CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Drying characteristics of yacon (*Smallanthus sonchifolius*) tubers

MASTER'S THESIS

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DIPLOMA THESIS ASSIGNMENT

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Agri-food Systems and Rural Development

Thesis title

Drying characteristics of yacon (Smallanthus sonchifolius) tubers

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Objectives of thesis

The objective of the thesis is to describe the drying characteristics of yacon tubers under different drying methods. Furthermore, to investigate the influence of different drying pretreatments on the final organoleptic properties of dried yacon chips.

Methodology

Two different drying methods will be used in this study: hot air drying process and freeze-drying. The hot air drying will be realised in the drying clima-box with a balanced system with on-time weight loss recording. The freeze-drying will be conducted in the food lyophilizer. The drying curves will be constructed to understand the drying kinetics of yacon tubers. Part of the yacon samples will be subjected to selected drying pre-treatments such as blanching, immersing in brine and dipping in lemon and ginger extracts. Dehydrated and pre-treated samples of yacon chips will be evaluated by a trained degustation panel to describe the final product quality and sensory properties.

The proposed extent of the thesis

60pp

Keywords

Smallanthus sonchifolius, drying, lyofylization, drying kinetics, drying pretreatments

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Recommended information sources

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Declaration

I hereby declare that I have done this thesis entitled Drying characteristics of yacon (Smallanthus sonchifolius) tubers independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 22nd April 2022

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Barbora Motýlová

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Abstract

Yacon (*Smallanthus sonchifolius*) is Andean crop harvested mainly for its sweet edible tubers. Although it is quite unknown, it has many to offer. Thanks to a high number of bioactive compounds such as fructooligosaccharides, inulin, and phenolics it has antioxidative, antimicrobial, antidiabetic, or anti-obesity properties and positive effect on weight management. In fresh state, yacon roots have a short shelf life and due to the high amount of water, tubers are fragile, heavy, and not easy to transport or store.

Drying is an efficient preservation method to prolong the shelf life of food and dried yacon slices may be a promising product with economic potential. The yacon slices were dried at three different temperatures (40, 50, and 60 °C) and drying curves were constructed. Impact of various temperatures on final colour was measured using CIELAB colour space. The changes for each coordinate and the overall combined colour change (ΔE) were calculated. The result shows that the temperature does not have an impact on the colour change during drying.

Not much research has been done on the freeze drying of yacon slices or consumer perception. Therefore, two different methods of drying (hot-air drying and freeze drying) were examined and the best conditions were established. Consumer perception of these two drying methods was evaluated, resulting in a greater likability of the freeze dried sample. The change in colour was measured, and the lyophilized sample had a significantly lighter colour. Furthermore, different pretreatments using ascorbic acid, lemon, salt, and ginger were used to improve its organoleptic properties and sensory analysis was conducted. Also colour differences compared to control sample were measured. The results indicate that some pretreatments (like lemon) can improve consumer perception. On the other hand, some pretreatments (like salt and ginger) were not evaluated as positive. Furthermore, ginger significantly darkens the final product, which was also evaluated by panellists as unpleasant.

Keywords

Hot-air drying, freeze drying, yacon tubers, sensory analysis, drying pretreatments

Contents

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List of the abbreviations used in the thesis

FOS Fructooligosaccharides

a_w water activity

BMI body mass index

Asc - yacon sample treated with 1% ascorbic acid

Lmn - yacon sample treated with fresh lemon juice

Slt - yacon sample treated by the solution of salt

Gng - yacon sample treated by fresh ginger juice

C - control sample (non- treated yacon tuber slice)

L - colour coordinate for lightness

a - colour coordinate for green-red

b - colour coordinate for blue-yellow

Δ - colour change in certain colour coordinate

Δ - overall colour change

H_o is null hypothesis

H_1 is alternative hypothesis

1. Introduction

Yacon is a perennial plant, native to Andean regions, which is mostly cultivated because of its sweet-tasting tuberous roots. These tubers are crunchy, and the texture may be quite similar to that of watermelon or apple. It is common to eat tubers raw, but it is also possible to boil or roast them. It can be used in beverages or processed into syrup, jam, vinegar, juice, chips, or flour. In Japan it is sometimes also pickled, used in fermented beverages or bakery products or freeze-dried powder can be made out of it (Almeida Paula et al. 2015).

Studies have reported that yacon has phenolic compounds that can have a positive effect on human health, especially in the cases of anti-inflammatory, anticancer, and antioxidant activity. Components such as fructooligosaccharides and inulins have an effect on the management of diabetes, immunity, obesity prevention and weight management (Yan et al. 2019).

Despite all the benefits, yacon is still quite unknown to the world and the big problem is its short shelf life of tubers due to abundant amount of water.

Therefore, processing of yacon tubers is common. Mostly it is in form of flour, powder or syrup, but also dried slices.

Not much research has been done on lyophilization of yacon slices or using pretreatments to improve some characteristics like taste or aroma. Pretreatments could improve the organoleptic properties of dried slices and make product attractive for the global market.

2. Literature Review

2.1. Plant Specification and Cultivation

This plant belonging to the family Asteraceae is related to plants like sunflower and Jerusalem artichoke. Yacon may grow up to 2.5 meters and small yellow flowers occur at the end of the growing season, which is about 6 – 7 months after planting in favourable conditions. Its tuberous roots vary greatly in size, shape, and colour. The weight of one tuber can be from 0.2 to 2.0 kg, and commonly they are from 15 to 20 cm long and 10 cm thick (see figure 1). It highly depends on environmental conditions, but we can produce more than 10 kg of tuberous roots on one single plant (Ojansivu et al. 2011). In addition to the tuberous storage roots which are consumed, there are also perennial rhizomes used for propagation.

Its scientific name is *Smallanthus sonchifolius*, but previously it was also known as *Polymnia sonchifolia* or *Polymnia edulis.* Other names used for this crop are Peruvian ground apple, yacon strawberry, and poiree de terre (French). Local names are llaqon, llacum, llacuma, aricuma, jiquimilla, yacumpi, jiquima and chicama (Ojansivu et al. 2011). Sometimes yacon is called jícama. Although jícama (*Pachyrhizus erosus*) is also an American tuberous root containing inulin, it is a different plant belonging to the family Fabaceae.

Figure 1 Yacon plant (Mora 2018)

Yacon was cultivated by prehispanic people for centuries, but it was not known much in other parts of the world. It was overlooked until the mid-80s when compounds beneficial for human health were found, and those findings stimulated interest in this crop. Nowadays yacon is considered as a functional food. Terminology “functional food” was developed in Japan and is used since the mid-80s. Previously, it was “Food for Specific Health Use” with the acronym FOSHU and refers to food that reduces the risk of chronic diseases and has physiological benefits due to its biologically active components beyond the basic nutritional properties of regular food (Almeida Paula et al. 2015).

This crop is highly adaptable, and it can grow in a wide range of altitudes (800 – 2800 above sea level) and can handle various temperatures from 0 – 24 °C. Its cultivation is quite effortless thanks to protective compounds like di- and sesquiterpenes which make the plant resistant to pests and diseases (Lachman et al. 2003). Although not widespread, yacon is nowadays cultivated in a few more countries apart from its original site. In the 1960s, it was brought to New Zealand from Ecuador, and in 1985 it was introduced to Japan (Almeida Paula et al. 2015). Nowadays yacon cultivation and consumption was reported also in countries like China, and South Korea, but currently also in Europe, particularly in the Czech Republic (Yan et al. 2019). How yacon cultivation spread into other countries is visible on the map below (figure 2).

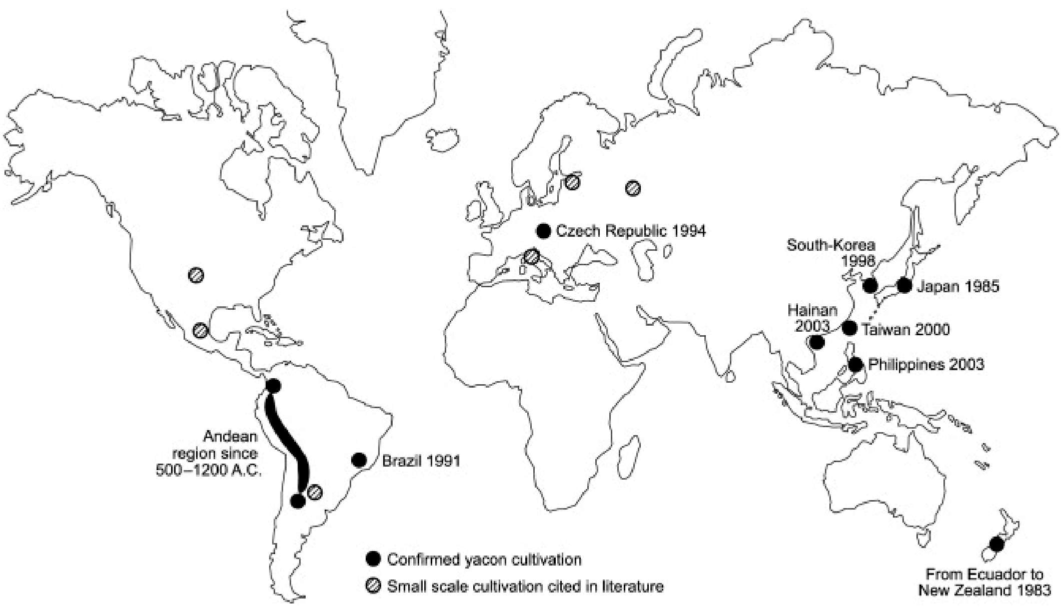


Figure 2 Yacon cultivation (Ojansivu et al. 2011)

2.2. Composition

The yacon plant is having many interesting compounds and their amount is highly dependent on many factors as part of the plant, cultivar, or even year of cultivation (Lachman et al. 2004). Sometimes young stems are used as vegetables (Valentová & Ulrichová 2003), but the main parts of the plant which are used are leaves and tubers.

2.2.1. Leaves

Leaves, which are often consumed in form of herbal tea are containing a significant amount of phenolics such as chlorogenic acid, ferulic acid, caffeic acid, and protocatechuic acid which are responsible mainly for antioxidant activity (Simonovska et al. 2003). Inoue et al (1995) found, that apart from three already known melampolides, there is a new compound from yacon leaves named sonchifolin. Sonchifolin is interesting due to its antifungal activity – especially against fungus harmful for rice – *Pyricularia oryzae* (Inoue et al. 1995). Dried yacon leaves also contain essential oils such as β-pinene, caryophylene and γ-cadinene (Adam et al. 2005).

2.2.2. Tubers

Tubers also have certain phenolics and antioxidants such as caffeic acid, feruic acid, chlorogenic acid, and tryptophan (Simonovska et al. 2003; Takenaka et al. 2003; Yan et al. 1999). But except for carbohydrates, there are not many micronutrients in greater amounts. The only one which is present in quite significant amount of potassium (Ojansivu et al. 2011). But these bioactive compounds are not the main reason of interest. Yacon tubers are extraordinary in the amount of fructooligosaccharides (FOS) and inulin.

2.2.2.1. Carbohydrates of Yacon Tubers

Carbohydrates (synonym of saccharides – a group including sugars, starch, and cellulose) are molecules consisting of carbon, hydrogen, and oxygen atoms. They are divided into four groups according to chemical structure: monosaccharides, disaccharides, oligosaccharides, and polysaccharides. The first two are smaller molecules with lower molecular weights and often end with suffix -ose such as glucose and fructose (monosaccharides) or sucrose (disaccharide).

Yacon is very rich in certain carbohydrates, especially inulins and FOS. Inulin is a term used for a heterogeneous blend of fructose polymers. Fructooligosaccharides (sometimes also called oligofructose or oligofructan) is a subgroup of inulin (Niness 1999). Both are prebiotics, and their main difference is in their structure. FOS are shorter (with a degree of polymerization (DP) ≤10) and more linear, whereas inulin is a longer chain with more cross-links (Beeson 2017). We can find them in various plants such as wheat, onion, leek, dandelion, garlic, agave, chickory, dahlia, Jerusalem artichoke, and yacon (Sousa et al. 2011).

