Compositional analysis of the Andean fruit *Pouteria Lucuma*

A comparison of different physical forms (powder, frozen pulp and fresh pulp)

Elsa Ramberg

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Supervisor:	**Santanu Basu, Department of Molecular Sciences, Swedish University of Agricultural Sciences**
Assistant supervisor:	Armaghan Amanipour, Aventure AB
Assistant supervisor:	Olof Böök, Aventure AB
Examiner:	Roger Andersson, Department of Molecular Sciences Swedish University of Agricultural Sciences

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Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of molecular sciences

Abstract

Lucuma (*Pouteria Lucuma*), an ancient fruit from the Andes, is now increasing in popularity in the global West due to the characteristic flavour and nutritional composition (e.g. high in fibres and phenolic compounds). The shelf life of the fresh fruit is short, therefore it is mainly used as frozen pulp or powder. The company Aventure AB's cooperation with the Bolivian organisation called Swebol biotech aims to develop food products that will promote Bolivian innovation, production, and public health. However, there is a lack of knowledge in the difference in composition and properties between different forms (powder, frozen pulp or fresh pulp) of lucuma. The aim of this thesis was to compare and analyse different forms of lucuma from different producers, as a part of the Aventure-Swebol project.

Three different powders, frozen pulp and fresh pulp were used. Dry matter content, energy content, pH, viscosity, colour, total phenolic compounds (TPC), antioxidant capacity (AC) and Sucrose, D-fructose and D-glucose were analysed. Sensory tests were performed to evaluate sweetness and define sensory characteristics of lucuma. The results showed that dry matter content, energy content, pH and colour was differentiating the most between the powders compared to the frozen and fresh samples. The highest and lowest TPC and AC value was seen in fresh pulp and in frozen pulp respectively. The content of D-glucose was the highest, followed by D-fructose and sucrose in descending order in most samples. The conclusion is that the composition of lucuma varies in the different forms analysed. The reason could be processing technique, variety and biotype, and grade of maturity. More scientific studies are needed to be able to decide what form is most suitable for further product development including health, sensory, technical and sustainability aspects.

Keywords: Pouteria Lucuma, powder, frozen pulp, fresh pulp, total phenolic compounds, antioxidant capacity, D-glucose, D-fructose and sucrose.

Sammanfattning

Lucuma (*Pouteria Lucuma*) är en uråldrig frukt från Anderna som på grund av sin karakteristiska smak och näringsinnehåll (t.ex. mycket fibrer och fenolföreningar) just nu ökar i popularitet i västvärlden. Hållbarheten hos den färska frukten är kort, vilket gör att den främst används i fryst form eller i pulverform. Företaget Aventure AB håller på att tillsammans den bolivianska organisationen Swebol biotech utveckla en lucumabaserad produkt som ska främja boliviansk innovation, produktion och folkhälsa. Det saknas dock kunskap om vilken form av lucuma (pulver, fryst eller färsk) som lämpar sig bäst. Syftet med detta examensarbete var att jämföra och analysera olika former av lucuma från olika producenter, som en del av Aventure-Swebol-projektet.

Tre olika pulver, fryst frukt och färsk frukt användes. Torrsubstans, energiinnehåll, pH, viskositet, färg, totala fenolföreningar (TPC), antioxidantkapacitet (AC) samt sackaros, D-fruktos och D-glukos analyserades. Sensoriska tester utfördes för att utvärdera sötma och definiera karaktärsdrag hos lucuma. Resultaten visade att torrsubstanshalt, energiinnehåll, pH och färg främst varierade mellan pulvren, jämfört med de frysta och färska proverna. Det högsta och lägsta TPC- och AC-värdet sågs i färsk frukt respektive i fryst frukt. Halten av D-glukos var högst, följt av D-fruktos och sackaros i fallande ordning i de flesta proverna. Slutsatsen blev att sammansättningen av lucuma varierar i de olika former som analyserades. Orsaken kan vara processteknik, sort och biotyp samt mognadsgrad av frukten. Fler studier behövs för att kunna bestämma vilken form som bäst lämpar sig för vidare produktutveckling med hänsyn till hälso-, sensorik och hållbarhetsaspekter.

Nyckelord: Pouteria Lucuma, pulver, fryst frukt, färsk frukt, fenoler, antioxidanter, D-glukos, D-fruktos och sackaros.

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Abbreviations

AC	Antioxidant capacity
ANOVA	Analysis of variance
DPPH	2,2-diphenyl-1-picrylhydrazyl
DW	Dry weight
FD	Freeze-dried
Fre	Fresh pulp
Fro	Frozen pulp
GAE	Gallic acid equivalents
NA	Not available
PC	Phenolic compounds
P1	Powder 1
P2	Powder 2
P3	Powder 3
TE	Trolox equivalents

Introduction

Many countries in Latin America, including Bolivia, are known for having a diverse range of various fruits. Despite their great potential, many of these fruits are still unknown to a big part of the world (Galluzzi & López Noriega 2014). Additionally, the consumption of fruits and vegetables must increase to improve global heath and the environment (Willett et al. 2019). Lucuma (*Pouteria lucuma*), an ancient fruit known as "gold of the Incas" traditionally grown in the Andean region, is a fruit now finding its way to the global West. See figure 1. During the recent years it has grown in popularity and is increasingly marketed as a superfruit. The number of posts on social media as well as the number of products found on the market including lucuma has increased (FONA International 2018). Lucuma is claimed to be rich in vitamins, minerals, phenolic compounds and carotenoids (Maza-De la Quintana & Paucar-Menacho 2020). It is also considered to have a high dietary fibre (García-Ríos et al. 2020) and starch content (National Research Council (U.S.) 1989).

Figure 1. Pouteria Lucuma (Pavón and Ruiz 1798).

Lucuma belongs to the *Sapotaceae* family and is locally known as lucuma, lucmo, lúcuma, lúcumo, mammon, cumala, rucuma or marco (Yahia & Guttierrez-Orozco 2011). In Bolivia it is also known as Lujmillo[1]. Nowadays it is grown mainly in the Andean region in Ecuador, Peru, and Chile but it is also found in Costa Rica, Mexico and Brazil. (National Research Council (U.S.) 1989). The only place in Europe where it has been cultivated is in some parts of Spain (Gómez-Maqueo et al. 2020). The taste of lucuma is sweet and sometimes described as caramel- or maple-like. The colour of the skin varies from green to yellow and the flesh is yellow or orange depending on variety, biotype and stage of ripeness, see figure 2.

[1] Leslie Karina Tejeda Perez, Researcher, Universidad Mayor de San Andrés (UMSA), meeting 2022-05-06

Figure 2. (a) A lucuma less ripe from Peru, (b) A riper lucuma from Peru, (c) Both fruits shown in cross section.

The texture of the fresh pulp brings to mind boiled egg yolk (Duarte & Paull 2015). Like many other fruits lucuma is found in different varieties or biotypes. Seda and Palo are two of the most common varieties. Seda is mostly used fresh due to its soft texture, and Palo is more commonly processed due to its woody texture. The pulp of the variety Palo can be frozen or dried and milled into a powder (Duarte & Paull 2015). Since the fresh fruit is easily damaged and maintenance of fruit quality is a major issue in the fresh fruit supply chain, dried and milled powder is the most common form of lucuma on the world market. (Yahia & Guttierrez-Orozco 2011). A few studies have been done comparing different varieties of lucuma and comparing the fresh lucuma with the lucuma powder, in terms of nutritional composition and bioactive compounds. For example, previous studies on the composition of lucuma has been done by; Machado Annechini et al. (2021) who are comparing drying temperatures on powder; Dini (2011) and Pinto et al. (2009) who are studying phenolic compounds in powder and fresh pulp; García-Ríos et al. (2020) who are comparing different biotypes; Aguilar-Galvez et al. (2021) who are comparing maturity stages and Fuentealba et al. (2016) who are comparing both biotypes and maturity stages. However, there is still a lack of knowledge on chemical and nutritional differences between varieties, biotypes and physical forms (powder, frozen and fresh pulp) of lucuma.

Traditionally, lucuma is consumed fresh, or used in products like ice cream, drinks, puddings or as a natural sweetener (National Research Council (U.S.) 1989). The fresh fruit, frozen pulp or the powder can be used as raw material for making the traditionally consumed lucuma products, depending on availability. Other than shelf life and bioactive compounds the different forms of lucuma vary when it comes to taste, colour and texture, which are all important factors in processed food production.

The company Aventure AB's cooperation with the Bolivian organisation called Swebol biotech aims to develop food products that will promote Bolivian innovation, production, and public health. Lucuma, with its nutritional benefits and very special flavour, is thought to have a great potential as the main ingredient in a new collaborative project for new product development. Lucuma is only grown to limited extent in Bolivia, in the La Paz region, but the potential for extended cultivation is promising (Callisaya 2021). However, there is a lack of knowledge in what form of lucuma is most suitable for product development regarding bioactive compounds such as phenolic compounds, taste such as sweetness, texture and colour.

0.1 Aim of this master thesis

The aim of this thesis was to compare and analyse different forms (powder, frozen pulp and fresh pulp) of lucuma fruit from different producers, as a part in the development of a value-added lucuma product that promotes Bolivian innovation.

Literature review

1.1 Cultivation

The lucuma tree is an evergreen tree with a height varying between 8 to 15 m. The crown of the lucuma tree is dense and the branches produces a white latex. Lucuma is not considered a tropical plant since it grows at temperate elevations in dry locations. Since the tree usually grows on high elevation it is only affected by a few pests, which is why it is suitable for organic production (Yahia & Guttierrez-Orozco 2011). It grows on elevations up to 3000 m and cannot stand temperatures below -5 °C. The ideal temperature lies between 18 and 24 °C for fruit development. The lucuma tree sets fruits all year round and the harvest time can vary from October to May depending on where the tree is cultivated (Duarte & Paull 2015). The trees start to produce fruits after 4-5 years (Yahia & Guttierrez-Orozco 2011). One tree can produce around 500 fruits every year and the fruits usually weigh 250-300 g, but in extreme cases they can weigh up to 1 kg. It takes 8-9 months from anthesis to harvest and the fruit is climacteric which means it will continue to ripen after harvest (Duarte & Paull 2015). When the fruit falls from the tree it is not fully mature and must be stored for several days until it is fully ripened (Yahia & Guttierrez-Orozco 2011).

