Master Thesis

Analysis of Process Technologies to Preserve Berries

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Popular Science Summary

“Is freezing the best way to preserve berries?”

Consumption of berries is important because they are rich in antioxidants and vitamins. Sweden has a big production of berries but only 2-5% of the Swedish forest berries are utilized (RISE, 2022). The most common berries that grow in the Swedish forests are lingonberries and bilberries. Lingonberries and bilberries are very similar to cranberries and blueberries respectively. However, cranberries and blueberries are mostly imported to Sweden. Something that could help to increase the utilization of the wild berries is understand the advantages and disadvantages of the different technologies to preserve them. Freezing is one of the most common technologies to preserve berries, but there are other technologies like lyophilization, microwave-vacuum drying, hot air drying, and osmotic dehydration that could be a better alternative, these technologies are assessed on this thesis comparing cost of the equipment, sensory properties, shelf life, nutritional properties and the environmental impact that could have the different technologies. The information was obtained through a literature review and the sustainability assessment was done through a questionnaire based on a Life Cycle Approach.

Since the berries are harvested once a year it is important to choose a good preservation technique to later produce healthy and tasty food berry products. From the berries can be extracted antioxidants and aroma, this refinery process is an established business in some countries and could be a great opportunity for entrepreneurs or people related with the berry business in Sweden. The literature review showed that freeze-drying and microwave-vacuum drying are modern technologies that preserve fruits keeping the majority of them nutrients, freezing and hot air drying are the most common techniques currently used, and osmotic dehydration is an old technique that doesn´t need a big investment and is easy to carry out. The sustainability assessment showed that the main difference between these technologies is in the supply chain and storage stages.

In my conclusion, comparing all the technologies I could see that no one is better than the other, rather it depends on the type of product you want to obtain. Also, I could see that one of the biggest challenges to increase the utilization of the wild Swedish berries is find a way to collect them because currently a lot of foreigners are brought to Sweden to collect the berries.

Abstract

From all the wild berries that grow in Sweden only 2-5% is utilized (RISE, 2022). The United Nation has 17 goals for sustainable development, and many of those goals are related to sustainable food production (United Nations, 2022). A sustainable food product should have low environmental impact, social equity, and economic viability, while still containing essential nutrients (Woodhouse et al, 2018). There are many parameters to take into consideration when evaluating sustainability, as it is a complex system with many factors, I will only evaluate from the environmental impact perspective.

The objective of this thesis is to analyze lyophilization, convective hot air drying, microwave vacuum drying, and osmotic dehydration to see if they are a better alternative to freezing berries, concerning cost of new equipment, environmental impact, preservation of nutrients, shelf life, and sensory properties. The berries considered are blueberries, bilberries, cranberries, and lingonberries because they have a similar composition. The study is conducted through a literature review. To evaluate the environmental impact of the mentioned technologies a sustainability checklist based on a Life Cycle Approach was conducted.

The overall conclusion is that from all the assessed technologies in this thesis there is no better technique when it comes to preserve berries, all of them have their advantages and disadvantages, but to increase the utilization of the wild Swedish forest berries the development of a more efficient way to collect them could be an interesting project to develop.

Keywords: berry processing, freezing, drying, lyophilization, microwave vacuum drying, osmotic dehydration, environmental impact.

Acknowledgment

I would like to dedicate this thesis to my grandfather Antonio Pedraza Uribe (1936-2022) you will always live on my thoughts. To my family because this would never have been possible without them.

I would like to thank to my supervisor Karin Östergren for give the opportunity to write this thesis with her, for all her mentorship, motivation, and assistance throughout this project. I appreciate so much all the time and energy you have spent helping me on this project.

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Content

1 Introduction

Sweden has a big production of wild berries, but only 2-5% of the production is utilized (RISE, 2022). The common method to preserve the berries is by freezing, like all the preservation technologies has advantages and disadvantages. Freezing extends over a long period of time the shelf life of berries however the sensory characteristics after thawing are not that good (Sinha, 2012). Freezing reduces the enzyme action however is not completely stopped, this cause changes in the sensory and nutritional properties of the food. Freezing food helps to stop but not to destroy microorganism that cause spoilage (Ohioline,2016). Currently there are more food preserving technologies like drying or osmotic dehydration that could be more environmentally friendly and possibly cheaper than the freezing (Uddstål personal communication, 2021).

1.1 Objectives

The objective of this thesis is to analyze the lyophilization, convective hot air drying, microwave vacuum drying, and osmotic dehydration to see if they can be a better alternative to freezing berries, concerning preservation of nutrients, cost of new equipment, environmental impact, and sensory properties.

