07	114603.91	119188.06

Medium and medium high economic level (%)	40	40	40	40	40
Subtotal 3	40752.98	42383.10	44078.43	45841.56	47675.23
Demand of sweeteners	10	10.1	10.2	10.3	10.4
Subtotal 4	4075.30	4280.69	4496.00	4721.68	4958.22
Prospects	122	128	135	142	149
Purchase Frequency					
Per capita consumption of yacón	20.92	20.92	20.92	20.92	20.92
Current demand for yacón (kg)	0	2686.56	2821.69	2963.33	3111.78

Table 44. Determination of demand in Quito.

QUITO DEMAND					
Estimation of the total number of clients	**2021**	**2022**	**2023**	**2024**	**2025**
Population	2781641	2892906.64	3008622.91	3128967.8	3254126.53
Not extreme poverty (%)	96.7	96.7	96.7	96.7	96.7
Subtotal 1	2689846.85	2797440.72	2909338.35	3025711.88	3146740.36
Age between 10-59 years (%)	64.1	64.1	64.1	64.1	64.1
Subtotal 2 (Universe Population)	1724191.83	1793159.502	1864885.9	1939481.32	2017060.57
Medium and medium high economic level (%)	65	65	65	65	65
Subtotal 3	1120724.69	1165553.68	1212175.82	1260662.86	1311089.37
Demand of sweeteners	10.0	10.1	10.2	10.3	10.4
Subtotal 4	112072.47	117720.92	123641.93	129848.274	136353.295
Prospects	3362	3532	3709	3895	4091
Purchase Frequency					
Per capita consumption of yacón	20.9	20.92	20.92	20.92	20.92
Current demand for yacón	**70337**	73881.65	77597.68	81492.78	85575.33