1.2 Varieties and biotypes

Pouteria Lucuma was previously known as *Lucuma Obovata* (Duarte & Paull 2015). The most common commercially produced varieties of lucuma are Seda and Palo, see figure 3 (Yahia & Guttierrez-Orozco 2011). Since lucuma is more commercially produced in Peru, these varieties are more common there. Seda has a softer texture and Palo a more woody texture (Duarte & Paull 2015). According to Callisaya (2021) both Seda and Palo can grow on the same tree when the climate is changing very suddenly. The botanical structure of lucuma is not clear. It seems like there are different biotypes within the varieties Seda and Palo.

A biotype belonging to the soft type lucuma is Beltrán 4, which is a result from a selection work in the 1970s at the Universidad Nacional Agraria (UNA) La Molina in Lima. Other biotypes from the same project are Lucuna B-1, Lucuna B-2 and Lucuna R-3 (Duarte & Paull 2015). Additionally Trompito and María Belén are biotypes found in Peru (Alegre Caballero & Del Carmen Ticse Aguilar 2017). The most common biotypes found in Chile are Montero and Rosalía. Biotypes such as Dispersa, Globosa, San Patricio, Vegara, Mercedes and Bozzolo are to be found in Chile as well (Duarte & Paull 2015). Fruit quality seem not only dependent on

seedling type, but climate and horticultural practice. Many valuable biotypes are still undiscovered growing in people's backyards (National Research Council (U.S.) 1989). According to Lavado Soto et al. (2012) there are 120 different biotypes of lucuma within the varieties of Seda and Palo.

Figure 3. Lucuma of the variety Palo (Castillo Málaga 2006).

1.3 The seed

The lucuma seed is round, glossy and has high resemblance to chestnut. See figure 4. The seeds are sensitive to drying and cracking (Duarte & Paull 2015) and is constituting 8 to 15 % of the lucuma fruit (Ponce 2017). The seeds are nowadays mostly a waste product even though they are thought to have a great potential. They contain phytosterols which are known to reduce low-density lipoprotein cholesterol (Guerrero-Castillo et al. 2021). According to Rojo et al. (2010) the fatty acids in the lucuma seed promotes skin regeneration.

Figure 4. (a) Lucuma on a market in Bolivia, (b) seeds from the Bolivian lucuma, (c) cross section of the Bolivian lucuma. (Photo by Leslie Karina Tejeda Perez 2022)

1.4 Composition

The pulp of lucuma is yellow, firm, dry, mealy, and sweet. It contains latex until ripened and has one to five brown seeds, usually two (Duarte & Paull 2015). Lucuma is high in carbohydrates and fibres, low in fat and protein content, and is claimed to have various positive health effects. It is considered to act protective to the nervous system due to its high content of vitamin B1, thiamine and niacin (Yapias et al. 2021). According to Yahia & Guttierrez-Orozco (2011) lucuma has an anti-inflammatory effect and Fuentealba et al. (2016) is stating that it is antihyperglycemic, partly due to the phenolic compounds found in lucuma. According to Pinto et al. (2009) lucuma is used as a part in the treatment of diabetes. Lucuma is considered to have a high content of dietary fibre, which is thought to be one of the reasons behind its positive health claims (García-Ríos et al. 2020). Additionally lucuma is high in carotenoids, which can be precursors of vitamin A and has been related to reduction of cancer, cardiovascular disorders and bone, skin and eye disorders (Gómez-Maqueo et al. 2020).

1.4.1 Phenolic compounds

Phenolic compounds (PC) are secondary metabolites produced by plants functioning as a part of the plants' defending system, such as insect defence or defence against mechanical damage (Kafkas et al. 2018). There are more than 8000 different PCs found in plants (de la Rosa et al. 2019). PCs are a diverse group of compounds, and they can be either phenolic acids with one aromatic ring or polyphenols with more than one aromatic ring. They can act as antioxidants whose activity is depending on the hydroxyl groups and phenolic rings in the compounds (Minatel et al. 2017). Phenolic acids, flavonoids and tannins are regarded as the most common dietary PCs. A strong correlation has been seen between PC content and the antioxidant activity in fruits and vegetables. It is therefore suggested that the antioxidant mechanism, reducing lipid oxidation in human tissue, is related to decreased risk of developing diseases such as cardiovascular diseases, arteriosclerosis, cancer and diabetes (Minatel et al. 2017). The stability of PCs varies depending on many different factors, for example, interactions with other molecules and bioactive compounds and processing methods such as heating or freezing. Heating has been shown to both increase and decrease the content of phenolic compounds (Minatel et al. 2017).

Previous studies have shown that the total phenolic compounds (TPC) content of lucuma is higher in fresh fruit than in powder. Aqueous extracts gave 11.4 mg gallic acid equivalents (GAE)/g dry weight (DW) for fresh fruit and around 5.5 mg GAE/g DW for powder. However, the antioxidant activity was found to be similar in both forms regardless to the content (Pinto et al. 2009). In the same study ethanolic extracts showed less difference in TPC content, around 3 mg GAE/g DW

for fresh fruit and 2 mg GAE/ g DW for powder. Pinto et al. (2009) reported higher antioxidant activity for fresh lucuma (Pinto et al. 2009). The content has also been found to vary between different varieties and stages of ripeness. According to Fuentealba et al. (2016) the total phenolic content (mg GAE/g DW) was found to be 61.6±10.9, 0.7±0.07 and 45.3±31.9 in the varieties Rosalia, Montero and Leiva 1 respectively. Additionally, in three different ripeness stages of Levia 1 the total phenolic content was 131.6±2.0, 45.3±32.0 and 0.7±0.1 mg GAE/g DW from the least ripe to the ripest. García-Ríos et al. (2020) reported a total phenolic content of 2.50±0.11 in Beltrán and 2.38±0.13 mg GAE/g DW in Seda, which is not considered as significantly different. Dini (2011) found that lucuma powder contains a higher amount of phenolics than other fruits usually used in snacks (51.1±14.1 mg GAE/1000 g). According to Vallespir et al. (2019) TPC decreased when beetroot, apple and eggplant was pre-treated with freezing and drying.

1.4.2 Antioxidant activity

Antioxidants are compounds that have the capability of reducing free radicals, and thereby have been suggested to reduce the risk of cell damage and diseases related to that. Fruits and vegetables are generally high in antioxidants compared to other foods. There are enzymatic and non-enzymatic natural antioxidants, the latter is divided into four groups: vitamins, carotenoids, polyphenols and minerals (Arias et al. 2022). According to Fuentealba et al. (2016) the antioxidant capacity was varying from 0.7±0.2 µmol Trolox equivalents (TE)/ g DW in the lucuma biotype Montero to 132.9±35.0 µmol TE/ g DW in the biotype Rosalia. The same study shows that the antioxidant capacity was varying from 466.3±78.5 µmol TE/ g DW to 0.9±0.4 µmol TE/ g DW with the stage of ripeness in the biotype Levia 1. According to García-Ríos et al. (2020) a higher antioxidant capacity was found in the lucuma biotype Beltrán than in Seda.

1.4.3 Sugar

Sugars play an important role in the structure of plant tissue, as carbon building blocks and energy source. They are particularly important during fruit and seed development as well as fruit ripening. Other than that, the sugar content as well as the sweetness of the fruit play an important role in fruit quality (Durán-Soria et al. 2020). The main sugars in lucuma are glucose, fructose and sucrose, starting with the highest concentration. Additionally, sugar alcohols such as myo-inositol are present with a lower concentration than previously mentioned sugars (Aguilar-Galvez et al. 2021; Fuentealba et al. 2016). A study comparing three different lucuma biotypes (Rosalia, Montero and Levia 1) found no differences in the content of total sugars. The same study showed differences in glucose and fructose between the biotypes as well as an increase in the same sugars with ripening stage

(Fuentealba et al. 2016). However, according to García-Ríos et al. (2020) there are no significant differences in glucose, fructose and sucrose content respectively in the varieties Seda and Beltrán. According to Aguilar-Galvez et al. (2021) there was no significant difference in glucose, fructose and sucrose content respectively in two different maturity stages.

1.5 Ripeness and postharvest handling

Matured lucuma is a spherical fruit in the size between 4 to 17 cm in diameter. The fruit is considered to be ripe when the peel changes colour from green to yellow green. However, some fruits keep their green colour even when ripe. See figure 5. When it's ripe the flesh gets softer and it will be easy to loosen the fruit from the tree. Lucuma is a climacteric fruit which means it will continue to ripen after harvest. However, if harvested too early it will not fully ripen but continue to be hard and astringent (Del Castillo Málaga 2006). Fully ripe lucuma sometimes gets a cracked peel and is very sensitive to harsh handling (Duarte & Paull 2015). There is no standard of measuring when lucuma is ripe, however soluble solids and acidity can be used to measure the ripeness (Yahia & Guttierrez-Orozco 2011). When comparing the composition of lucuma at different ripeness stages, it can be seen that the dry matter content is increasing and that the dietary fibre content is decreasing with maturity (Aguilar-Galvez et al. 2021). The total sugar content has been shown to be increasing with the stage of ripeness (Fuentealba et al. 2016), as well as decreasing (Aguilar-Galvez et al. 2021). Total phenolic compounds and antioxidant capacity has been shown to decrease with ripeness stage (Fuentealba et al. 2016). Other than stage of ripeness, storage conditions can affect the composition of lucuma (Inga et al. 2021).

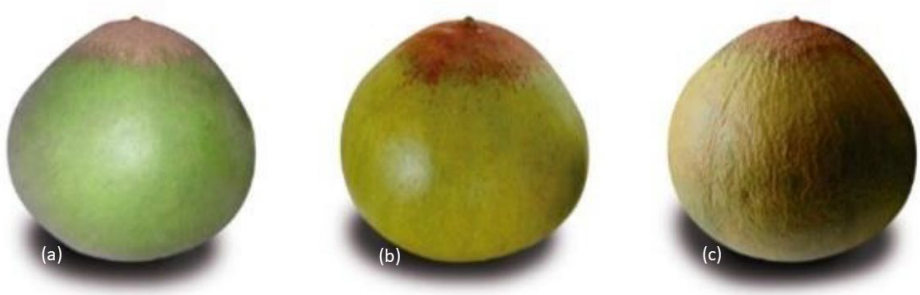

Figure 5. (a) Lucuma in physiological maturity. (b) Lucuma in organoleptic maturity, ripened in climate chamber. (c) Lucuma in organoleptic maturity, matured in ambient climate (Inga et al. 2021).