1.2 Research question

- How long could be the shelf life of the berries after drying/ osmotic dehydration process comparing with freezing?
- How much energy require the drying and the osmotic dehydration comparing with freezing?
- Which of the mentioned technologies (drying, osmotic dehydration and freezing) has less impact on the sensory properties of the berries?
- Which of the mentioned technologies (drying, osmotic dehydration and freezing) have less environmental impact considering processing, transport, and storage stages?

1.3 Delimitation of the study

The study was performed as a qualitative study through desktop research. The environmental impact to run each unit operation was evaluated through a sustainability checklist based on a Life Cycle Approach. The environmental impact is only assessed on the processing, transport, and storage stage. Only information about cranberries, lingonberries, blueberries, and bilberries was considered. The freezing technology evaluated is Individual Quick Freezing (IQF).

2 Methodology

2.1 Information search

The information search was carried out as described in the next 4 points

2.1.1 General literature search

The description of cranberries, blueberries, lingonberries, bilberries, and the unit operations (freezing, lyophilization, hot air drying, microwave vacuum drying, and osmotic dehydration) was obtained by books. The information about Swedish, Nordic, and global berry business was obtained searching in google browser for these concepts. The articles for the systematic literature review were obtained from Elsevier, science direct, and google scholar.

2.1.2 Systematic literature review

Relevant literature was searched on Elsevier, science direct and google scholar databases using these keywords: freezing berries, vacuum drying berries, berry dehydration, microwave drying berries, berries freeze-drying, hot air-drying berries and osmotic dehydration of berries. The criteria to include/exclude information was consider only articles that talks about energy consumption, shelf life, and impact on nutritional and sensory quality for each unit operation and only for blueberries, bilberries, cranberries and lingonberries.

2.1.3 Interviews

Interviews were made with experts in the field to gain further information about berry processing. The interview was made by Zoom with Roger Uddstål and in videocall by WhatsApp with Jan Vanbart. Roger Uddstål works on RISE having many years of experience on berry production. Jan Vanbart works as a temporary contract with berry company owners. The interviews were unformal, more like a conversation. The interviews were not recorded or transcribed, but careful notes were taken.

Roger Uddstål guided me to get information about the different assessed technologies. Jan Vanbart provided information about the process to collect berries, the logistics issues to transport the berries to the freeze facility, and the quality process to comply with the government regulations. All the interviews provided valuable knowledge that allowed me to have a better understanding of the berry business in Sweden.

2.1.4 Obtention of equipment prices

During the meeting with Roger Uddstål he suggests me to get the prices of the different equipment’s from Alibaba website because it was the most accessible way to get them since physical companies don´t give quotations to the open public.

2.2 Analysis

2.2.1 Assessing process alternatives

To assess the processing technologies, I will focus on comparing prices of new equipment, shelf life, and the impacts on the nutritional and sensory quality.

2.2.2 Environmental assessment

The environmental assessment was conducted by a checklist obtained from the article "Sustainability checklist in support of the design of food processing" written by Karin Östergren, Anna Woodhouse, Jennifer Davis, and Caroline Pénicaud. The article mentions that the checklist was created to provide a tool based on a Life Cycle Assessment theory to create awareness on sustainability issues and identify hotspots when designing a process in the food industry. The checklist has four columns (Appendix A, Table 7). The first column contains elements related to the three pillars of sustainability: environmental, social, and economic aspects. The second column (upstream) is set to assess the stage where the food ingredients are produced. The third column (process) is set to assess the processing of raw material. The fourth column (downstream) is set to assess the retail and consumer use of the product. Finally, the fifth column is set for comments open to anything that could help the process designer. The user of the table must mark either yes or no in every relevant aspect. The checklist was validated by the feedback of companies, in the article is not mentioned the number of participating companies, is just mentioned that the number of companies which provided feedback is low compared to the number of companies in the food industry, nevertheless the feedback was consistent among the participants.

In this thesis was compared Individual Quick Freezing (IQF) against osmotic dehydration, and in other table was compared IQF against lyophilization, convective hot air drying, and microwave vacuum drying to identify hotspots and get awareness about the environmental impact. The drying technologies were grouped as one because they follow the same process diagram (see Figure 2). The column for upstream issues will not be considered for this thesis because I am not analyzing agricultural aspects. For the "process" column, will only be considered the equipment (freezer, freeze-dryer, convective oven, microwave vacuum dryer, and osmotic dehydrator) examined in this thesis, not the entire elements that make up a berry processing factory. In the "downstream" column, only the transport, retail, and consumption of the food product will be considered. For filling the checklist, will be marked with an "x" the aspects in which there is a relevant difference between the processes, and since this thesis only considers the environmental aspect of the sustainability only the boxes water, energy, packaging, transport, and storage will be considered.