Yacon roots are mainly water which exceeds 70% (Lachman et al. 2003), but in dried root matter, the main component is FOS in the amount of 40 to 70%. Except for FOS there is also from 15 to 40 % of simple sugars – glucose, fructose, and sucrose (Ojansivu et al. 2011).

Such a remarkable amount of FOS is not very common, because in most other tubers it is usually starch. When we look at table 1, we can see how yacon differs in the amount of FOS and starch compared with other Andean tubers.

Table 1 Composition of Andean tuberous roots (% of dry matter) (Leidi et al. 2018)

	Arracacha	Yacon	Ahipa	Mashua
Dry matter	9–24	9–14	15–21	7–20
Protein	0.7	2.8	3.2	1.5
Lipid	0.3–0.5	0.3–0.6	0.4–0.6	0.7–0.9
Starch	49–86	0.4–2	35–54	20–80
FOS[a]	0	38–64	0	0
Sugar	4–15	11–29	28–47	7–55
Fiber	1.1–4.7	3.9–4.2	4.4–25.9	0.9–6.9
Ash	1.0	2.8	3.8	0.6

A study by Lachman et al. (2007) analyzed further saccharides in yacon roots as we can see in the chromatogram below (figure 3). Due to the dependence of amounts of carbohydrates on conditions, it is good to mention that those yacon plants were cultivated in the Czech Republic on trial fields at Czech University of Life Sciences Prague- Suchdol at altitude 286 m a.s.l. where average vegetation temperature is around 14.5°C and precipitation 525mm. The plants were harvested after around 158 days of vegetation period in October/November. We can see that inulin is the major component when talking about sugar, then fructose is also at high levels, and glucose and saccharose are at lower levels.

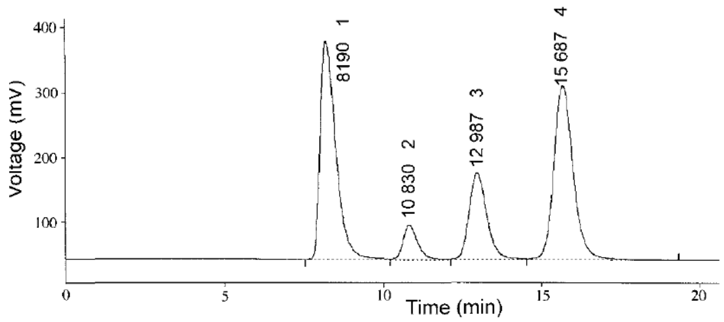


Figure 3 Chromatogram of saccharides in Bolivian genotype of yacon tubers (1 - inulin, 2 - saccharose, 3 - glucose, 4 - fructose) (Lachman et al. 2007)

The amount and composition of carbohydrates in the yacon tubers are not always the same. It varies not only among cultivars but also among years of cultivation or conditions. As we can see in table 2 below, in one cultivar (from Bolivia) it can be 120 g/ kg in the year 1996 and 460 g/ kg five years later. Also, we can see, that certain genotypes, like the German one, can have only 80 g/kg compared to 243 g/kg in the same year with yacon from New Zealand.

Table 2 Comparison of inulin, fructose, saccharose, and glucose contents in dry matter of yacon tubers among different ecotypes and year of cultivation (Lachman et al. 2004)

Ecotype/year	Inulin	Fructose	Saccharose	Glucose
	(g/kg d.m.)			
BOL/95	236	113	20.1	45.8
BOL/96	120	124	19.4	102
BOL/00	169	295	35.5	113
BOL/01	460	250	19.5	122
BOL/AVE	246	195	23.6	95.4
ECU/96	215	115	20.4	91.5
ECU/00	231	275	37.4	114
ECU/01	420	217	19.7	104
ECU/AVE	289	203	26.2	103
NZ/95	117	184	23.1	80.7
NZ/96	204	113	20.9	77.0
NZ/00	243	287	49.8	54.8
NZ/01	375	283	27.5	106
NZ/AVE	235	217	30.4	79.5
GER/96	181	104	20.9	67.8
GER/00	80	90.2	19.7	20.4
GER/01	163	432	26.1	179
GER/AVE	141	209	22.2	89.0

BOL = Bolivia; NZ = New Zealand; ECU = Ecuador; GER = Germany; AVE = average value

And it is not the only the year of cultivation and genotype influencing the amount and composition of carbohydrates, the storage time and storage conditions are playing a crucial role. After harvesting yacon tuberous roots, the chemical composition of carbohydrates is changing. Fructans are converted into sucrose, fructose, and glucose. How fast this transformation will happen is mainly temperature-dependent. After only one week of storage at 25 °C, 30 – 40% of FOS can change to simpler sugars (Almeida Paula et al. 2015). This process is significantly slower when yacon is kept under refrigeration, as we can see in table 3 below describing post-harvest time influence on the composition of saccharides in cooler conditions. We can see that levels of inulin are almost half after 140 days of storage compared to the first day of storage. On the other side, the levels of fructose saccharose and glucose slightly increased. This experiment was done at conditions of 10 °C and 75 % of air relative humidity.

Table 3 Effect of storage for 140 days on saccharides content in Bolivian ecotype yacon tubers (Lachman et al. 2007)

Days of storage	Inulin	Fructose	Saccharose	Glucose
	(g/kg d.m.)			
0	236	113	20.1	45.8
140	121	125	44.4	60.2

This study also found that there is a relationship between the amount of free fructose and sweetness. A higher level of fructose is correlated with higher sweetness. Therefore, the tubers are sweeter in taste a few days after harvesting compared to tubers consumed directly when harvested. This should be considered in further processing, especially in decision making in terms of what we want the tubers use for. If the goal would be the extraction of inulin, it would be better to process tubers as fast as possible after harvest. If the main goal is to have sweet-tasting tubers that may be more favourable for consumption, processing a few days after harvest would be recommended (Lachman et al. 2007).

2.3. Health Benefits of Yacon

Still, not much research has been done about the effects of yacon consumption on humans. Most of the studies that focused on the benefits of yacon on human health were done in vitro or in vivo mainly in rats, and those studies declare positive effects on human well-being.

Yacon has many bioactive compounds and many health benefits. Certain compounds have various impacts on different health benefits, and otherwise many different compounds have a positive impact on one health benefit. Therefore, many compounds and their effects are interrelated.

2.3.1. FOS and its Health Benefits

The major attention deserves compounds that are in yacon tubers abundant. Inulin and FOS have some positive effects on human health and reduce the risk of chronic diseases. It can also decrease the probability of colorectal cancer and improve immunity (Caetano et al. 2016). The main interest in yacon is focused mainly on its prebiotic and antidiabetic properties, as well as its impact on weight management.

2.3.1.1. Prebiotic Activity

Inulin, same as FOS, is fructan, so some characteristics are similar like water solubility (therefore both are classified as soluble fiber). Same as FOS is not digested by enzymes in the upper gastrointestinal tract, but later is fermented in the colon, therefore has low caloric value and is considered a prebiotic (Niness 1999; Yan et al. 2019).

FOS and inulin intake is reducing pathogenic bacteria while beneficial for health-promoting bacteria such as *Lactobacillus* and *Bifidobacterium.* The presence of those two probiotics is an indication of a balanced gut micro-flora (Pedreschi et al. 2003; Valentová & Ulrichová 2003). The intestinal microbiota transforms FOS into a short chain fatty acids, which may help with lipid metabolism, glucose homeostasis, and regulation of immunity (Caetano et al. 2016). Yacon prebiotic activity is explained in figure 4 below.

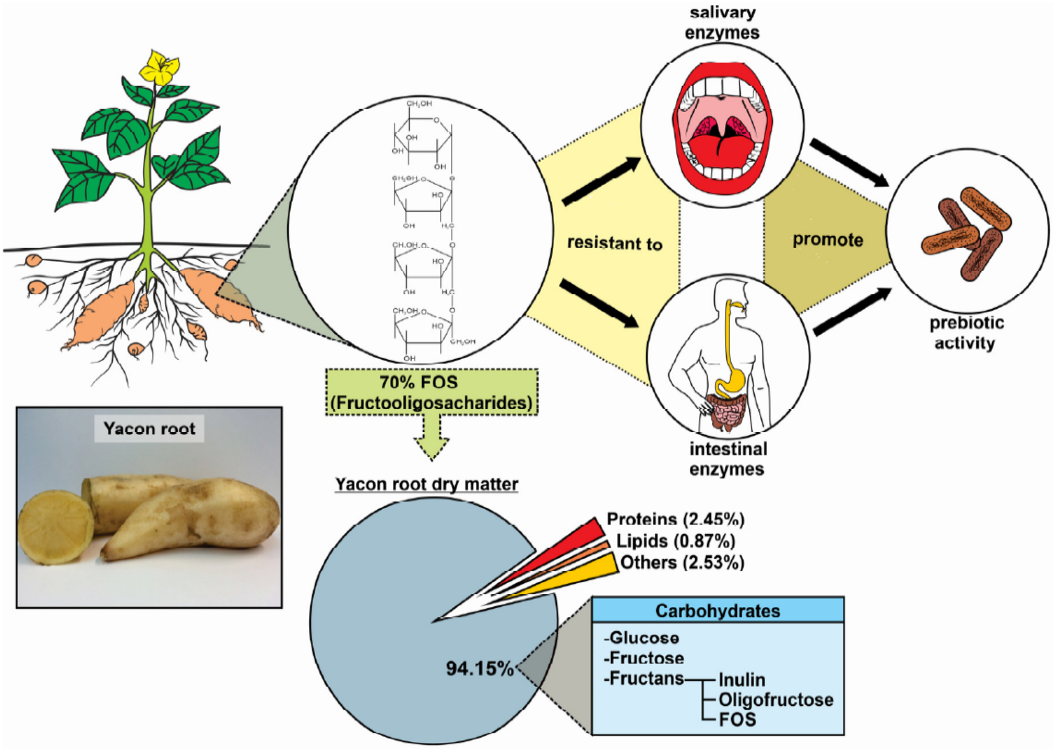


Figure 4 Prebiotic activity of FOS (Caetano et al. 2016)

2.3.1.2. Diabetes

Diabetes is a chronic metabolic disorder related to high blood sugar levels. It may be caused by insulin hormone dysfunction, and it is related to multifactorial disorders that lead to hyperglycemia (Contreras-Puentes & Alvíz-Amador 2020). In developed countries, diabetes is the most common chronic disorder, and it is the leading cause of death worldwide (Caetano et al. 2016). Several compounds such as FOS and others present in yacon tubers may have positive hypoglycemic properties and positive effects on diabetic disorders. FOS which have some impact on blood sugar are in figure 5 below.