Fresh lucuma can be stored in fridge to slow down fast ripening. However, storing the fruit at 7 °C for longer than one week will impact the ripening and the fruit will not ripen uniformly. Keeping the fruit between 13 and 18°C will keep it fresh for two weeks before decaying. Additionally, the fruit is sensitive to water loss, therefore it needs to be kept in high humidity (Yahia & Guttierrez-Orozco 2011). According to Yahia & Guttierrez-Orozco (2011) modified atmosphere can help to keep the fruit quality. Lucuma is often processed by freezing or drying. Before processing the fruit is washed, disinfected, peeled, and seeded. Vacuum packed frozen pulp can be stable for two years without significant changes in quality. Irradiation of the fruit does barely affect the shelf life of the fruit (Yahia & Guttierrez-Orozco 2011). Treating the lucuma pulp with hurdle technology, combining lowering of water activity to 0.90 and 0.92 and pH to 4.4 and 4.7 can decrease spoilage of bacteria, yeasts and moulds (Cisneros et al. 2021).

1.6 Lucuma powder and frozen pulp

Lucuma is commonly used in the industry as a powder or frozen pulp. The powder is dehydrated, often sun-dried, and grinded pulp. The colour is slightly brown and the texture is coarse. The powder is used for making ice cream and pastries. It takes around 5kg of fresh fruit to make 1 kg of powder (*Análisis de mercado lucuma* 2021). When comparing different drying temperatures (55 °C, 65 °C and 75 °C), it has been shown that higher temperatures decreases the nutritional value of the powder (Machado Annechini et al. 2021). A problem during the milling in production of lucuma powder can be food waste and loss of product due to ineffective production systems (Lavado Soto et al. 2012). When cutting the fresh lucuma fruit, a natural oxidation will occur which results in a change in colour from yellow to more brown and during sun-drying it is easy to lose in quality, especially in colour and flavour (Del Castillo Málaga 2006). When making the frozen pulp the fruits are prepared by washing, disinfecting, peeling, and deseeding. They are often heat-treated before they are frozen. The usage in the industry is the same as for the powder. (*Análisis de mercado lucuma* 2021).

1.7 Product development

The flavour of lucuma is often referred to as sweet, maple and caramel (Duarte & Paull 2015). It is thought to be a very characteristic flavour not found in many other fruits. (Lavado Soto et al. 2012). A study comparing twelve different lucuma powders and their aroma compounds reports that there are differences in the aroma compounds found in different products but the main attributes in the samples were buttery, sweet, caramelized, waxy, green, nutty, and cucumber. The same study

showed that the difference in rating of lucuma and caramel ice cream among U.S consumers were small. The overall liking, overall aroma liking and overall flavour liking was higher in the lucuma ice cream, whereas the overall liking for texture was higher in the caramel ice cream (Singh 2017). The big variation in varieties and biotypes of lucuma and a lack of knowledge by the producers of the fruit, powder and frozen pulp makes it challenging for product developers to find raw material that keeps a consistent quality (Del Castillo Málaga 2006).

1.8 Lucuma in Bolivia

In Bolivia lucuma is often referred to as lujmillo. There has not been a great interest for commercially produced lucuma in the population of Bolivia. However, the demand for lucuma and lucuma-products is increasing and in the Rio Abajo, La Paz region and the Cota Cota, La Paz region the pre-requisites to grow lucuma are promising (Callisaya 2021).

Since the number and range of fruits in the Andes are very huge, it is not uncommon with confusion in the naming of fruits. Another fruit, known as quince in English, is in Latin America known as membrillo or lucuma (Silliman 1831). The scientific name is *Cydonia Oblonga* and it belongs to the family *Rosáceas* (Vivero n.d.)

Bolivian production of fruits and vegetables are very local, and the production is often not more extended than what can be sold on the local market[2], see figure 6. Lucuma is a regional fruit which has potential to grow in popularity and find its way to the global and domestic food market, and thereby help the economy of the Bolivian farmers.

Figure 6. Woman selling lucuma on a Bolivian market, she is getting her fruits from wild growing trees. (Photo by Leslie Karina Tejeda Perez 2022)

[2] Leslie Karina Tejeda Perez, Researcher, Universidad Mayor de San Andrés (UMSA), meeting 2022-05-06

Materials and method

2.1 Materials for chemical and physical analysis

The lucuma powder was supplied from three different commercial companies using fruit pulp from Peru. The fresh lucuma fruit from Peru was procured and supplied by the company Bud Holland. The frozen lucuma pulp was supplied by Syros, using fruit from Peru. The powders with brand name NXTDRIED, Ecoandino and Rawpowder will be referred to as Powder 1 (P1), Powder 2 (P2) and Powder 3 (P3) respectively. See Appendix 1. The frozen and fresh pulp will be referred to as Fro and Fre respectively. The freeze-dried samples will be referred with a prefix FD such as FDP1, FDP2, FDP3, FDFro and FDFre. The different forms of lucuma used for the study and their nutritional information, provided by the suppliers, are listed in table 1. There was no nutritional information available from the supplier of the fresh fruit. The powders were stored in a dry and dark storage room at ambient temperature until use. Frozen lucuma pulp was stored in the freezer at -18 °C until use and the fresh lucuma fruit was stored in the fridge in 4-5 °C until use, according to the instructions from the supplier.

Table 1. The different physical forms of lucuma used in the study and their origin and nutritional information received from the suppliers.

	Powder 1 (P1)	Powder 2 (P2)	Powder 3 (P3)	Frozen (Fro)	Fresh (Fre)
Supplier	NXTDRIED	Ecoandino	Rawpowder	Syros	Bud holland
Origin	Peru	Huaral, Peru	Huaral, Peru	Peru	Peru
Nutritional information (per 100g)					
Energy (kcal/kJ)	352.0/1473.8	357.2/1495.5	306/1290	110/462	NA
Total fat (g)	1.3	0.36	1.1	<0.5	NA
Of which saturated fat (g)	0.0	NA	0.3	<0.1	NA
Carbohydrate (g)	80.7	84.34	57.3	20.8	NA
Of which sugars (g)	33.9	NA	31.6	15.4	NA
Dietary fibre (g)	28.2	23.66	25.9	9.9	NA
Protein (g)	4.4	4.15	4	1.7	NA
Salt (g)	0.5	NA	<0.1	0.04	NA
Vitamin C (mg)	5.6	NA	NA	NA	NA
Vitamin A (µg retinol)	495	NA	NA	NA	NA
Moisture (%)	NA	<7	NA	NA	NA

Note: Not available (NA)

Information about varieties or biotypes were not available from the suppliers. None of the powders were freeze-dried during production, Powder 1 was dried using a vacuum-microwave drying technology and Powder 2 and 3 were air-dried. The forms (powder, frozen pulp and fresh pulp) and suppliers of lucuma was limited to what was available at the time of the project, unfortunately Bolivian lucuma could not be received at the time of the project. Chemicals and equipment used are listed in table 2. All measurements were performed in duplicates, repeated once (n=4). Two fresh fruits were used for each analysis.

Table 2. Chemicals and equipment used in this study

Chemicals and equipment	Supplier
Chemicals	
Acetone 99.9 %	Merck, Germany
(Dissolved in distilled water to 70 % v/v)	
β-Fructosidase (pH 4.6), lyophilised powder	Megazyme, USA
(Dissolved in 20 ml of distilled water)	
Buffer (pH 7.6) plus sodium aside (0.02 % w/v)	Megazyme, USA
as a preservative	
Distilled water	
2,2-diphenyl-1-picrylhydrazyl (DPPH)	Thermo scientific, Germany
Folin-Ciocalteu reagent	VWR chemicals
Gallic acid	Merck, Germany
Hexokinase plus glucose-6-phosphate	Megazyme, USA
dehydrogenase suspension	
Methanol 99.9 %	Fisher chemicals, Belgium
NADP+ plus ATP	Megazyme, USA
(Dissolved in 22 ml of distilled water)	
Phosphoglucose isomerase suspension	Megazyme, USA
Sodium carbonate 20 % w/v	Sigma-Aldrich, Germany
Trolox	Thermo Scientific, Germany
Equipment	
Mixer	Bamix, Switzerland
Brookfield Ametek DV-1 LV viscometer	Brookfield, USA
Centrifuge Eppendorf Centrifuge 5804 R	Eppendorf, Germany
Coffee grinder	Bosch, Germany
Freeze-dryer Christ Alpha 1-4	Christ, Germany
Freezer -80 °C, Forma Scientific Bio-Freezer	Forma Scientific, USA
Incubator	Binder, Germany
Konica Minolta Spectrophotometer CM-700d	Konica Minolta, Japan
Magnetic stirrer RCT basic	IKA labortechnik,Germany
Orbital shaker IKA®¬KS 130 Basic	IKA, Germany
Oven	Termaks, Norway
Parr 6200 Calorimeter with a standard	Parr Instrument, USA
1108P Oxygen Bomb	
pH meter FiveEasy plus	Mettler Toledo, Switzerland
Pipettes	Eppendorf, Germany; Sartorious, Germany
Spectrophotometer PerkinElmer Lambda Bio +	PerkinElmer, USA
Weighing Scale AG204 DeltaRange (four decimals)	Mettler Toledo, Switzerland

2.2 Reconstitution of powders

The three powders used in this study were reconstituted by mixing with 60 % distilled water, e.g. for making 100 g of reconstituted powders 40 g powder and 60 g of distilled water was used. Reconstitutes were used together with the thawed frozen pulp and the mixed (using a mixer) fresh pulp for analysis of pH and viscosity. The same samples were used for the pre-treatment of freeze-drying.

2.3 Pre-treating samples by freeze-drying

Reconstituted powders, thawed frozen pulp and mashed fresh fruit were spread in aluminium trays and kept in -80 °C until freeze-drying, to perform the same pre-treatment on all samples. Samples were then freeze-dried for 5 days with an ice condenser temperature of -55 °C and a pressure of 0.770 mbar, corresponding to a temperature of -23 °C. After freeze-drying samples were grinded in a coffee grinder and sieved through a 355 mm sieve. Thereafter, samples were kept in -18 °C until further analysis. The weight of the sample was measured before and after freeze-drying. Since not many previous studies has been performed comparing powder, frozen pulp and fresh pulp, for analysis of dry matter content, total phenolic content, antioxidant capacity and sucrose, D-fructose and D-glucose, the analysis was performed both with samples in their original form (fresh, thawed frozen and powder) and samples with the pre-treatment of freeze-drying to be able to evaluate the methods.

2.4 Dry matter content

Dry matter was determined by using a slightly modified AOAC (2000) method. Aluminium vessels made from aluminium foil were dried at 105 °C for three hours and cooled in desiccator for 15 min. 3 g of sample was placed in vessels, dried for 48 h and cooled in desiccator for 30 min before weighing. Moisture content was calculated according to the following equation:

$$\frac{W1 - W2}{W1} * 100 = \%\ of\ moisture$$

W1=Weight of sample before drying (g)
W2=Weight of sample after drying (g)

The dry matter (%) was calculated by subtracting the moisture content from 100.

2.5 Energy content

Only the freeze-dried samples were used to find the energy content. It was measured by using a Parr 6200 Calorimeter with a standard 1108P Oxygen Bomb. The method obtained from the manufacturer was used. Approximately 1.5 g of freeze-dried grinded and sieved lucuma powder sample was used to form a pellet. Results were obtained in mega joule (MJ)/Kg and calculated to kilo joule (kJ)/100 g and kilo calories (kcal)/100 g.

2.6 pH

The pH was measured using a pH meter in the reconstituted powders (60 % water), thawed frozen pulp and fresh fruit at room temperature. The pH meter was calibrated with a three-point calibration.

2.7 Viscosity

The viscosity was measured, using a viscometer, in the reconstituted powders (60 % water), thawed frozen pulp and fresh fruit (mixed) at room temperature. The rotations speed of 0.3 rpm and the spindle model LV-5 (65) supplied from the manufacturer was used for all the samples. The viscosity (Pa s) was only measured at the end point after 3 min.

2.8 Colour

To analyse the colour, samples were put in a non-transparent cup in a dark bag and a spectrophotometer was used for measurements. For colour measurements, powders were used in their original form, the frozen pulp was thawed, and the fresh pulp was mashed. Results were expressed in a*, b* and L*, where a higher a* value indicates a more red colour, a higher b* value indicates a more yellow colour and L* is a measurement of light where 0=black and 100=white (Konica Minolta u.å.)

2.9 Total phenolic compounds

2.9.1 Extraction

Extraction was performed by using a combined method of Xu & Chang (2008) and Lutz et al. (2015). 0.25 g of frozen and fresh pulp, and 0.5 g of powder (both untreated and freeze-dried samples) were mixed with 5 ml of acetone (70 %) in centrifuge tubes. The samples were shaken for 3 h at room temperature at a speed of 320 rpm on an orbital shaker. The samples were kept in the dark for 13 h, before centrifuging at 4 °C and at a speed of 4000 rpm for 10 min. The supernatants were transferred to new tubes and kept at 4 °C. 5 ml of acetone (70 %) was added to the residues and the procedure was repeated. The two extracts were combined and stored at 4 °C until TPC analysis. Remaining extracts were stored at -18 °C for analysis of antioxidant capacity.

2.9.2 Analysis

The TPC content was determined by using a modified method of Singleton & Rossi (1965). 100 µl of sample extract, 50 µl of Folin-Ciocalteu reagent, 150 µl of 20 % w/v Sodium Carbonate and 700 µl of distilled water was mixed and incubated for 30 min at 37 °C. The absorbance was read at 765 nm and the values were compared with a standard curve of gallic acid ranging from 7.8-250 GAE mg/l, Appendix 2. Distilled water was used as a blank. Total phenolic content (TPC) was calculated by using the average absorbance for each sample. Results were expressed as mg GAE/g DW.

2.10 Antioxidant capacity

The method of Vuong et al. (2013) was used to find the DPPH radical scavenging activity. A stock solution was prepared by dissolving 24 mg DPPH with 100 ml methanol and then stored at −20 °C until required. The working solution was prepared fresh before each measurement by mixing 10 ml stock solution with 45 ml methanol to obtain an absorbance at 515 nm of 1.1±0.02. A volume of 3.8 ml of the working solution was added to 0.2 ml of sample extract (from TPC analysis). It was incubated in darkness at room temperature for 3 h before measuring the absorbance at 515 nm. Distilled water was used as a blank. Trolox was used as the standard for a calibration curve (2.5 mg/l-160 mg/l), Appendix 3, and the results were expressed as µmol of TE/g DW). The absorbance was used to calculate the amount of TE/g DW.

2.11 Sucrose, D-fructose and D-glucose

The contents of sucrose, D-fructose and D-glucose were determined using commercial enzymatic assays (K-SUFRG, Megazyme International, Bray, Ireland). The analysis was performed on both the untreated samples and the freeze-dried samples. In short, this involved converting each sugar to glucose-6-phosphate (G6P) and quantifying NADPH after oxidation in the presence of $NADP^+$ and G6P-dehydrogenase. The results were expressed in mg/g of dry sample (Megazyme u.å.).

2.11.1 Extraction

Approximately 0.5 g of the sample was mixed with 50 ml of distilled water with a magnetic stirrer (300-360 rpm for 5-10 min). 50 ml of distilled water was then added, and the solution was filtered through Whatman filter paper no. 1 (Megazyme u.å.).

2.11.2 Analysis

Analysis of the extractions were performed according to assay scheme following the kit instructions, Appendix 4. The absorbance was read at 340 nm. Distilled water was used as a blank. Following equations were used to obtain the results.

Determination of free D-glucose:

$$\Delta A_{D-glucose} = (A2 - A1)_{sample} - (A2 - A1)_{blank}$$

(From the D-glucose/ D-fructose sample).

Determination of sucrose:

$$\Delta A_{sucrose} = \Delta A_{total\ D-glucose} - \Delta A_{D-glucose}$$

(From the D-glucose/D-fructose sample)

$$\Delta A_{total\ D-glucose} = (A2 - A1)_{sample} - (A2 - A1)_{blank}$$

(From the sucrose sample)

Determination of free D-fructose:

$$\Delta A_{D-fructose} = (A3 - A2)_{sample} - (A3 - A2)_{blank}$$

(From D-glucose/D-fructose sample only).

ΔA stands for average absorbance of the different samples. The values of $\Delta A_{D\text{-glucose}}$, $\Delta A_{sucrose}$ and $\Delta A_{D\text{-fructose}}$ had to be at least 0.100 absorbance units to achieve sufficiently accurate results.

The concentration of D-glucose, sucrose and D-fructose was then calculated according to following equation:

$$c = \frac{V \times M \times \Delta A}{\varepsilon \times d \times v}$$

c = concentration (g/l)
V = final volume (ml)
M = molecular weight of the substance assayed (g/mol)
ε = extinction coefficient of NADPH at 340 nm = 6300 (l x mol^{-1} x cm^{-1})
d = light path (cm)
v = sample volume (ml)

2.12 Sensory evaluation

All the samples tested during the sensory evaluation were randomised and coded with three-digit codes.

2.12.1 Materials for sensory evaluation

- Plastic spoons
- Cups and lidded containers
- Wafers
- Drinking water
- Questionnaire, Appendix 5 and 6
- Lucuma samples (3 reconstituted powders (with 60 % water), 1-2 frozen pulp (thawed to room temp) and 1 fresh pulp (mixed and in room temp)
- Reference samples (sucrose and water solution) with determined sweetness
    - 2 % sucrose, 7.5 % sucrose and 16 % sucrose. Corresponding to 2, 7.5 and 15 on a 15 point scale (Baron 2021).

2.12.2 Attribute difference test including sweetness

The test was performed to evaluate the sweetness of the five different samples of lucuma. The test was done at Aventure office and 15 persons joined in the sample test. 10 g of the 5 samples (3 samples of reconstituted powders (with 60% water)), 1 sample of frozen pulp (thawed to room temp) and 1 sample of fresh pulp (mixed and at room temp) were served in randomised order in cups. Samples were tested individually with water and wafers in between to neutralise. Panellists were asked to rate the sweetness (individually for the 5 samples) on a 1-15 scale comparing with determined reference samples corresponding to the sweetness of 2, 7.5 and 15 on the scale.

2.12.3 Descriptive analysis focusing on characteristics

For the sensory evaluation of the characteristics of lucuma an additional frozen pulp from the supplier Frutti Mania was used, originating from Bolivia, Ecuador, Peru, Central America, Colombia and Venezuela (Distribuidora Latinoandina 2020). The test was performed to answer the question: What descriptors can be used for profiling the flavours of Pouteria lucuma?

5-7 panellists were chosen in a way to get a diversity in age, gender and cultural background. They were asked not to have coffee right before the test and to not wear perfume the day of the test. The session was during a period of 1 h. 6 samples (3 reconstituted powders (with 60 % water), 2 frozen pulp (thawed to room temp) and 1 fresh pulp (mixed and at room temp) were served in randomised order in lidded containers. Samples were tested individually with water and wafers in between to neutralise. See Appendix 7.

Panellists were asked to answer the questions individually. They were allowed to write as many association words as they liked. The questions to answer were:

- What are your first associations when it comes to aroma?
- When tasting the sample, what are your first associations?
- What are your first associations when it comes to texture?

When everyone was finished, the panel leader wrote all the words for each category (aroma, taste and texture) on the board and the panel discussed together agreeing on five to six key sensory attribute words describing lucuma for each category.

2.13 Statistics

All measurements except for the sensory tests were done in duplicates and repeated once, giving n=4 for each chemical and physical analysis. Results were expressed as mean values ± standard deviation. Minitab was used to perform one-way Analysis of variance (ANOVA) followed by a Tukeys test (<0.05) for mean comparison.

Results and discussion

3.1 Dry matter content and energy content

The highest value of dry matter content was in the freeze-dried powder 3 (FDP3) and the lowest was in the frozen pulp (Fro), 94.18±0.19 % and 36.99±0.12 % respectively. See table 3. There was no significant difference of the dry matter content between powder 1 (P1), powder 2 (P2) and powder 3 (P3) and their respectively freeze-dried form. However, a significant difference was seen between P1 and FDP1 compared to P2, FDP2, P3 and FDP3. This could be due to different drying methods adopted (vacuum-microwave drying vs air drying), different varieties and biotypes of fruits and different ripening stage used in manufacturing of the different powders. The dry matter content is significantly lower in the untreated Fro and fresh pulp (Fre) than in the freeze-dried samples. According to the manufacturer of P2, the moisture content is supposed to be <7 %, it was found to be 7.03 %. Yahia & Guttierrez-Orozco (2011), Del Castillo Málaga (2006) and García-Ríos et al. (2020) found the moisture content of fresh lucuma to be 62 %, 72.3 % and 56.9 % respectively in their studies. According to Fuentealba et al. (2016) the moisture content of the biotype Levia 1 was decreasing from 72.3 % to 57.8 % with the stage of ripeness. These results are similar to the results from this study where the moisture content was found to be 60.04 % of the untreated fresh pulp, with a relatively high standard deviation which indicates a difference between the pulp from the two fresh fruits analysed.