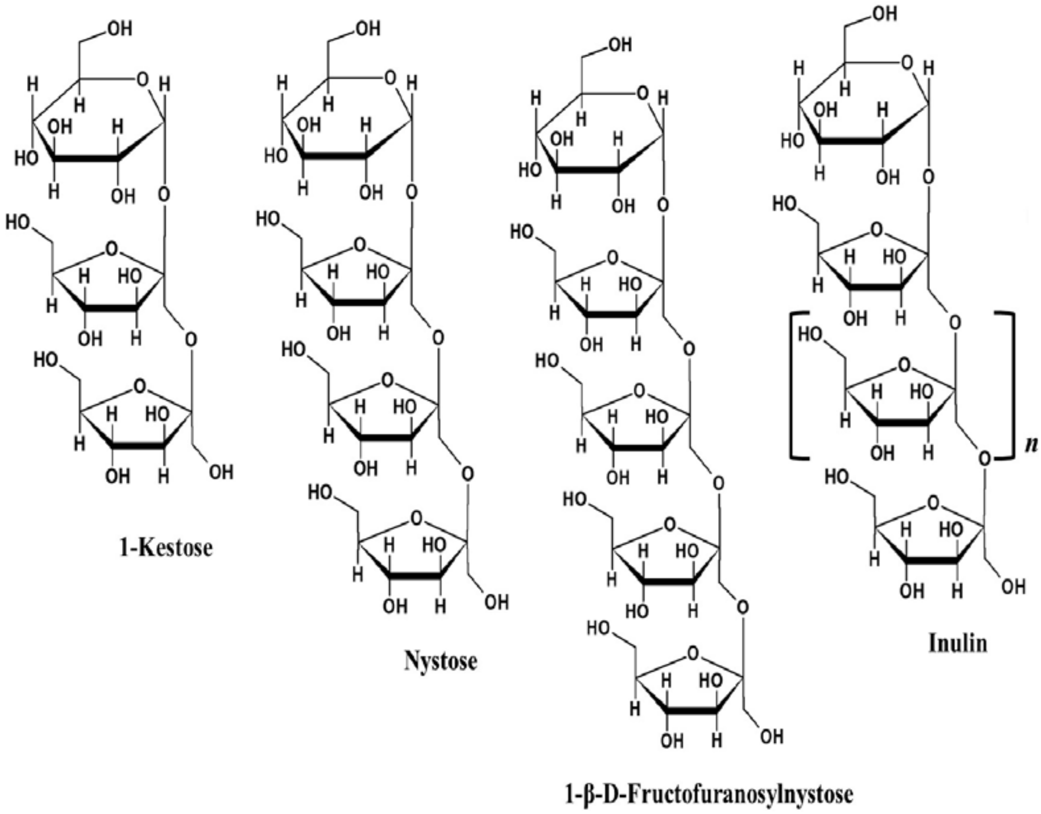


Figure 5 FOS compounds in yacon related to hypoglycemic effect (Contreras-Puentes & Alvíz-Amador 2020)

Several studies investigated FOS from yacon and its impact on human health. For example, Scheid et al. (2014) proved that freeze dried yacon powder is decreasing serum glucose levels in elderly people. Satoh et al. (2013) did research on rats and and his results indicate that yacon is reducing blood glucose. Genta et al. (2009) examined the effects of daily consumption of yacon syrup on obese women and proved that it has beneficial health effect on obese pre-menopausal women with insulin resistance.

There are various ways how FOS can have some antidiabetic properties. Figure 6 explains the mechanisms by which FOS can affect diabetes-related disorders.

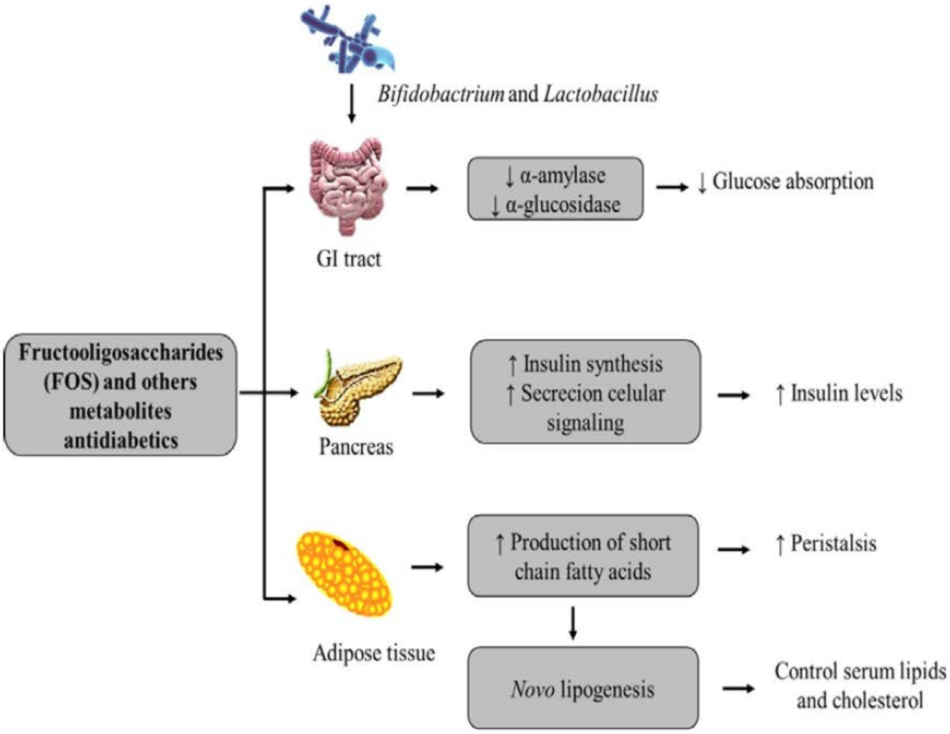


Figure 6 Antidiabetic effects of FOS (Contreras-Puentes & Alvíz-Amador 2020)

2.3.1.3. Obesity and Weight Management

Obesity is often defined based on body mass index (BMI), where individuals with a BMI of 25 to 29.9 are considered overweight and those with a BMI greater than 30 are considered obese. Obesity is related to many other health issues as it is a major risk factor for diabetes, cardiovascular disease, cancer, hypertension, sleep apnea, liver disease, etc. Obesity has increased worldwide in the last few years and nowadays is associated with mortality, disability, and enormous health costs (Ahima & Lazar 2013).

Several studies on rats were done with positive results on weight management and Genta (2009) observed that daily intake of yacon syrup leads to a significant decrease in body weight, waist circumference, and BMI among obese premenopausal women.

Although the effect of yacon on weight loss and its hypolipidemic properties are commonly discussed, studies based on human trials are still scarce and the underlying mechanisms are still unclear (Caetano et al. 2016).

2.3.2. Other Beneficial Health Components of Yacon

Apart from FOS, there are many other health-beneficial compounds. In small amounts, yacon is containing micronutrients such as calcium, phosphorus, potassium, magnesium, sulfur, copper, manganese, zinc, and iron. There was also determined the presence of vitamins A, E, C, and beta-carotene (Khokhla 2016).

There are terpenes, catechol, flavonoids, and phenolic compounds that have mainly antidiabetic or antioxidant activity. Some of those compounds which are mainly antioxidants or have a hypoglycemic effect are shown in figure 7.

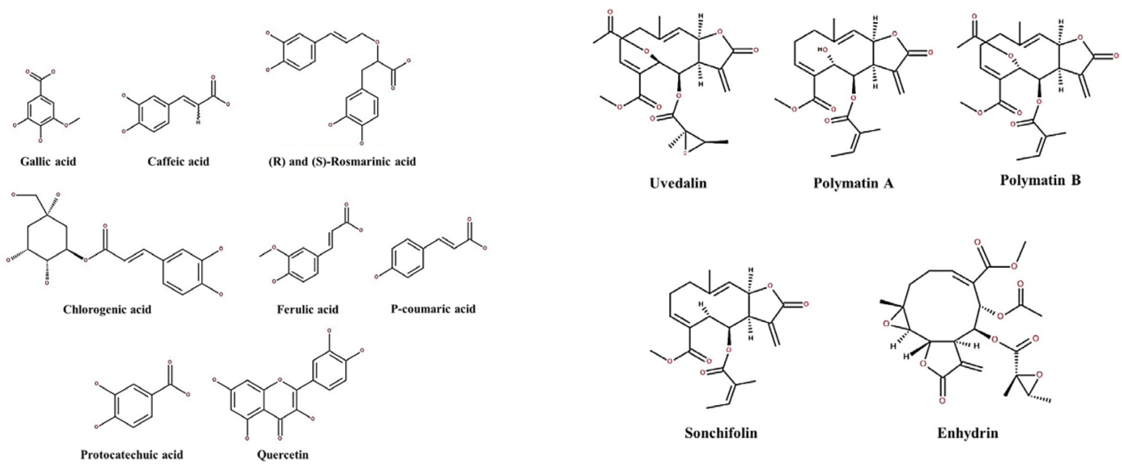


Figure 7 Some of the chemical constituents present in yacon with antioxidant activity related to hypoglycemic effect or direct effect on hypoglycemia (Contreras-Puentes & Alvíz-Amador 2020)

2.3.3. Yacon Consumption and Safety

The health effects are still discussed, and not many human studies have been done. Some in vitro experiments were performed, but most in vivo studies were not conducted on humans, but on animals (Yan et al. 2019). Studies on rats by Genta (2005) proved that there is no toxicity in yacon and FOS according to the clinical studies and also the Food and Drug Administration recognized yacon as generally safe (Yan et al. 2019).

Although recommended doses of yacon are safe and overdose is not life-threatening, some symptoms of overdose might be uncomfortable. Those may include bloating, diarrhoea, flatulence, and abdominal pain. Yacon also accelerates colonic transit (Geyer et al. 2008), therefore it may lead to an increase in stool frequency.

One important side effect should be considered. Hydrolysis of oligofructans to fructose begins shortly after harvesting and can even be accelerated during processing (Graefea et al. 2004). This should be taken into account when talking about the benefits of oligofructans and the safety for diabetics. Cold and controlled storage as well as monitoring of the composition of saccharides are recommended to preserve its functional properties.

2.4. Drying Fundamentals

The fact that yacon contains a very large amount of water is also indicated in its name. The etymological origin of the name is “yaku” from Quechua Indian language is composed of two words – Yakku which means „tasteless“ and Unu which means „water“ (Almeida Paula 2015; Contreras-Puentes & Alvíz-Amador 2020). Due to the high amount of water, which can be around 70 % but even over 90 % (Lachman et al. 2003; Ojansivu et al.2011), it has very short shelf life. Also, tubers with such an amount of water are fragile and heavy when we are thinking about transportation and storage on a larger scale.

The suitable way how to prolong shelf life is to extract abundant water from the product by dehydration where the main purpose is usually prolonging the shelf-life of food and preventing spoilage. In addition to longer shelf life, drying also leads to a reduction of weight and bulk, which decreases storage and transportation costs. Dried products are also easier to handle and, in some cases, more convenient for customers, therefore it might be more suitable for the global market.

Dehydration (also known as drying) is application of heat under controlled conditions in order to remove water that is normally present in the product by evaporation (or sublimation in the case of freeze-drying). The heat input is also needed to combat the latent heat of water vaporization (or sublimation) (Chen & Mujumdar 2008). Latent heat is specified as the energy that is absorbed or released by a substance during a change of its phase that occurs without a change in its temperature. Latent heat originates from the forces that hold the particles (atoms and molecules) in the substance (Black 2022). Transfer of heat to the wet solid-dried product may happen by convection, conduction, or radiation, sometimes also by a combination of them (Mujumdar 2006).

Speaking of the process of drying, there are two main groups in-air and in-vacuum. During the in-air process mostly higher temperatures are occurring in terms to achieve a higher rate of drying. On the other side, in-vacuum process is used when we want to maintain the activity of valuable microorganisms, like probiotic bacteria, for example. It is because vacuum drying mostly uses lower temperatures and freeze-drying is common (Chen & Mujumdar 2008).

2.4.1. Fundamentals of Hot-Air Drying

During drying two main processes are taking place

1. Energy (mostly as heat) is transferred from the environment into the product and moisture is evaporated from surface
2. Internal moisture is transferred to the surface of the product and its subsequent evaporation

Process 1 depends on external conditions such as temperature, air humidity, airflow, pressure, and exposed surface. Process 2 is depending more on the physical nature of the solid dried material as temperature or moisture content (Mujumdar 2006).

A very important role plays microstructure of dried product because it has an impact on the movement of the water within the material. Usual material characteristics influencing drying rate are porosity and tortuosity, but the composition of material has also a crucial impact on the transport of heat and water (Chen & Mujumdar 2008). Figure 8 shows the movement of water molecules in the product through the material to the surface and then drying air is taking them away.