The energy content was only measured on freeze-dried samples. It was found to be the highest in P2 and lowest in Fre, 416.47±0.91 kcal/100 g and 153.28±0.94 kcal/100 g respectively. There was no significant difference between the powders but a significant difference between the powders, frozen and fresh sample. See table 3. The energy content values reported by the manufacturers (P1-352 kcal/100 g, P2-357.2 kcal/100 g, P3-306 kcal/100 g and Fro-110 kcal/100 g) are lower than what was found in this study. According to Yahia & Guttierrez-Orozco (2011) the energy content of fresh fruit was 143.8 kcal/100 g, which is also slightly lower than the results from this study. The reason for this could be different analysing methods and/or varying moisture content.

Table 3. Dry matter and moisture content of different forms of lucuma. P1 -Powder 1, P2 -powder 2, P3 -powder 3, Fro -Frozen, Fre -Fresh and FD -Freeze-dried sample.

	P1	P2	P3	Fro	Fre
Dry matter content (%)					
Untreated	88.38±0.09^{BC}	92.97±0.07^{A}	91.70±0.03^{AB}	36.99±0.12^{D}	39.96±4.92^{D}
Freeze-dried	88.88±0.05^{BC}	93.65±0.13^{A}	94.18±0.19^{A}	86.98±0.31^{C}	87.93±1.12^{BC}
Moisture content (%)					
Untreated	11.62	7.03	8.30	63.01	60.04
Freeze-dried	11.12	6.35	5.82	13.03	12.07
Energy content					
kcal/100g	403.74±1.32^{B}	416.47±0.91^{A}	414.71±0.57^{A}	164.53±0.43^{C}	153.28±0.94^{D}
kJ/100g	1690.69	1744.00	1736.63	688.97	704.04

Note: Different letters within the same category stand for significant differences ($p < 0.05$).

3.2 pH, viscosity and colour

pH and viscosity were measured in the reconstituted powders, thawed frozen pulp and mixed fresh pulp, all at room temperature. The highest pH value was found in P1 and the lowest in Fre, 5.38±0.02 and 5.00±0.06 respectively. There was no significant difference in pH between the frozen and the fresh sample. See table 4. Garcìa-Rìos (2016) reported a pH of 5.60±0.02 and 5.50±0.04 of fresh lucuma pulp in the biotype Beltrán and Seda respectively. According to Alegre Caballero & Del Carmen Ticse Aguilar (2017) the pH of frozen lucuma pulp was 4.8, 4.9 and 4.6 in the biotype Baltrán, Trompito and María Belén respectively. No previous studies have been found on the pH in reconstituted powders.

The viscosity was higher in the fresh pulp compared to the reconstituted powders at a shear rate of 0.3 rpm. The highest value of viscosity was found in Fre and the lowest in P3, 3091±154 Pa s and 1076±310 Pa s respectively. The viscometer and spindle used could not manage to measure the thawed frozen pulp due to a too high viscosity. See table 4. The data was only obtained at the end point, after 3 min.

Table 4. pH, viscosity and colour of different types of lucuma. P1 -Powder 1, P2 -powder 2, P3 -powder 3, Fro -Frozen, and Fre -Fresh sample.

	P1	P2	P3	Fro	Fre
pH	5.38 ± 0.02^{B}	5.44 ± 0.04^{A}	5.33 ± 0.09^{B}	5.03 ± 0.02^{C}	5.00 ± 0.06^{C}
Viscosity (Pa s)	1586 ± 96^{C}	2326 ± 496^{B}	1076 ± 310^{C}	Not determined	3091 ± 154^{A}

Note: Different letters within the same row stand for significant differences ($p < 0.05$).

Colour was measured in the dried powders, thawed frozen pulp and mashed fresh pulp. The highest a* and b* value was found in Fro, the lowest a* value was found in P1 and the lowest b* value was found in P2. Comparing the a* (red colour) and b* (yellow colour) in the frozen and fresh sample, they are more similar than comparing with the powders. See figure 7. However, the b* values for the frozen and fresh sample were significantly different. The b* values for the powders shows no significant difference, but there was significant difference between P1 and P3 in the a* values. This indicates that Fro and Fre are more red and yellow than the powders. See figure 8. The results for L* (light) indicates that the powders are lighter than the frozen pulp and fresh pulp. The highest L* value was measured in P1 and the lowest in Fro. All the samples were significantly different except for P1 and P2. See figure 9. It could be discussed whether the differences in colours and light between the powders and the fresh and frozen pulp are an effect of the drying process where a browning, probably as a result of the Maillard reaction or enzymatic browning, occurred. Additionally, the type of fruit and maturity stage could affect the colour (Somjai et al. 2022).

Figure 7. The colours of powder 1 (P1), powder 2 (P2), powder 3 (P3), frozen pulp (Fro) and fresh pulp (Fre).

According to García-Ríos et al. (2020) the fresh lucuma pulp has an a* value of 16.6±3.0 and 13.9±5.4, a b* value of 68.8±3.2 and 52.6±6.9, and a L* value of 71.6±2.3 and 69.2±3.6 in the varieties Beltrán and Seda respectively. Aguilar-Galvez et al. (2021) reported a* values of 1.9±2.2 and 9.8±1.4, b* values of 38.3±9.4 and 47.8±0.9 and L* values of 81.2±1.7 and 76.2±1.3 of the fresh lucuma

pulp before physiological maturity and at physiological maturity respectively. These are comparable to the values of the fresh pulp of this study (a* (18.53±1.39), b* (55.23±1.39) and L* (54.50±0.89)).

Alegre Caballero & Del Carmen Ticse Aguilar (2017) reported a* values of 15.14±0.055, 15.26±0.087 and 16.61±0.494, b* values of 54.29±0.182, 55.92±0.618 and 55.30±0.488 and L* values of 60.13±0.298; 59.83±0.730 and 61.08±0.246 in frozen pulp in the biotypes Beltrán, Trompito and María Belén respectively. These values can be compared to the colour measurements of frozen pulp in this study (a* (21.10±0.84), b* (57.36±4.15) and L* (53.15±0.19)). No results of colour measurements of lucuma powder were found in previous studies.

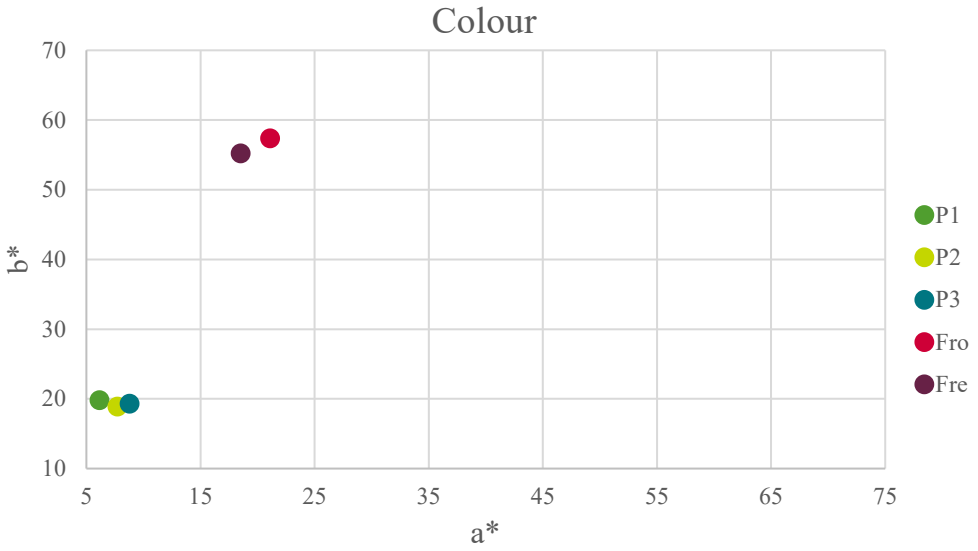

Figure 8. a and b* values for the different lucuma samples (P1-powder 1, P2-powder 2, P3-powder 3, Fro-frozen pulp and Fre-fresh pulp). A higher a* value indicates a more red colour and a higher b* value indicates a more yellow colour.*

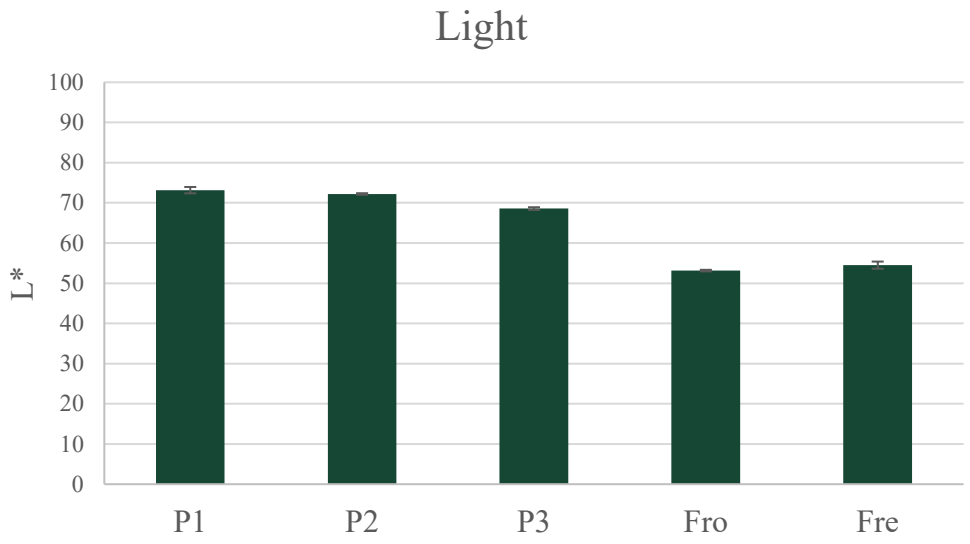

Figure 9. L value for the different lucuma samples (P1-powder 1, P2-powder 2, P3-powder 3, Fro-frozen pulp and Fre-fresh pulp). L*=0 indicates black and L*=100 indicates white.*

3.3 Total phenolic compounds and antioxidant capacity

The content of total phenolic compounds (TPC) and antioxidant capacity (AC) was measured in the untreated samples as well as the freeze-dried. The highest content of TPC was found in Fre and the lowest in FDFro, 13.03±13.35 mg GAE/g DW and 2.02±0.09 mg GAE/g DW respectively. According to Vallespir et al. (2019) TPC decreases when beetroot, apple and eggplant was pre-treated with freezing and drying. A similar trend can be seen in this study.