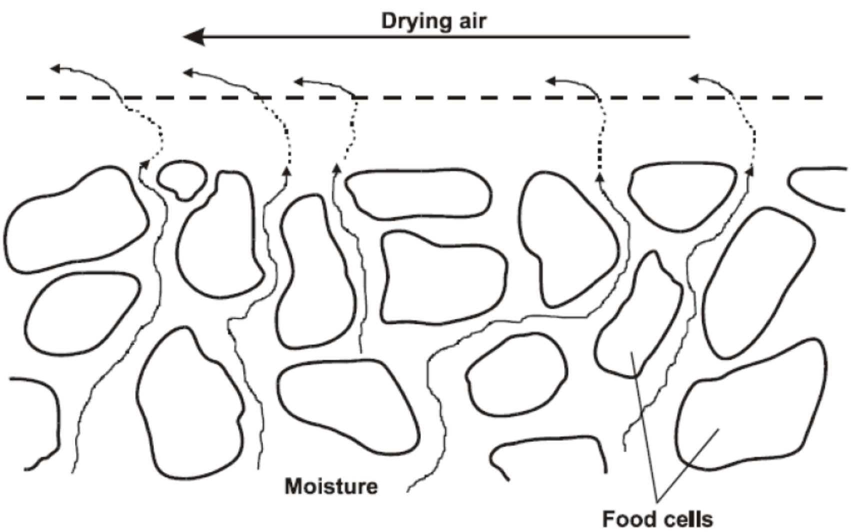


Figure 8 Moisture movement inside dried material (Brenndorfer et al. 1985)

As water is leaving the material, the product is losing its weight as we can see in figure 9. The weight loss curve may vary depending on the nature of food being dried or drying conditions as we can see below.

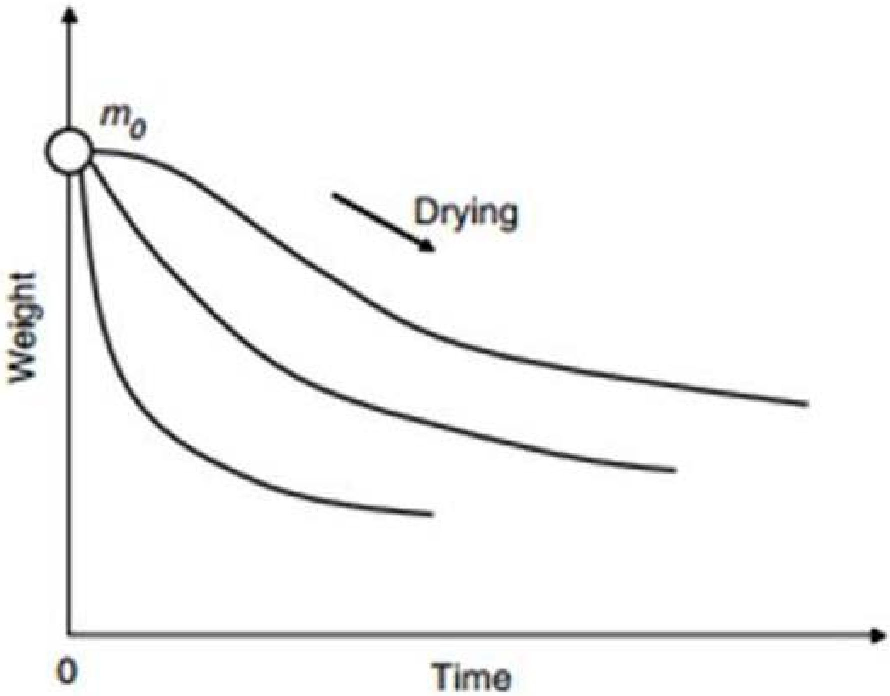


Figure 9 Weight loss in time during drying (Chen & Mujumdar 2008)

2.4.2. Fundamentals of Freeze Drying

In the case of freeze drying (lyophilization or cryodesiccation), the dehydration process is happening by sublimation of ice from the frozen product (compared to conventional drying where the dehydration process is by vaporization).

This method can provide a dried product of very high quality, and it is suitable for many heat-sensitive or oxygen-sensitive food products. But it has its price, this drying method has high maintenance and operating costs, and a long drying time under continuous vacuum is requiring a lot of energy, therefore it is a very expensive process (Chen & Mujumdar 2008).

Figure 10 shows the phase diagram of water which explain the principle of lyophilization. In this phase diagram of water, are displayed three states of water (vapor, liquid, and solid) and also two important points C and T. Point C is the critical point, where vapor and liquid can co-exist. Point T is the triple point of water where all three phases – solid, liquid, and vapor coexist and it is at 0,01 °C and 0,612 kPa. In the graph, we can also see the line of atmospheric pressure of 101.330 kPa.

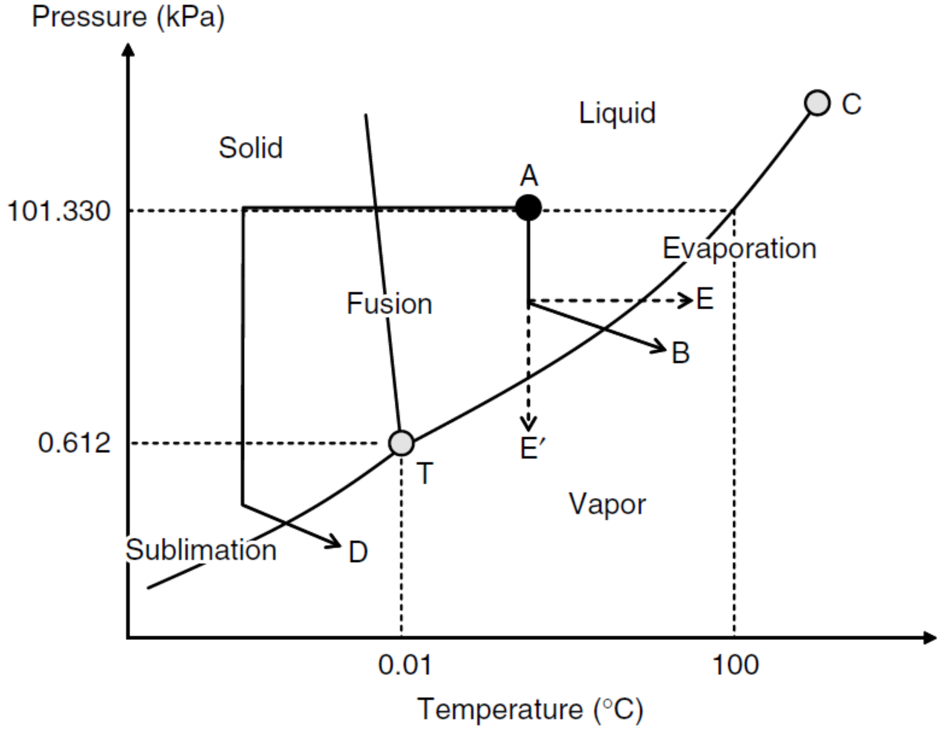


Figure 10 Phase diagram of water (T – triple point, C – critical point) (Chen & Mujumdar 2008)

For heat-sensitive products, we can also use vacuum drying, which is expressed in the graph on the path from point A to point B. We can see that pressure is lowered below atmospheric pressure, so then we can use lower temperatures to make water evaporate - it means to cross the line between liquid and vapor phase on graph limited by points T and C (Chen & Mujumdar 2008).

In case of freeze drying, we follow the path from point A to point D. At first, the temperature of the product is lowered (less than 0,01 °C), so the water in the product solidifies. Then in the second step, the pressure is lowered somewhere below 0,612 kPa. In areas below 0,01°C and below 0,612 kPa, sublimation needed for freeze drying can occur. For sublimation of ice into vapor is needed to add some heat (a few degrees Celsius) and cross the line between the solid and vapor area in the graph. This line is described in the table 4 below:

Table 4 Pressure-temperature data for pure water. ΔH_s and ΔH_v are latent heat of sublimation and vaporization (Chen & Mujumdar 2008)

T (°C)	P_w^o (Pa)	P_w^o (Torr)	ΔH_s ($kJ\,kg^{-1}$)	ΔH_v ($kJ\,kg^{-1}$)	T (°C)	P_w^o (Pa)	P_w^o (Torr)	ΔH_v ($kJ\,kg^{-1}$)
−70	0.261	0.00196	2834.2		25	3167.01	23.75	2442.5
−60	1.080	0.0081	2836.7		30	4242.23	31.82	2430.7
−50	3.936	0.0295	2837.9		35	5621.92	42.16	2418.8
−40	12.84	0.0963	2838.8		40	7374.88	55.31	2406.9
−35	22.35	0.1676	2838.9		45	9581.33	71.86	2395.0
−30	38.01	0.2851	2838.8		50	12333.96	92.50	2383.0
−25	63.29	0.4747	2838.5		55	15739.14	118.04	2370.8
−20	103.26	0.7745	2838.1		60	19917.85	149.38	2358.5
−15	165.30	1.2398	2837.5		65	25006.83	187.55	2346.0
−10	259.90	1.9493	2836.6		70	31159.57	233.70	2333.9
−5	401.76	3.0132	2835.0		75	38547.23	289.10	2321.0
0	614.91	4.6118	2834.4	2501.6	80	47359.47	355.20	2309.5
5	873.01	6.5476		2489.8	85	57805.41	433.54	2295.5
10	1228.23	9.2117		2477.9	90	70114.2	525.86	2283.2
15	1705.18	12.7889		2466.1	95	84535.81	634.02	2270.0
20	2337.74	17.5331		2454.4	100	101330.00	760	2257.5

In the table we can see the temperature and related pressure, which in the figure 11 graph are making the line between solid and vapor (for numbers below triple point) and the line between liquid and vapor in case of temperatures higher than 0°C. Crossing this line means evaporation in case of temperatures above 0 ° C and sublimation in case of temperatures below 0 ° C, which is needed to successfully lyophilize. The pressure is expressed in Pascals, but also in Torrs, which is a common unit of pressure used in freeze drying technology. Also, there is mentioned latent heat which is needed for sublimation or vaporization. Evaporated water is condensed on the condenser.

In the field of lyophilization, often units as torrs (Torr) and millitorr (mTorr) are used instead of regular SI unit Pascal (Pa). This is because lyophilization in many devices mostly occur within a range of 100 mTorr and 1000 mTorr; therefore, using makes it easier to remember and be more oriented in the vacuum used for lyophilization. 1 Torr (1000 mTorr) equals 133.322 Pa and normal pressure is 760 Torr (760, 000 mTorr) (Schmiedberger 2018).

Under vacuum, the heat transfer is not as efficient. Convection is poor because there are not as many fluid molecules available, so heat transfer is mainly by conduction. Therefore, the heat conductivity of the material is crucial and the porosity of the material plays an important role. When the porosity of the material is high, the conductivity is low, and *vice versa* (Chen & Mujumdar 2008).

A great impact on the final dried product quality has the rate of freezing, as this is the main factor influencing the size of ice crystals. In general, when the product is frozen quickly, smaller crystals are created, and it is better for the final quality of the product. When the material is slowly frozen, it creates large ice crystals. Those after sublimation leave behind relatively large spores, which results in worse structural quality and resistance of the product (Dern 2005).

In results by King (1968) it is shown that quick-frozen meat is mostly having lighter colour compared to slowly-frozen meat. Same with coffee Karel and Flink (1975).

The freeze drying of yacon in the scientific literature is mentioned only rarely and is mostly in the form of freeze dried powder (Scheid et al. 2014; Weber & Rossi 2020). Only two studies were found mentioning freeze dried chips by Khajehei et al (2018) and Bernstein and Noreña (2014) but none of them fully described the methodology how to freeze dry yacon. The process is mentioned only partially by Bernstein and Noreña (2014), in which the time of 72 hours and the pressure of 64 torrs (8532.632 Pa) are mentioned, but the drying temperature used is missing. Moreover, studies mentioning lyophilized yacon are mostly focusing on the amount of compounds or structural properties and colour, but no study on consumer perception of lyophilized yacon slices was found.