Comparing with previous studies Fuentealba et al. (2016) reports that the total phenolic content (mg GAE/g DW) was found to be 61.6±10.9, 0.7±0.07 and 45.3±31.9 in the varieties Rosalia, Montero and Leiva 1 respectively. Additionally, in three different ripeness stages of Levia 1 the total phenolic content was 131.6± 2.0, 45.3±32.0 and 0.7±0.1 mg GAE/g DW from the least ripe to the ripest. García-Ríos et al. (2020) reported a total phenolic content of 2.50±0.11 in Beltrán and 2.38±0.13 mg GAE/g DW in Seda.

The standard deviation in the TPC content of the untreated fresh sample was very large. See figure 10. The TPC content has been reported to decrease with ripeness (Fuentealba et al. 2016). The two lucuma fruits used for the analysis of TPC were in different ripening stages, which is probably why the standard deviation was so high. When analysing the TPC and measuring the absorbance of the FDFre one of the samples had an absorbance higher than the instrument could detect at 765 nm. Therefore, the TPC value for FDFre was only based on pulp from one fruit.

Additionally, the untreated fresh sample and the freeze-dried fresh sample was not based on the same fruits. These factors are probably some of the reasons for the big difference in TPC content of Fre and FDFre. TPC for this form of product would probably be higher as we could not include the very high absorbance value from the other measurement for TPC calculation. No significant difference can be seen in the TPC content of P1, FDP1, P2, FDP2, P3, FDP3, Fro and FDFro. A small decrease in TPC content was seen in FDFro compared to Fro. The same trend was not found in P1, P2 and P3.

Phenolic compounds are sometimes bound tightly in to the food matrix and is hard to dissolve (Zhang et al. 2020). Since the food matrix is a very complex system and is easily affected by different factors such as temperature and addition of ingredients (Capuano et al. 2018) it could be discussed whether disturbing or changing the food matrix of the different forms of lucuma, as is done during drying, dissolving in water, freezing, heating and freeze-drying, affects the bound phenolics to dissolve in a varying degree. This could be a reason for the increase of TPC between the untreated powders and the freeze-dried form and the decrease of TPC between the untreated frozen pulp and the freeze-dried form. Due to this trend, it seems like reconstituted powders (60% water) are better in retaining phenolic compounds compared to fresh or frozen lucuma pulp during freeze-drying.

Previous studies have reported a higher TPC content in fresh pulp than in powder with similar results to this study (Pinto et al. 2009). However, no previous studies were performed comparing the TPC content in the powder, frozen pulp and fresh pulp of lucuma.

Additionally, it has been reported that the method using Folin-Ciocalteu regent for determining the TPC content is not completely accurate since the Folin-Ciocalteu regent also can react with compounds such as reducing sugars, ascorbic acid and reducing amino acids (Granato et al. 2016). Hence, this could skew the results.

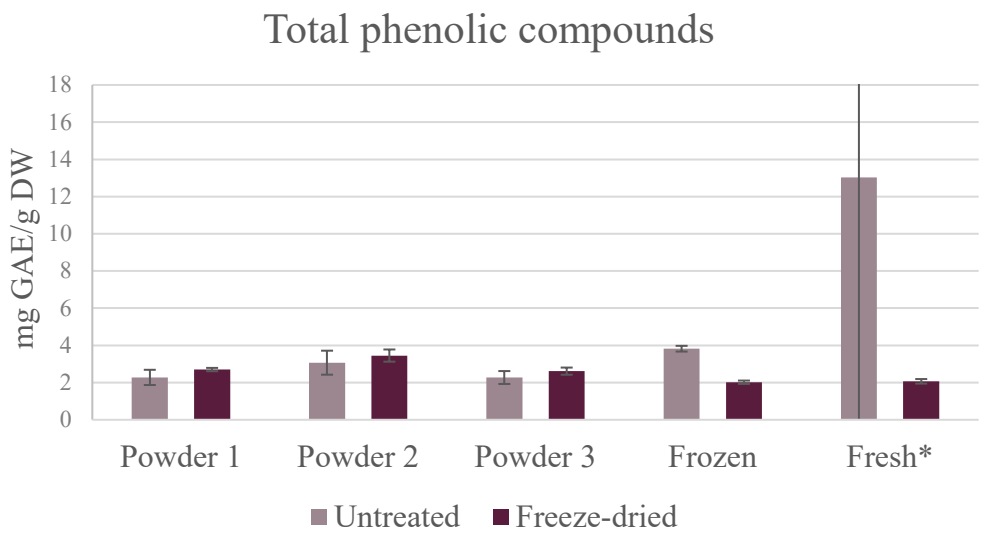

*Figure 10. Total phenolic compounds in different forms of lucuma. *The result for the freeze-dried fresh sample is only based on two datapoints.*

The antioxidant capacity (AC) was also following a similar pattern like the TPC content. See figure 11. The highest AC value was found in Fre and the lowest in FDFro, 7798±6258 µmol TE/g DW and 466±99 µmol TE/g DW respectively. The standard deviation for the untreated fresh sample was very large. The AC has been reported to decrease with ripeness similarly to the TPC content (Fuentealba et al. 2016). The two lucuma fruits used for the analysis were in different ripening stages, which is probably why the standard deviation was so high. One measurement for the untreated frozen and fresh sample gave negative values of µmol TE when performing the calculations. That datapoint was ignored, which is why the results for the antioxidant capacity for the untreated frozen and fresh sample was based on only three datapoints.

Fuentealba et al. (2016) reports AC values for fresh pulp lower than what was found in this study 132.9±35.0 µmol TE/g DW and 0.7±0.2 µmol TE/g DW for the biotypes Rosalia and Montero respectively. García-Ríos et al. (2020) found similar results in the biotypes Beltrán and Seda, 19.3±1.3 µmol TE/ g DW and 17.3±1.0 µmol TE/ g DW respectively. The reason for the big difference in results could be stage of ripening or that different extraction methods were used. No comparable results from previous studies were found on AC in powder and frozen pulp.

The untreated fresh sample was the only sample that had a significantly different AC than the other samples. The treatment of freeze-drying seems to have a big impact on the AC since the difference in Fre and FDFre was very big. However, the untreated fresh sample and the freeze-dried fresh sample was not based on the same fruits, which could also affect the results.

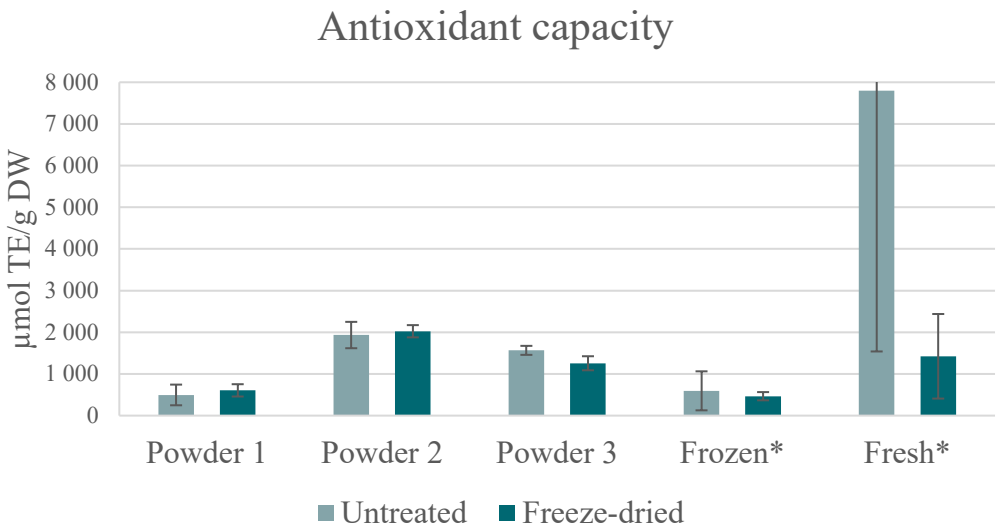

*Figure 11. Antioxidant capacity in different forms of lucuma. *The results for the untreated frozen and the untreated fresh sample are only based on three datapoints.*

Many phenolic compounds have antioxidative properties (Minatel et al. 2017) which is probably why the TPC content and the AC was mostly following the same pattern. See figure 10 and 11. Since the TPC and AC values are lowest in the frozen pulp it could be discussed whether the transformation of liquid water into ice, resulting in factors such as change in volume of the internal water when it is converting to ice and appearance of ice crystals in varying size, lead to breakage of the cellular walls and thereby promoted loss and/or oxidation of TPC and antioxidants. Even though there was not a significant difference between the TPC content, and the antioxidant capacity values in the different powders and their freeze-dried form, it seems like the different drying techniques, or the different biotypes used when producing the powder had an impact on the TPC and AC. However, this must be studied further to be able to draw any conclusions.

Lastly, the extraction methods used for the TPC and AC analysis has not been well studied before, and it can be discussed whether the extraction of the untreated powders, frozen pulp and fresh pulp can be comparable since the two later contains more water.

3.4 D-glucose, D-fructose and Sucrose

All samples except for P3 and FDP3 had a higher content of D-glucose than D-fructose (Table 5). Sucrose had the lowest content in all samples. Previous studies has shown the same trend (Aguilar-Galvez et al. 2021; Fuentealba et al. 2016). The highest value of D-glucose was found in FDFro and the lowest in Fre, 187.8 mg/g DW and 35.27 mg/g DW respectively. The highest value of D-fructose was found

in FDP2 and the lowest in Fre, 109.5 mg/g DW and 30.89 mg/g DW respectively. The highest value of sucrose was found in FDP2 and the lowest in Fre, 69.17 mg/g DW and 13.62 mg/g DW respectively. The content of sucrose in P1, FDP1, Fro and FDFro was too low to detect. See table 5. The analysis of Fro and Fre resulted in much lower sugar values than the analysis of FDFro and FDFre. A reason for this could be the difference in matrix of the untreated frozen and fresh pulp and the freeze-dried and grinded same samples, where the sugar molecules probably are more easily dissolved and less bound in the freeze-dried samples. Another reason for the increased sugar content in the freeze-dried samples could be that the freeze-dried samples were grinded to a powder. The powders have less particle size and more surface area than the same amount of frozen pulp and fresh pulp, which were extracted by mixing with solvent with a magnetic stirrer. Therefore, it could be assumed that the results from the freeze-dried samples gave more accurate results. There was no significant difference between the untreated samples P1, P2, P3 and FDP1, FDP2, FDP3 in the analysis of D-fructose and sucrose. In the analysis of D-glucose there was only a significant difference between the untreated and freeze-dried samples of P1. For the sugar analysis it could be suggested to use the pre-treatment of freeze-drying before extraction to obtain as accurate results as possible.

Table 5. Concentration of D-glucose, D-fructose and sucrose expressed in mg/g DW. P1 -Powder 1, P2 -powder 2, P3 -powder 3, Fro -Frozen, Fre -Fresh and FD -Freeze-dried sample

	P1	P2	P3	Fro	Fre
D-Glucose (mg/g DW)					
Untreated	164.39±2.06^{C}	112.18±0.90^{D}	97.17±1.41^{E}	35.73±1.94^{F}	35.27±2.60^{F}
Freeze-dried	179.14±7.03^{AB}	122.15±5.00^{D}	99.82±0.96^{E}	187.84±7.21^{A}	167.69±10.21^{BC}
D-Fructose (mg/g DW)					
Untreated	108.03±1.65^{AB}	102.80±1.33^{ABC}	99.86±2.59^{BC}	31.94±2.69^{D}	30.89±3.78^{D}
Freeze-dried	101.65±5.31^{ABC}	109.45±2.05^{A}	102.69±3.62^{ABC}	96.56±4.24^{C}	105.62±6.93^{ABC}
Sucrose (mg/g DW)					
Untreated	Not determined	59.44±4.62^{AB}	41.77±3.44^{B}	Not determined	13.62±9.21^{C}
Freeze-dried	Not determined	69.17±13.84^{A}	60.23±14.12^{AB}	Not determined	63.95±17.40^{AB}

Note: Different letters within the same row stand for significant differences ($p < 0.05$).

3.5 Sensory evaluation

3.5.1 Sweetness

The aim of performing a sensory analysis on sweetness of the different lucuma samples was to investigate whether it was possible to see any relationship between the results from sensory test of sweetness and the chemical profile of D-glucose, D-fructose and sucrose. However, the results from the sensory test of sweetness showed no statistical difference between the samples even though the content of D-glucose, D-fructose and sucrose was varying between many of the samples. This is thought to be due to too few panellists and that an untrained panel was used for the sensory analysis. The total sugar content was not analysed in this study, neither the content of sugar alcohols such as myo-inositol. There could therefore be other molecules that contributes to sweetness but those were not analysed. According to the suppliers the sugar content of P1 is 33.9 g/100 g, P2 -31.6 g/100 g and frozen pulp 15.4g/100 g which is a relatively big difference. However, the powders were reconstituted with 60 % which makes the content/100 g more similar. Additionally, it is hard to tell how big the difference of sweet perceiving molecules must be in order to give a difference in the sweetness. It could also be further explored whether the matrix of the samples could have an impact on the perception of sweetness, if the cells are more ruptured and the sugar molecules and sugar alcohols were less bound.

3.5.2 Characteristics

The panel discussion from the sensory test focusing on characteristics resulted in an agreement on five to six attributes for each category (aroma, texture and taste) for the six samples together. The attributes agreed on by the sensory panel during the panel discussion was for aroma: dried fig, wood, raisin, cereals and fermented fruits, for texture: paste, creamy, mealy, satiating and smooth, and for taste: sweet, dried figs, muscovado, acidic, bitter and dried rosehip. The sweet taste is probably due to the relatively high sugar content (approxemately 30 g/100 g for P1 and P2 and 15 g/100 g for the frozen pulp according to the suppliers). The acidic flavour can be described with the low pH which was around 5. Phenolic compounds is sometimes giving a bitter taste, therefore the high content of TPC can be related to the same flavour attribute (Minatel et al. 2017).

According to Singh (2017) the main aroma attributes in twelve different lucuma powders were buttery, sweet, caramelized, waxy, green, nutty, and cucumber. None of these attributes are the same that the panel in this study agreed on. However, the attributes: cucumber, sweet, green, nutty and caramelized were present during the panel discussion. According to Duarte & Paull (2015) the taste of lucuma is described as maple and caramel. These attributes were not discussed in this panel discussion.

Most previous studies and literature found about lucuma is originating from South and North America. There could therefore be a cultural reason for the difference in the chosen attributes. Or the reason could simply be because an untrained sensory panel was used in this study.

Conclusion and future perspectives

From this study it can be concluded that the composition of lucuma depends on the variety or biotype, the stage of ripeness as well as the processing that has been performed on the pulp. Regarding health, TPC content and AC values are higher when the fruit is less ripe, which would indicate that this is the best format of raw material for further product development. However, the taste of the fruit is not pleasant before the fruit is fully ripe. To avoid the powdery texture the fresh or frozen fruit would be more suitable for further product development, however the TPC and AC was indicated to be the lowest in the frozen pulp. In order to find the most suitable raw material for product development of a value-added lucuma product, more studies have to be done. There are still many composites and bioactive compounds of lucuma that would be interesting to examine, such as fibre content, carotenoids, vitamin B3 and some minerals. The glycaemic index of lucuma would also be valuable to get a better understanding. As a part of the product development, it would also be helpful to study properties such as phase separation and composition of starch since carbohydrates are the main composites. Additionally, there is no standardized way of deciding when the fresh lucuma fruit is fully ripened. If performing more studies comparing these three different forms (powder, frozen pulp and fresh pulp) of lucuma it would be suggested to decide on the same ripening stage for all the fresh fruits that are used as well as using a mix of pulp from different fruits when performing the analysis of the fresh fruits. To get an even broader understanding, it would be interesting to try different extraction methods for the TPC and AC analysis and for the D-glucose, D-fructose and sucrose analysis. At last, to add a sustainability aspect, a life cycle analysis of the different forms of lucuma could be performed to find the most sustainable alternative.

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Popular science summary

Lucuma (*Pouteria Lucuma*), known as the gold of the Incas, is an ancient fruit from the Andean region of Latin America. It is sweet and the flavour is often described as maple-like or caramel-like. Lucuma is a popular flavour in ice-creams in Peru and is commonly used in sweets and pastries. The colour of the pulp is varying from pale yellow green to orange and the texture resembles boiled egg yolk. The skin-colour is varying from green to yellow and the shape is round or elliptical, almost like something between an avocado and mango.

Lucuma has been increasing in popularity in the global West the recent years, it is marketed as a superfruit with a beneficial nutritional composition. It is referred to as high in fibre, phenolic compounds, carotenoids, vitamins, minerals and with a high antioxidant capacity.

The fresh fruit has a limited shelf life and is sensitive to transportation. Therefore, it is common to use lucuma powder (dried pulp) or frozen lucuma pulp instead of the fresh pulp for product development in industry. There are two main varieties of lucuma: Seda (which is soft in its texture and mostly used for fresh consumption) and Palo (which is firm in its texture and more commonly used for production of powder and frozen pulp). There is a big lack of knowledge in how the composition of lucuma is changing in the different forms (powder, frozen pulp and fresh pulp) and varieties of lucuma.

The company Aventure AB together with the Bolivian organization Swebol biotech is now starting a collaborative project. The aim of the project is a new healthy lucuma based product that can be a part in the promotion of Bolivian innovation, production and public health.

The aim of this thesis was to compare and analyse different forms (powder, frozen pulp and fresh pulp) of lucuma fruit from different producers, as a part in the development of a value-added lucuma product that promotes Bolivian innovation. To do this the composition of three different powders, frozen pulp and fresh pulp were used. Dry matter content, energy content, pH, viscosity and colour as well as total phenolic compounds (TPC), antioxidant capacity (AC) and the three different sugars; sucrose, D-fructose and D-glucose were analysed. Two sensory tests were performed to evaluate the sweetness of the different forms of lucuma, and to find descriptive words for the characteristics of lucuma regarding aroma, texture and flavour.

To summarise the main findings of this study, the dry matter content and the energy content was differentiating the most between the powders compared to the frozen and fresh samples. The same pattern was seen for the pH and the colour. The TPC content and AC value was highest in the fresh sample, therefore it seems like processing has an impact on TPC and AC. Regarding sugars it was seen that in most of the samples the content of D-glucose was the highest, followed by D-fructose and sucrose in descending order.

According to the sensory test, there were no difference in sweetness between the samples. The descriptive words agreed on by the sensory panel during the panel discussion was for the category aroma: dried fig, wood, raisin, cereals and fermented fruits, for texture: paste, creamy, mealy, satiating and smooth, and for flavour: sweet, dried figs, muscovado, acidic, bitter and dried rosehip.

It can be discussed whether the differences in the results are due to the processing used on the samples during production (drying, freezing, blanching etc.), or due to different varieties or biotypes in the different raw materials analysed, or due to different maturity stages of the fruits used for the raw materials. According to previous studies all these factors can have an impact on the composition of the fruit.

The conclusion of this study was that the composition of lucuma is varying between the different forms (powder, frozen pulp and fresh pulp) analysed. This is probably due to processing technique, variety and biotype, and grade of maturity. However, to get a better understanding for what form of lucuma is more suitable as the raw material in product development when including health, sensory, technical and sustainability aspects more research is needed.

Appendix 1

Figure 12. The different products used for analysis. (a) Powder 1, (b) Powder 2, (c) Powder 3, (d) Frozen pulp and (e) Fresh fruits.