2.5. Product Quality

After processing of product, estimation of stability and quality is necessary. After the dehydration process, there are many characteristics to evaluate. Important factors related to water content in the case of food processing are moisture content and water activity (aw).

2.5.1. Moisture Content

This characteristic basically expresses how much water is in the product. The amount of water in the product influences properties such as weight, conductivity, viscosity, density, and others. Generally, it is determined as weight loss during drying (Mermelstein 2009).

Among with a_w and pH, the water content is related to the potential microbiological growth. Even though spoilage mostly depends mainly on a_w, to avoid microbiological growth the moisture content should be kept below certain % of moisture. The optimum is highly dependent on the type of food ranging from 2 to 20 % (Perera 2005).

There are many methods how to assess moisture content (Zambrano et al. 2019), but commonly the content of the water in the material is reported on either wet basis or dry basis. The wet basis is calculated as the mass of the water in the sample divided by the total mass of the sample. The dry basis is calculated as the mass of water in the sample divided by the mass of solids in the sample. Equations for calculation of moisture content (FAO 2021) is below:

$$Moisture(dry\ basis) = 100\ \times\ \left(\frac{Wet\ Weight - Dry\ Weight}{Dry\ Weight}\right)$$

$$Moisture(wet\ basis) = 100\ \times\ \left(\frac{Wet\ Weight - Dry\ Weight}{Wet\ Weight}\right)$$

Wet Weight is weight of sample after drying, and Dry Weight is weight of completely dried sample after drying it in 105 °C for 24 hours.

2.5.2. Water Activity (a_w)

Water activity determines how much of that water which is in the product is unbound and thus free and available for microorganisms to grow. There are certain minimal levels of a_w that the microorganisms need for their growth. Mostly it is 0,9 for the majority of pathogenic bacteria, 0,7 for spoilage molds and we can say that no microorganism will grow if a_w will be below 0,6. Several factors play an important role in the growth of organisms within the product, for example, nutrients availability, pH, or temperature, but water activity is often the most important factor regarding food safety (Mermelstein 2009).

The water activity has values from 0 to 1 and is calculated as the ratio of the partial vapor pressure of the water above the product to the vapor pressure of the pure water at the same temperature and pressure. In case of pure water, when it is placed in a closed container, there are molecules with enough energy that constantly leave the water in the form of vapor and return to the liquid state. Those volatile molecules are exerting pressure on the top and sides of the container known as vapor pressure. There is constant random motion of the water particles, and the vapor molecules are in dynamic equilibrium with the liquid water, and the overall pressure in the container remains constant.

In the case of certain material, the principle is the same. There is a closed container, and water molecules can escape the material in the form of water vapor and return back. Same as before, those molecules above the material are exerting a pressure on the top and sides of the container known as vapor pressure, but some molecules cannot leave the material, because they are somehow interacting with other components contained in the material. Water activity is calculated using the equation 13 below:

$$a_w = \frac{P}{P_0}$$

P is vapor pressure in food, P_0 is vapor pressure of pure water (Bogart 2018)

3. Aims of the Thesis

Main aim

The main aim of this thesis is to investigate the drying characteristics of yacon tubers in various temperatures and to figure out suitable drying methods and pre-treatment for potential consumers.

Specific aims

i) Investigate the drying characteristics in three different temperatures.

ii) Determine the proper drying conditions for the freeze-drying method.

iii) Compare consumer perception of heat-dried and freeze-dried yacon slices.

iv) Evaluation of organoleptic properties of yacon chips according to used drying pre-treatment.

4. Material and Methods

4.1. Material

Fresh yacon tubers which were used for this thesis were obtained from Výzkumný ústav bramborářský (Potato Research Institute) in Havlíčkův Brod in the Czech Republic. The cultivar used was Graciella which is typical by long tubers with light-coloured skin and also light, almost white coloured flesh. The tubes were kept in vacuum-packed plastic bags in the refrigerator for three weeks.

4.2. Instrumentalization

The research was done on three drying facilities – SP VirTis AdVantage Pro Freeze Dryer (figure 11), Binder climate chamber with weighing balances (figure 12), and basic hot-air dryer (figure 13).

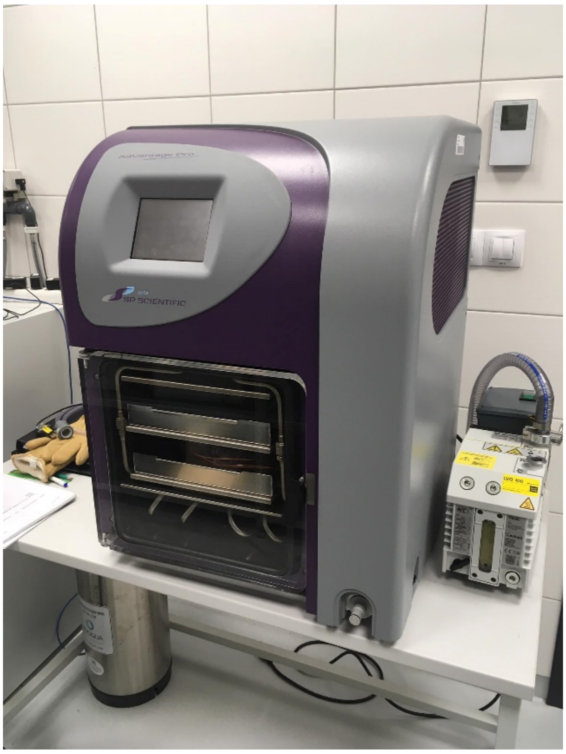


Figure 11 SP VirTis AdVantage Pro Freeze Dryer

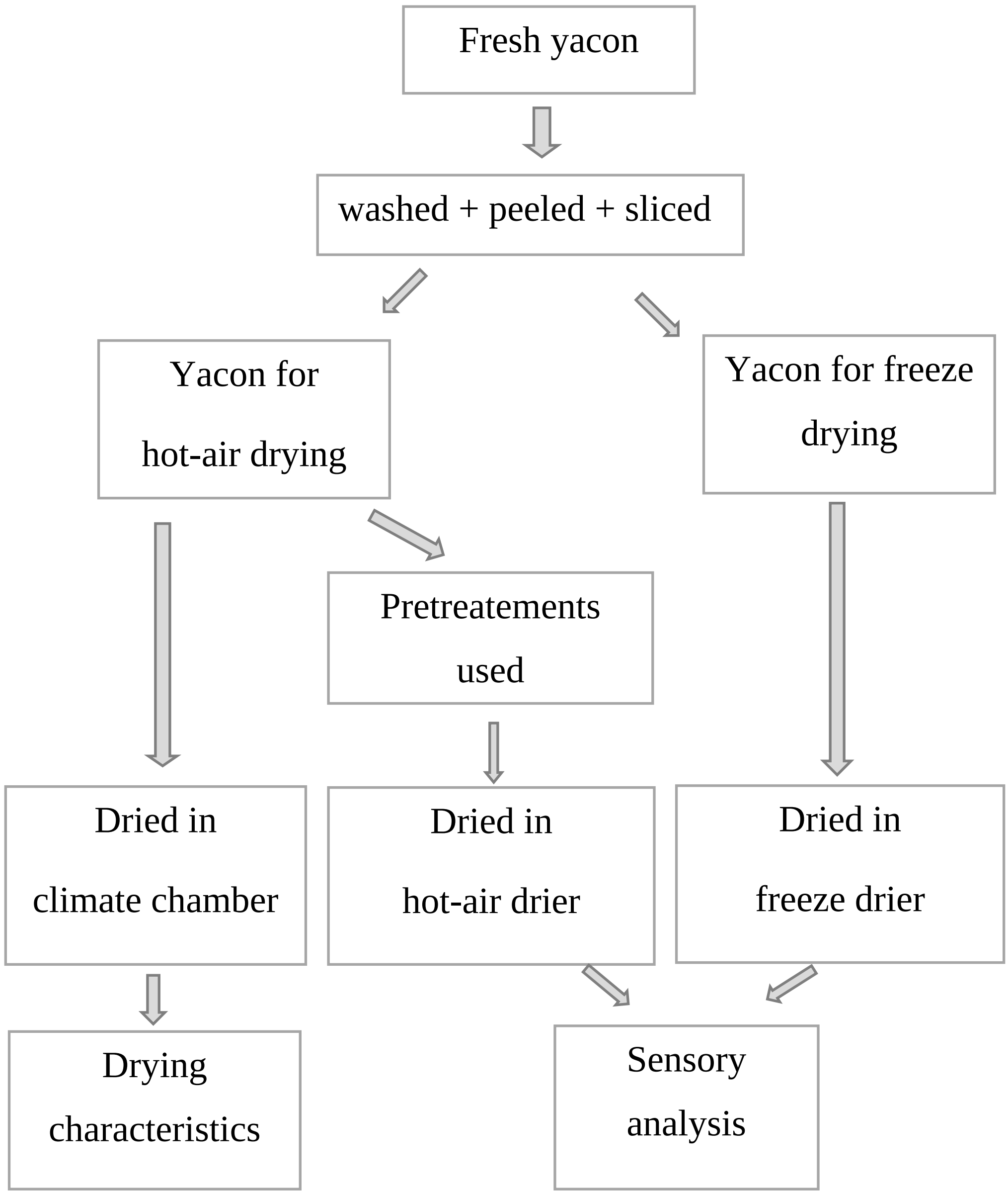
Figure 12 Binder climate chamber

Figure 13 Hot-air dryer

Other used facilities were Aqualab PAWKIT, Portable Water Activity Meter to measure a_w. Konica Minolta Cm-600d spectrophotometer to measure colour. Radwag PS 600 R2 weighting balances and the Memmert drying chamber were used to establish the moisture content. The GRAEF VIVO D-59757 Arnberg cutter was used to cut slices of similar thickness.

4.3. Experimental Procedure

The following diagram illustrates the experimental procedure of drying yacon:



4.3.1. Drying Experiment

Only the healthy–looking tubers were chosen. Tubers were washed in water, peeled, and sliced on a slicer on 4 mm thick slices. Tubers for lyophilization were sliced into 2 mm thick slices in order to achieve quite a similar size after the drying process because there is no such shrinkage using freeze drying compared to hot-air drying. The diameters were various as a result of the different shapes and sizes of each tuber.

4.3.1.1. Hot-air Drying

To investigate drying characteristics in various temperatures, the Binder climate chamber was used, where regulating drying conditions (temperature, humidity, and air velocity) is possible. In addition, the weight loss over time could have been recorded due to the three connected hanging scales that were used to continuously weigh the samples during drying.

Temperatures of 40°C, 50°C, and 60°C were chosen. The air velocity was 0,77 m/s and relative humidity was 30 % for all three experiments.

Fresh yacon slices of 4mm thickness were placed on drying racks and placed inside the climate chamber. Three average slices were chosen and placed on small hanging racks inside of the drying chamber. Those small hanging racks were connected to three weighing balances placed on the drying chamber by a string going through holes in the top part of the chamber. Those weighing balances were connected to a computer and were recording data about the weight of the samples every 10 minutes. Those data were lately used in excel and drying curves were constructed. The mean values of three measured samples were used. Because of windy conditions inside of climate chamber, the curves were full of peaks. Therefore, the data were slightly adjusted to make the curves smoother. Colour was measured before and after drying. The colour was always measured three times in three different places of the three slices using a spectrophotometer, and then the mean value was used. After drying, the a_w and moisture content was also measured.

4.3.1.2. Freeze Drying

For freeze drying fresh yacon slices of 2mm thickness were used, compared to 4mm thickness in case of heat drying, because during lyophilization the product maintains quite the same proportions compared to normal drying where shrinkage of the product is evident. Slices were placed one by one on metal trays. Pieces were not overlapping or touching each other but touching fully the metal tray. It is because heat transfer during drying at low pressures is mainly by conduction from the shelf, therefore the product should be in good contact with the shelf. Heat transfer by convection is rare compared to other forms of drying. If the product is not in direct contact with the shelf as much as possible, it significantly reduces heat transfer which is needed for the product to be frozen.

Loaded trays were placed on shelves and 4 sensors which enable monitoring current temperature inside of product were located inside four various samples. The process started by freezing with slight Pre-freeze at – 20 °C and thanks to sensors it was possible to monitor decreasing temperature of a sample and start with lyophilization when even in the middle of the sample was the required temperature. During the pre-freeze step, frost seal was used, which created a bit lower pressure to seal the doors of the freeze drier. It was done because in case of freezing and then using low pressure, the rubber assuring proper seal might not work as it should. After thermal treatment lyophilization started. Various experiments were conducted with various conditions. Finally the pressure used was 774 mTorr (103.192Pa), the temperature was chosen - 16 °C, and the time of drying was 50 hours.

4.3.1.3. Pre-treatments for Sensory Analysis

In the case of drying yacon with different pre-treatments for consumer perception, a basic hot-air dryer was used, due to its bigger capacity, therefore was possible dry all samples all together in one day under the same conditions.

Ascorbic acid, lemon, salt, and ginger were used. Those pre-treatments were used because they are widely accessible and commonly used in food processing. Ascorbic acid was 1% concentration. To get a ginger juice, the fresh ginger was grated and squeezed to obtain fresh ginger juice. Lemon juice was extracted from fresh lemons. In the case of salt, the solution of 500 ml of water and 25 grams of salt was prepared. The slices of fresh yacon were separated into groups with quite the same number of pieces and soaked in those liquids for 10 minutes.

The treated yacon slices were placed separately on drying racks and labeled to not mix them up. Then they were put into a dryer and dried at the average temperature 50 °C for 9 hours. Air velocity was 0,44 m/s. The dried samples were packed in plastic bags and stored in the dark in the laboratory storage room at the room temperature of 20 ° C.

4.4. Estimating physical properties of dried product

4.4.1. a_w

For measuring a_w, the Aqualab PAWKIT, Portable Water Activity Meter was used. The sample was cut into small pieces and placed into the device.

4.4.2. Moisture Content

Dried samples were weighted (wet weight), then dried for 24 hours at 105 °C, and then again weighted (dry weight). Before second weighting after taking them from the hot oven they were put into a desiccator until they had room temperature. Then moisture content was calculated based on the wet basis formula:

$$Moisture(wet\ basis) = 100\ \times\ \left(\frac{Wet\ Weight - Dry\ Weight}{Wet\ Weight}\right)$$

Moisture content of multiple samples was measured and mean value was used.

4.4.3. Colour Evaluation

To measure and compare the colour of the samples, a spectrophotometer by Konica Minolta was used, and data were described in the CIE L* a* b* colour space.

CIELAB colour space was developed by the International Commission on Illumination, in the French Commission internationale de l'éclairage, therefore the abbreviation is CIE. The CIELAB colour space (L*a*b*) is using three main parameters as we can see in figure 14. L* is representing the light–dark spectrum. It has values from 0 (black) to 100 (white). Letter a* represents the green-red spectrum where -60 represents green and + 60 represents red. The blue-yellow spectrum is represented by b*, where -60 means blue and +60 yellow (Jangam et al. 2010).

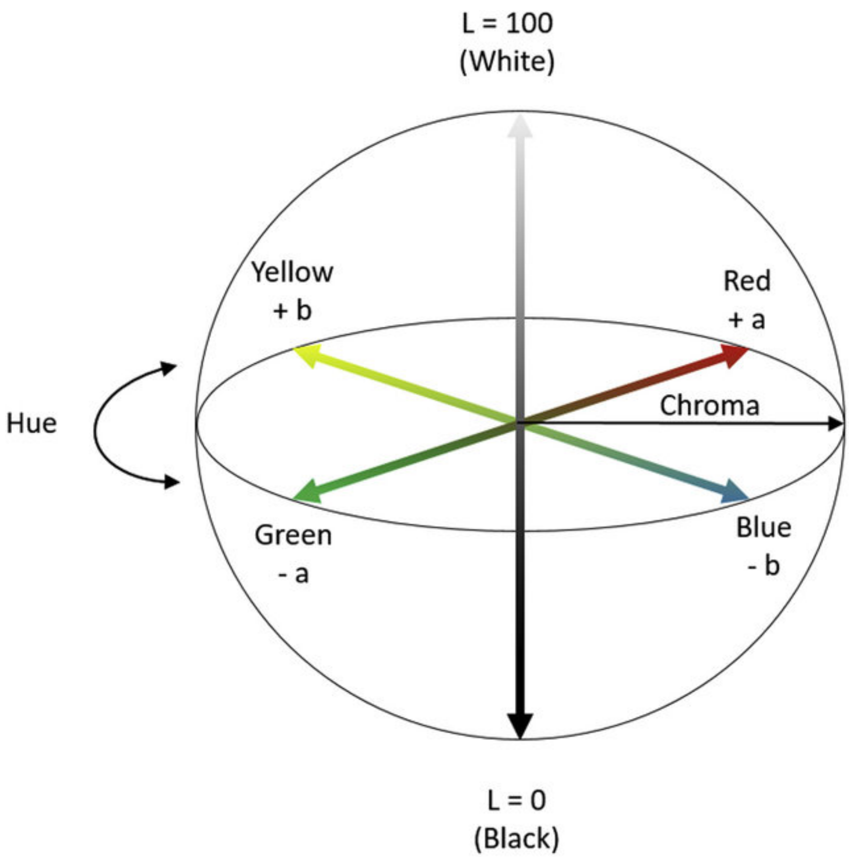


Figure 14 Lab colour space (Bao Chau et al 2020)

To analyse change in colour three random readings were made on each dried slice and then the average values were used for L*, a*, and b*. The fresh reference colour was estimated as a mean of multiple fresh slices. The colour was measured in the glossiness excluded mode.

In case of samples with pre-treatments only colour of the dried sample was measured. Colour of each sample was measured 3 times on 3 different places of a sample and the mean value was used. Treated samples were compared to non treated sample.

To calculate overall colour change for drying in various temperatures given equation was used (Chua et al. 2000; Kučerová 2015):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

where $\Delta L = L_{dried} - L_{fresh}$

$\Delta a = a_{dried} - a_{fresh}$

$\Delta b = b_{dried} - b_{fresh}$

For comparison of different pretreatments, the same equation was used, where treated samples were compared to the control sample

where $\Delta L = L_{treated} - L_{control}$

$\Delta a = a_{treated} - a_{control}$

$\Delta b = b_{treated} - b_{control}$

4.5. Sensory Analysis

Two sensory analysis tests were performed. At first test the panellists were comparing the different forms of drying. Natural non treated samples were used, one was hot-air dried, and second was freeze-dried. Both samples were brought at the same time as in figure 15.

Figure 15 Comparison of hot-air dried and freeze dried sample

In the second test, panellists evaluated different pretreatments. The samples were brought to them one by one on order: ascorbic acid treated, natural control sample, lemon juice treated, salt solution treated, and ginger juice treated. The order was random, only the ginger-treated one was given as last on purpose because of its very strong taste.

All samples were given three-digit codes. During the first test panellists were only informed that a different way of processing of yacon was used. In the second test they were informed that different pre- treatments were used, but they did not know what pre-treatments were exactly used.

For both tests, the same 12 semi-trained panelists were used. They evaluated parameters: general appearance, colour, aroma, texture, taste, juiciness, hardness, and general likeability for all samples. A hedonic scale from 1 to 5 was used, where 1 was very bad (or not juicy in case of juiciness and hard in case of hardness) and 5 was very good (or juicy in case of juiciness and soft in case of hardness). They could also describe if they felt any aftertaste (and they could describe it), as well as add any additional comments to each sample. Panellists had bread and a glass of water available.

The analysis was carried out in the sensory laboratory of the Faculty of Tropical AgriSciences.

Figure 16 Panelists evaluating organoleptic properties of yacon samples

Data from the sensory analysis were statistically analyzed. Various pre-treatments were given abbreviations – Asc for samples treated with 1% ascorbic acid, Lmn for those treated with fresh lemon juice, Slt for those which were treated by the solution of salt, Gng for samples that were treated with fresh ginger juice, and C for the control sample.

For data were calculated median, mean, standard deviation, and variation coefficient. To evaluate significant differences different tests were used. For comparison of freeze dried and hot-air dried samples U-Mann Whitman test was used. For comparing various pre-treatments the Kruskal-Wallis test was used.

5. Results and Discussion

5.1. Drying Characteristics

5.1.1. Hot-air drying

Yacon tuber slices of thickness 4 mm were dried to desirable moisture contents in range from 15 to 19 % and water activity (a_w) range 0.463 to 0.513. These are common recommended values for dried food products. Slices were dried using different air temperatures (40, 50 and 60 °C) and related drying times (8.5; 6.5 and 4.5 hours) were used in same airflow (0.77 m/s) and same air relative humidity (30 %). Drying curves as a function of weight loss in time were constructed (see figure 17).

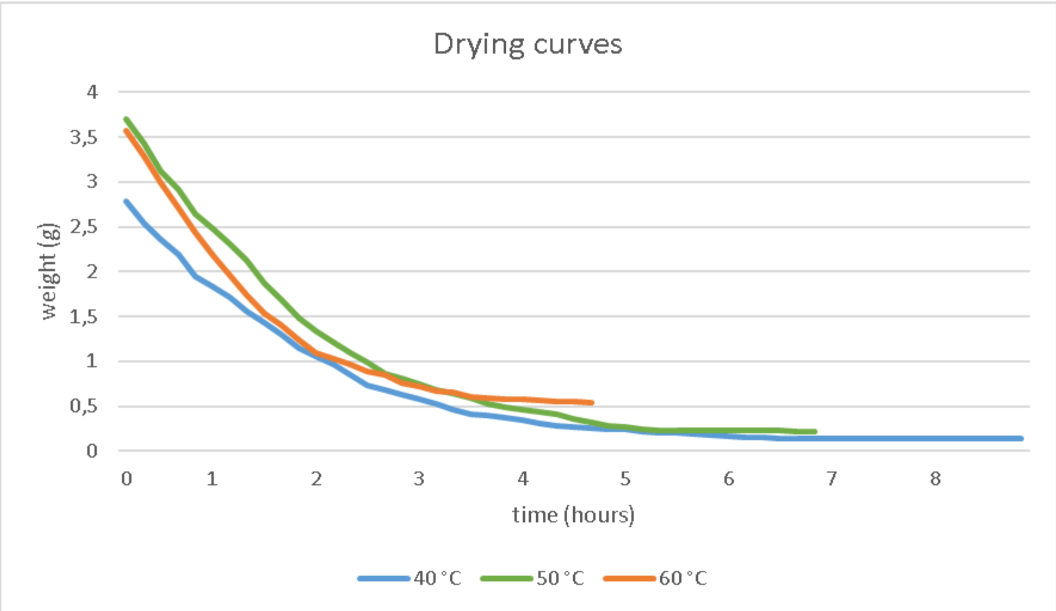


Figure 17 Drying curves of yacon slices in various temperatures

We can compare different drying temperatures in time where shortest curve stands for yacon dried in 60 °C and longest time was required for 40 °C. It is visible that, as expected, with higher temperatures used, the decrease in weight is more rapid as the water evaporates from the product faster. It is required longer time to dry yacon in lower temperatures and there is long falling rate period as moisture inside of product is moving to the surface to evaporate.

5.1.2. Freeze-drying

After series of experiments yacon slices of 2 mm thickness were successfully dried. Freeze dried yacon slices had moisture content 12.597 % and a_w 0.422. Best conditions for freeze drying yacon slices were estimated as pre-freeze at - 20 °C, and then dried at temperature -16 °C with pressure 774 mTorr for 50 hours. Fast prefreezing using lyophilizator was better than using freezer due to its higher freezing rate. Faster freezing is associated with smaller ice crystals, and therefore the quality of the final product is higher. Slow freezing creates large crystals of ice leading to bigger spores and leading to poorer structure of the final product, as was examined in multiple studies (Ceballos et al. 2012; Voda et al. 2012; Hammami & René 1997).