Appendix 2

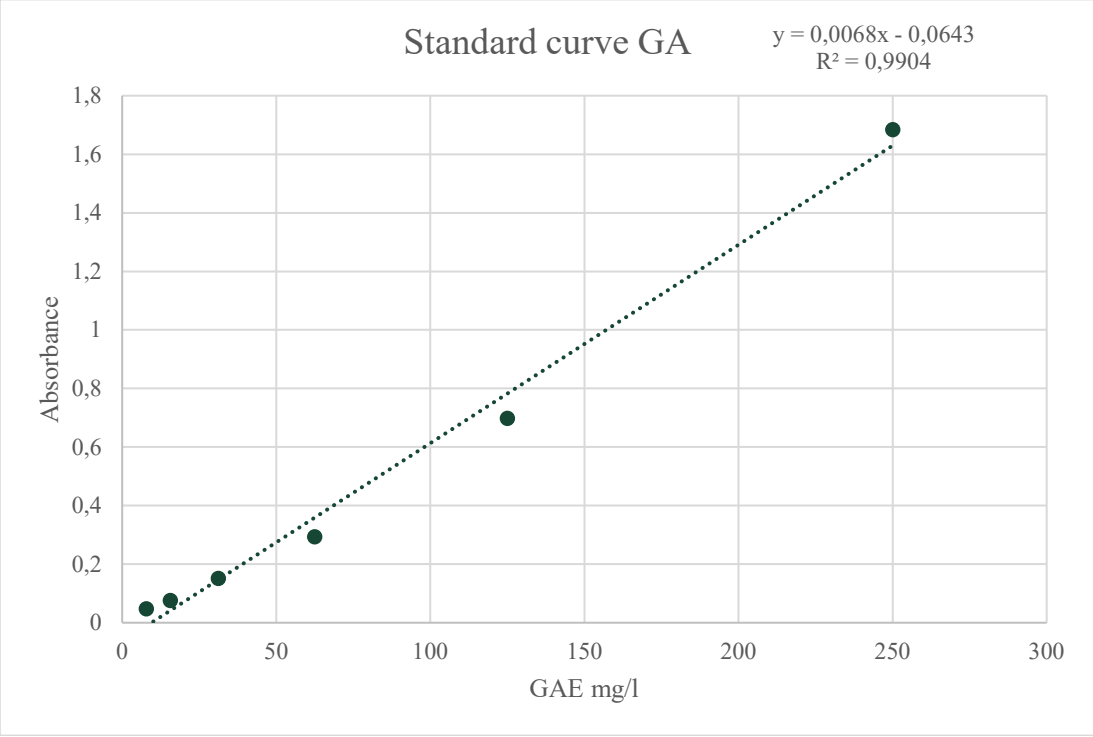

Figure 13. Standard curve with mg gallic acid equivalents (GAE).

Appendix 3

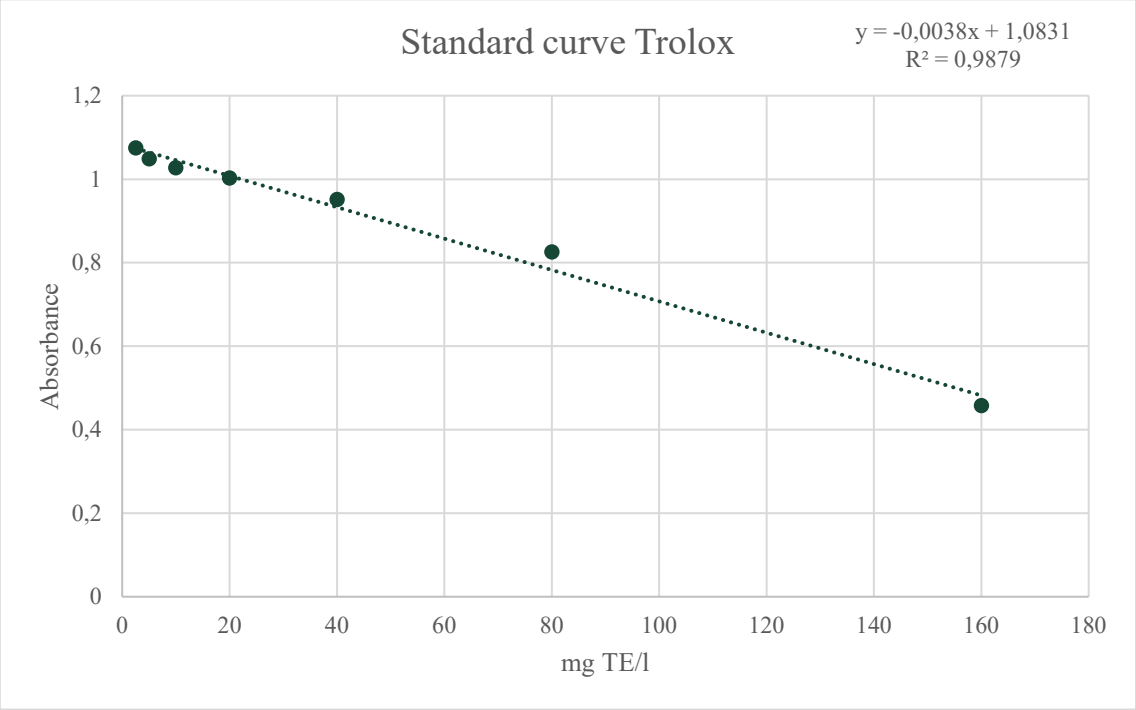

Figure 14. Standard curve with mg Trolox equivalents (TE).

Appendix 4

PROCEDURE:

Wavelength: 340 nm
Cuvette: 1 cm light path (glass or plastic)
Temperature: ~ 25°C
Final volume: 2.42 mL (D-glucose)
2.44 mL (D-fructose)
Sample solution: 4-80 µg of sucrose + D-glucose + D-fructose per cuvette (in 0.10-1.00 mL sample volume)

Read against air (without a cuvette in the light path) or against water

Pipette into cuvettes	Blank sucrose sample	Sucrose sample	Blank D-glucose/ D-fructose sample	D-Glucose/ D-fructose sample
solution 6* (β-fructosidase)	0.20 mL	0.20 mL	-	-
sample solution	-	0.10 mL	-	0.10 mL

Mix** and incubate for 5 min (NOTE: before pipetting solution 6, first warm it to 25-30°C). **Then add:**

distilled water (at ~ 25°C)	2.00 mL	1.90 mL	2.20 mL	2.10 mL
solution 1 (buffer)	0.10 mL	0.10 mL	0.10 mL	0.10 mL
solution 2 ($NADP^+$/ATP)	0.10 mL	0.10 mL	0.10 mL	0.10 mL

Mix** and read absorbances of the solutions (A_1) after approx. 3 min and start the reactions by addition of:

suspension 3 (HK/G6P-DH)	0.02 mL	0.02 mL	0.02 mL	0.02 mL

Mix** and read the absorbances of the solutions (A_2) at the end of the reaction (approx. 5 min). If the reaction has not stopped after 5 min, continue to read the absorbances at 2 min intervals until the absorbances remain the same over 2 min***.

Then add:

suspension 4 (PGI)	-	-	0.02 mL	0.02 mL

Mix** and read the absorbances of the solutions (A_3) after approx. 10 min.

*Pipette both solution 6 and sample solution into the bottom of the cuvette and mix by gentle swirling.

** For example with a plastic spatula or by gentle inversion after closing the cuvette with a cuvette cap or Parafilm®.

*** If the absorbance continues to increase, this may be due to effects of colour compounds or enzymes in the sample. These interfering substances may be removed during sample preparation.

Appendix 5

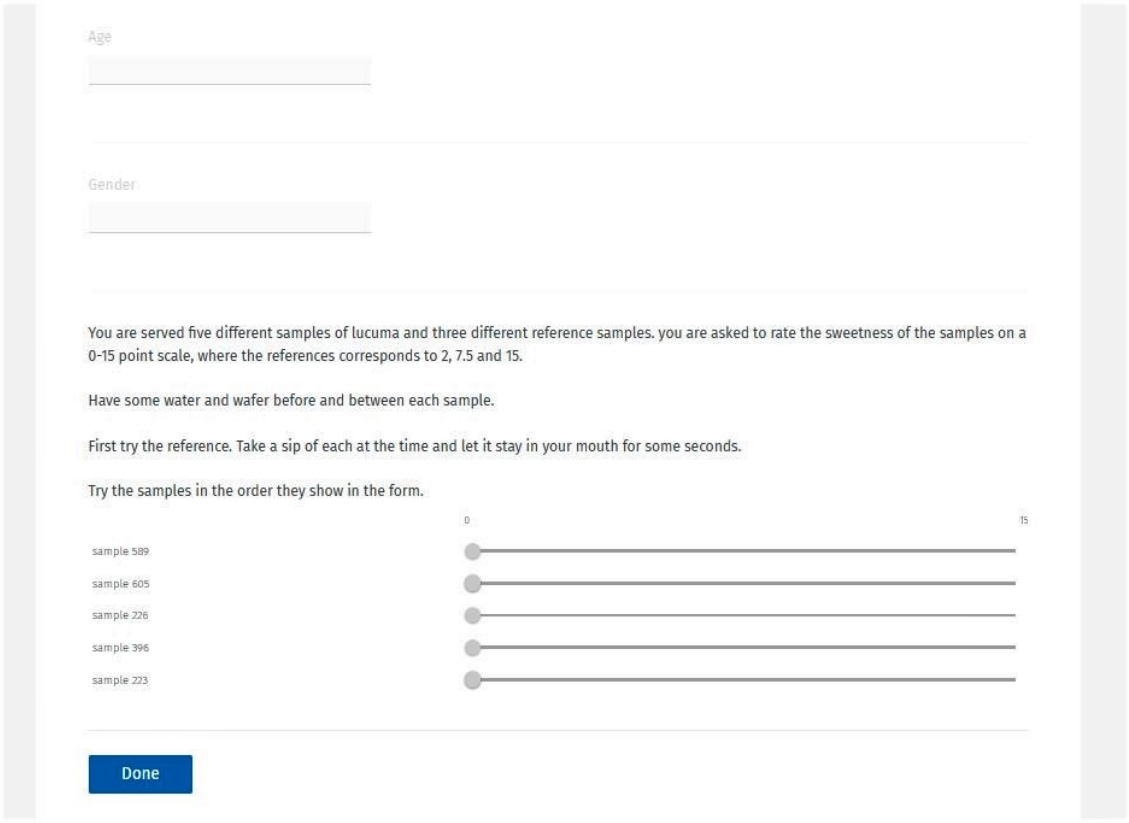

Figure 15. Questionnaire for the sensory evaluation of sweetness. (https://www.questionpro.com/t/AVKkuZr3xh)

Appendix 6

Characteristics of lucuma 30/3

You are going to be served six different samples of the fruit lucuma in lidded plastic containers. First you will try the samples individually, one by one, following the instructions below. Second, we will have a discussion and conclude the opinions of the group.

Drink water and eat some wafers before and between the samples.

Start with the sample on the left, write the number, and answer the two questions. Then continue with each sample one by one.

1. Open the lid of the container and smell the sample. Write down any words to describe the aroma.
2. Take a spoon full and taste the sample. Write down any words to describe the texture.
3. Write down any words to describe the taste/flavour.

Sample nr	Aroma	Texture	Taste/Flavour

To show that you are done, put the lid back on all the containers.

Appendix 7

Figure 16. The setup for the sensory test and panel discussion evaluating the characteristics of lucuma.

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