A similar experiment was carried out by Bernstein and Norea (2014) which used 1 mm thick yacon slices. They freeze dried yacon slices at pressure 64 mTorr for 72 hours, but the drying temperature is not mentioned in the article. As lyophilization is expensive time-consuming technology, I would propose drying at conditions found in this thesis, as they last 22 hours less and are efficient even when having thicker slices of yacon.

5.2. Colour Evaluation

During yacon processing, there is slight enzymatic browning occurring. It is happening because when the skin is peeled, the cell membranes are disrupted and compounds such as tannins and polyphenols are mixed with other components such as cytoplasmic enzymes, and it is in the presence of free oxygen. Darker colour might be unattractive for potential consumers; therefore, methods to control browning could be considered such as storage at lower temperatures, dehydration, oxygen removal, or the use of antioxidants (Almeida Paula 2015).

5.2.1. Hot-air dried in various temperatures

Change in colour using different drying temperatures was measured. Table 5 shows the values of fresh yacon slices compared with dried samples at various temperatures. In column Δ are differences for each colour coordinate separately and ΔE shows the overall change in colour.

Table 5 Changes in colour in various drying temperatures

	Fresh	Dried at 40 °C			Dried at 50 °C			Dried at 60 °C		
		dried	Δ	ΔE	dried	Δ	ΔE	dried	Δ	ΔE
L	57.483	66.997	9.514		66.66	9.177		64.563	7.08	
a	-0.696	2.403	3.099	**15.216**	2.357	3.053	**16.959**	2.45	3.146	**14.895**
b	9.669	21.133	11.464		23.6	13.931		22.39	12.721	

As various research indicates (Mohammad et al 2008) the change in colour (especially browning) of dried product increase, as drying air temperature increase. But in the table we can see that the overall colour change is 15.216 for 40 °C, 16.959 for 50 °C and 14.895 for °C. Those results indicate that the change in colour is not dependent on the temperature used, or at least that this trend is not linear. There is a difference between fresh and dried samples, but the difference among dried samples is very small. The highest change that occurred at 50 °C may not be given by the temperature used, but maybe by a longer time when the fresh yacon slices were exposed to air after processing before drying.

5.2.2. Hot-air dried and freeze dried

The comparison of colour change using freeze drying and drying in a conventional hot-air dryer is shown in the table below.

Table 6 Change in colour within different drying methods

	Fresh	Hot-air dried			Freeze dried		
		dried	Δ	ΔE	dried	Δ	ΔE
L	57.483	57.347	-0.136		77.14	19.657	
a	-0.696	3.093	3.789	**17.545**	-0.023	0.673	**24.142**
b	9.669	26.8	17.131		23.67	14.001	

The results are interesting especially in the change in the L coordinate that describes the lightness. There is not a large change in lightness when comparing fresh and hot-air dried (the difference is -0.1363 only), but there is a significant increase in lightness when the yacon is freeze-dried (+ 19.657) compared to fresh one. The same results as that freeze dried yacon samples have lighter colour than hot- air dried yacon samples had Bernstein and Noreña (2012). Differences in appearance are well visible at figure 18

Figure 18 Hot-air dried (left) and freeze dried (right) yacon slices

5.2.3. Pretreatments

Pretreatments such as ascorbic acid (Asc), lemon (Lmn), salt (Slt), and ginger (Gng) were used and the colour was measured. Colour was compared to non-treated control sample (C). Table 7 shows the changes (Δ) in colour for each colour coordinate separately, as well as the overall change in colour (ΔE) compared to reference sample C.

Table 7 Impact of treatments on colour change

	C	**Asc**	**Lmn**	**Slt**	**Gng**	**ΔAsc**	**ΔLmn**	**ΔSlt**	**ΔGng**
L	57.347	56.617	70.21	68.553	38.66	-0.73	12.863	11.206	-18.687
a	3.093	12.687	1.313	0.673	9.387	9.594	-1.78	-2.42	6.294
b	26.8	33.373	34.487	26.657	23.287	6.573	7.687	-0.143	-3.513
						ΔE=11.652	ΔE=15.09	ΔE=11.465	ΔE=20.029

In terms of lightness, we can see that some treatments (like Lmn and Slt) lighten the final product, while some (Gng) may the product be significantly darker. The overall change in colour is the smallest when Asc and Slt treatment is used, while in the case of Gng treatment the change in colour is the biggest. The final overall appearance of the products is shown at figure 19.

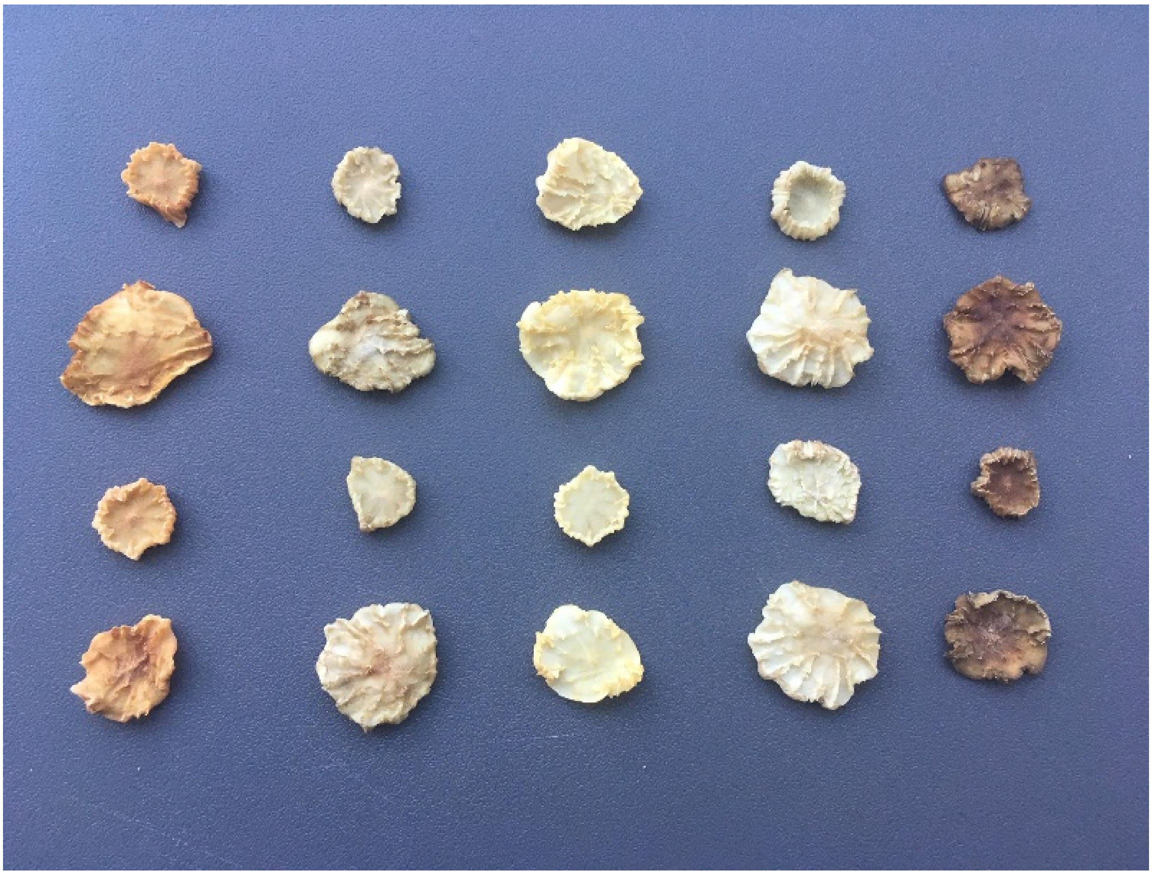


Figure 19 Colour variability of various pre-treatments (from left: Asc, C, Lmn, Slt, Gng)

5.3. Sensory Analysis

5.3.1. Method of drying

The results of the first panel focused on comparing two methods of drying (hot-air drying and freeze drying) are indicated in the spider diagram below. The higher likability of the freeze dried sample among panellists is evident. The only parameters where both methods were evaluated same is aroma and juiciness. In all other cases panellists evaluated freeze dried sample as better.

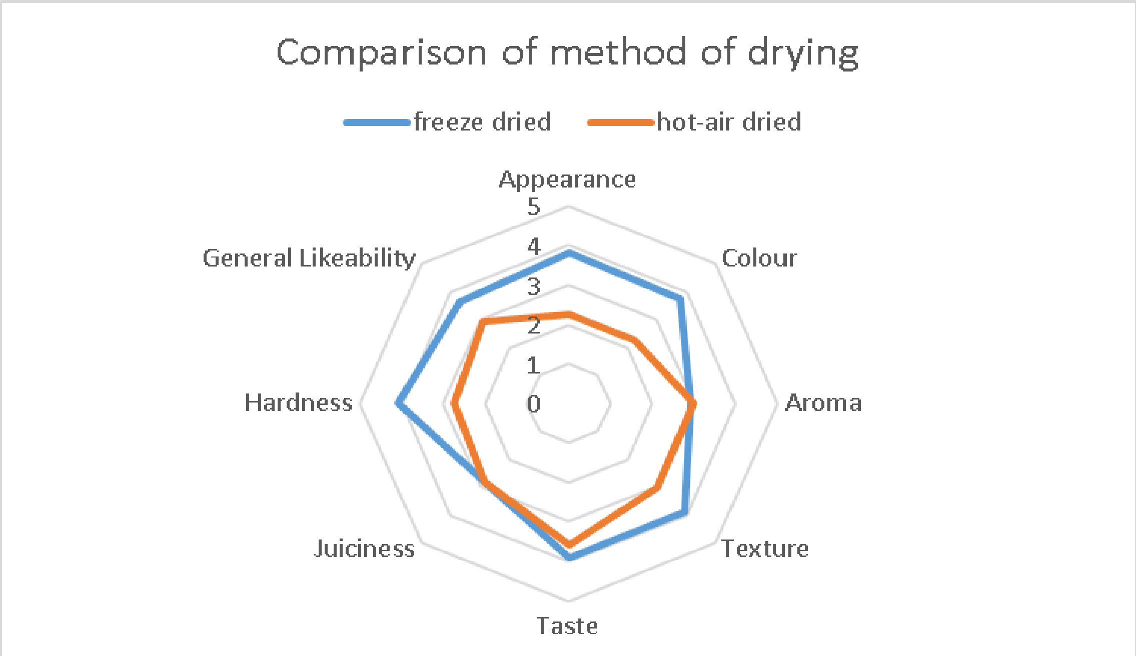


Figure 20 Spider diagram of sensory evaluation of two methods of drying (n=12).

Statistical analysis (see table 8) shows detailed comparison of hot-air dried and freeze-dried yacon samples by panellists. The results are described separately for all parameters. Median, mean, standard deviation and variation coefficient were calculated.

Table 8 Statistical comparison of two methods of drying

Response	Treatment	Median	Mean	Standard deviation	Variation coefficient (%)
General Appearance	Freeze - dried	4.0	3.8	0.8	20.9%
	Hot air - dried	2.0	2.3	0.9	36.9%
Colour	Freeze - dried	4.0	3.8	0.8	19.2%
	Hot air - dried	2.0	2.3	1.1	48.4%
Aroma	Freeze - dried	30	2.9	0.5	16.9%
	Hot air - dried	3.0	3.0	0.6	19.2%
Texture	Freeze - dried	4.0	3.9	0.8	19.4%
	Hot air - dried	3.0	3.0	1.1	36.0%
Taste	Freeze - dried	4.0	3.9	0.8	19.4%
	Hot air - dried	3.5	3.6	1.1	29.0%
Juiciness	Freeze - dried	3.0	2.8	0.9	31.7%
	Hot air - dried	2.5	2.8	0.9	31.7%
Hardness	Freeze - dried	4.0	4.1	0.9	21.1%
	Hot air - dried	3.0	2.8	0.6	21.6%
General Likeability	Freeze - dried	4.0	3.7	0.7	17.0%
	Hot air - dried	3.0	29	0.9	29.6%

As indicated in the spider diagram above, the freeze dried samples tend to have higher (better) score. The biggest difference among those two samples is in texture, hardness, and general likability. For all those characteristics were evaluated better in case of freeze dried sample.

The median of freeze dried samples and the median of hot air-dried samples were compared to determine whether they are or are not statistically equal (see table 9).

H_o: median of freeze dried and median of hot air dried are statistical equal.

H_1: median of freeze dried and median of hot air dried are not statistical equal.

Table 9 Statistically significant differences among methods of drying

Response	P value
General Appearance	**0.001**
Colour	**0.002**
Aroma	0.745
Texture	**0.032**
Taste	0.407
Juiciness	0.927
Hardness	**0.001**
General Likeability	**0.035**

Significative statistical difference occurred between:

- General appearance: qualification is highest for freeze dried.
- Colour: qualification is highest for freeze dried.
- Texture: qualification is highest for freeze dried.
- Hardness: qualification is highest for freeze dried.
- General Likeability: qualification is highest for freeze dried.

Nevertheless, for aroma, taste, and juiciness no significant difference was recorded between freeze - dried and hot-air dried.

5.3.2. Pretreatments

Pretreatments ascorbic acid (Asc), lemon (Lmn), salt (Slt), ginger (Gng), and non-treated control sample (C) were used for sensory analysis. Spider diagram below (figure 21) shows that certain pre-treatments could have positive effect on certain characteristics compared to control sample (C). On the other hand, some treatments were evaluated negatively compared to control sample.

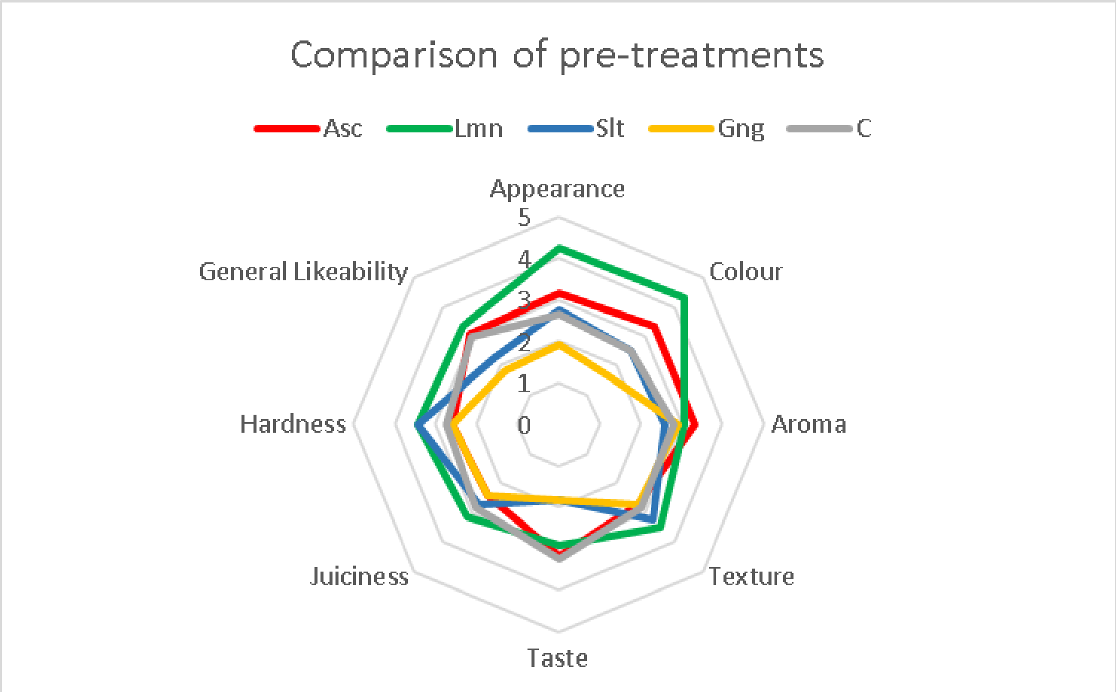


Figure 21 Spider diagram of pre-treatments used during yacon tubers processing (n=12)

Lemon has really high values for two related characteristics – appearance and colour, but also other characteristics were evaluated well. Good values for appearance and colour also had ascorbic acid. The worst appearance was in case of using ginger. As measured above, the colour of ginger was much darker than all the other samples and it was evaluated as not pleasant by panellists. For more detailed information describing median, mean, standard deviation and variation coefficient about each treatment and each parameter see table 10 below

Table 10 Statistical comparison of pretreatments

Response	Treatment	Median	Mean	Standard deviation	Variation coefficient (%)
General Appearance	Asc	3.0	3.2	1.0	31.1%
	C	3.0	2.7	0.8	28.0%
	Gng	2.0	1.9	0.8	39.6%
	Lmn	4.0	4.3	0.6	14.0%
	Slt	3.0	2.8	0.9	30.2%
Colour	Asc	3.0	3.3	1.0	28.3%
	C	2.5	2.5	0.8	30.6%
	Gng	2.0	1.7	0.7	37.4%
	Lmn	4.0	4.3	0.7	14.4%
	Slt	2.5	2.5	1.0	38.3%
Aroma	Asc	3.0	3.3	0.5	14.1%
	C	3.0	2.8	0.4	13.2%
	Gng	3.0	2.9	0.8	26.0%
	Lmn	3.0	3.1	0.7	20.8%
	Slt	3.0	2.6	0.9	33.4%
Texture	Asc	2.5	2.8	0.9	30.2%
	C	3.0	2.8	1.0	34.8%
	Gng	3.0	2.8	0.9	30.2%
	Lmn	3.0	3.5	0.9	24.7%
	Slt	3.5	3.3	0.9	25.5%
Taste	Asc	3.0	3.2	1.4	42.4%
	C	4.0	3.3	1.1	31.1%
	Gng	1.0	1.8	1.3	66.2%
	Lmn	3.0	2.9	1.0	32.7%
	Slt	2.0	1.8	0.9	49.0%
Juiciness	Asc	2.0	2.4	1.2	46.1%
	C	3.0	2.8	0.6	19.5%

	Gng	2.0	2.4	0.8	31.4%
	Lmn	3.0	3.2	0.9	28.3%
	Slt	3.0	2.8	0.8	26.2%
Hardness	Asc	2.5	2.6	0.9	33.4%
	C	3.0	2.8	0.6	21.6%
	Gng	3.0	2.6	0.8	29.4%
	Lmn	4.0	3.4	0.8	22.2%
	Slt	3.0	3.4	0.8	22.2%
General Likeability	Asc	3.0	3.1	1.0	30.9%
	C	3.0	3.0	1.1	36.0%
	Gng	1.0	1.8	1.3	66.2%
	Lmn	3.0	3.3	0.9	25.5%
	Slt	2.0	2.3	0.9	36.9%

In terms of general appearance, we can see that lemon is best and ginger worst. The same trend is as in the case of colour. In the case of aroma, all samples were evaluated as mean value 3, so any pretreatment is had some impact on aroma. In terms of texture and juiciness there are not big differences. As we can see in table 11, those three parameters (aroma, texture and juiciness) were not evaluated as there is some significant difference among them. On the other hand, there are great differences in taste, where control sample has the highest value and ginger the lowest. In terms of hardness the lemon sample was evaluated as the softest one and ascorbic acid as hardest. When we look at general likability, most samples were evaluated as mean value (3) and salt was evaluated as slightly worse (2) and ginger as the worst (1) among others.

The median values were analysed to compare if there is significant difference (see table 11). We can see P-value for Kruskal-Wallis test. Those values in bold indicate significant difference of at least one sample among others.

H_0: The median of the five population is the same

H_1: At least one median is different

Table 11Statistically different characteristics of pretreatments

Response	P-value
General Appearance	**< 0.0001**
Colour	**< 0.0001**
Aroma	0.141
Texture	0.219
Taste	**0.003**
Juiciness	0.151
Hardness	**0.017**
General Likeability	**0.005**

Pretreatments had some impact on characteristics in case of general appearance, colour, hardness and general likability. How exactly it was evaluated (if better or worse) is indicated in table 12.

Table 12 Statistical differences among pretreatments

Response	P-value	Conclusion
General Appearance	**< 0.0001**	Qualification in Ginger is less than lemon
	< 0.0005	Qualification in Control is less than lemon
	< 0.001	Qualification in Salt is less than lemon
Colour	**< 0.0005**	Qualification in Ginger is less than ascorbic acid
	< 0.0001	Qualification in Ginger is less than lemon
	< 0.0005	Qualification in Control is less than lemon
	< 0.0005	Qualification in Salt is less than lemon
Aroma	0.141	There are no differences among those five groups
Texture	0.219	There are no differences among those five groups
Taste	**0.005**	Qualification in Salt is less than control
	< 0.003	Qualification in Ginger is less than control
Juiciness	0.151	There are no differences among those five groups
Hardness	**0.017**	Despite the significance of 0.017, no differences were detected between treatments
General Likeability	**0.001**	Qualification in Ginger is less than lemon

In optional additional comments panellists often mentioned that they do not smell any aroma. Yacon as it is has not any strong aroma and according to the results any pre-treatment had any impact on it. Panellist also often commented that in case of Slt and Gng pretreatment the taste is too strong and, in some cases, the original taste of yacon is not perceptible at all. In one case of Gng treatment was mentioned that the taste is great (despite low mean score), but how sample looks decrease greatly its overall likability.

6. Conclusions

Drying of Yacon (*Smallanthus sonchifolius*) was investigated in various drying conditions and pretreatments were used to improve its organoleptic characteristics.

Yacon slices were dried in 40, 50 and 60 °C and times 8.5; 6.5; and 4.5 hours were estimated. The final dried products had a moisture content between 15 and 19 % and a_w between 0.463 and 0,513 which are common recommended values for dried products and drying curves were constructed.

The CIELAB colour space was used to evaluate change in colour using the above-mentioned temperatures. Results indicate that there is change in colour comparing fresh slices to dried slices. But there is no linear trend as expected that with higher temperature used will be higher change in colour. However, the differences in colour among samples dried under various conditions are very small.

Suitable freeze drying conditions were estimated as a combination of – 16 °C, 774 mTorr and 50 hours. Compared to the scientific literature that mentions 64 mTorr 72 hours. Both conditions are suitable, but as lyophilization is an expensive and time-consuming process, a shorter time of 50 hours as in this thesis could be recommended.

Freeze dried sample has lighter colour than hot-air dried and even than fresh sample. Hot-air dried and fresh sample do not vary in colour as much as freeze dried and fresh. This lighter colour of freeze dried sample as well as other characteristics were evaluated as better in consumer perception.

Not much research has been done on various pretreatments during yacon processing and its impact on its organoleptic properties. In this thesis 4 pretreatments (ascorbic acid, lemon, salt, and ginger) for hot-air drying and consumer perception were evaluated. Using lemon can significantly improve its characteristics like colour and appearance. These are important characteristics for consumers, therefore, using lemon may make product potentially attractive for the global market. Ginger and salt had low score in most of characteristics, but possibly using lower concentrations could improve its acceptance. Nevertheless, the parameter “taste” was evaluated as best in case of non-treated control sample.

This highly adaptable crop, which can grow in a wide range of conditions, has great potential. Drying of yacon tubers can make product more marketable. Lyophilization and pretreatments can make this product even more attractive to potential customers on the global market. It can be a sweet tasting snack with some good health properties including prebiotic, antidiabetic, and antioxidant activity as well as the reduction of obesity and better weight management. But due rapid change of FOS into simpler sugars, proper storage, processing and monitoring should be considered.

Further research could be done on different pretreatments and their concentrations, as well as willingness of customers to pay higher prices for lyophilized yacon slices due to its higher processing cost.

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