3 Background

3.1 Berry business

3.1.1 Global

The biggest producer of blueberries in the world is United States, in 2020 they produced 294 000 tones which is 34.92% of the total world production. In 2020 the total production of blueberries in the world was estimated around 841 886 tons. Peru, Canada, Poland, and Mexico are the other biggest producers. (Konoema, 2020)

3.1.2 Nordic

In the Nordic countries the commerce of berries is divided in three groups. The first group is integrated by those private collectors that sell the berries to a bigger company. The second group is integrated by those who collect or purchase berries to produce jams or juices to sell either locally or internationally. The third group is integrated for those who collect or buy berries to freeze them to sell it internationally or to local supermarkets. The biggest group is this last one, sell frozen berries to other countries is a profitable business for Nordic countries but could be even better the profit if they could develop their own process industry, for example industries to extract antioxidants and aroma. But even the existence of these business it represents a small percentage of use of all the amount of wild berries available. There are countries like Switzerland that have a more developed berry processing industry but with active research and development Sweden can be at the same level. (Paassilta et al, 2009)

3.1.3 Swedish

Sweden imported about 6000 tons of bilberries in 2007 and exported about 8000 bilberries. The main buyers of Swedish bilberries are China and Japan. The Swedish berry business have been growing but can be developed much more. As a result of the growing in the last years Swedish berry companies decided to create the Swedish Forest berry Association to communicate everything related to these issues. One of the biggest problems that face Sweden to grow up the berry business is in the picking of the berries because there is a few local people willing to collect so berry business owners have to bring foreigners to collect the berries. These foreigners come specially from the Asia pacific region. The other challenge that has Sweden is that the berry must be freeze maximum 24 hours after being cut from the plant, the problem is that the freezer locations are far from many points of berry collection. (Paassilta et al, 2009)

3.2 Berries

Berry is a small and bright colored fruit produced from a single ovary. They are rich in vitamins, minerals, and antioxidants. Common examples are raspberries, blackberries, strawberries, blueberries, cranberries, lingonberries, and bilberries. (Folta & Kole, 2016)

3.2.1 Cranberry and lingonberry description

Vaccinium macrocarpon is commonly known as cranberry in North American which is verry similar to *Vaccinium Oxycoccus* commonly known as lingonberry in Europe, they have a slightly difference amount of anthocyanin. About the size of the berry *Vaccinium Oxycoccus* (lingonberry) is usually a little bit smaller than *Vaccinium macrocarpon* (cranberry). These names assigned to the berries are recognized by the U.S.D.A. (Sinha et al, 2012)

3.2.2 Chemical composition of cranberry and lingonberry

The proximate composition of raw cranberries is placed in the Table 2. Cranberries are rich in tannins; this polyphenolic compound creates astringency which is a typical characteristic on berries. Also, citric and malic are the predominant acids followed by quinic (~1.0%) and benzoic (~0.01 %), which is uncommon in most popular fruits (Sinha et al, 2012). As you can see in Table 2 and Table 3 cranberry and lingonberry are very similar, for this reason the same process conditions can be applied for both.

Table 1 Nutritional quality of cranberries

Nutritional quality of cranberry	
Component	Percent
Water	86.5
Protein	0.4
Ash	0.2
Fat	0.2
Dietary fiber	4.2
Carbohydrates	8.5

From Sinha et al (2012)

Table 2 Nutritional quality of lingonberry

Nutritional quality of lingonberry	
Component	Percent
Water	86.3
Protein	0.8
Ash	0.3
Fat	1.2
Dietary fiber	3.7
Carbohydrates	7.7

From Amit (2020)

3.2.3 Blueberry and bilberry description

Blueberry *(Vaccinium Caesariense)* and bilberry *(Vaccinium myrtillus)* have a similar outer appearance and a fruity and floral notes due to esters, ethyl acetate, and 3-isopropyl-butyrate, but the inner flesh is different. Bilberries has 3-7 mg/ 1g of anthocyanin, this makes its inner flesh red while blueberry has a green flesh with an estimated content of 1.1 mg/g of anthocyanin. (Purple Superfoods, 2020) (Sinha et al, 2012)

3.2.4 Chemical Composition of blueberry and bilberry

The proximate composition of raw blueberry and bilberry is placed in Table 4 and Table 5 respectively, as you can see in these tables, they are very similar, for this reason the same process conditions can be applied for both.

Table 3 Nutritional quality of blueberry

Nutritional quality of blueberry	
Component	Percent
Water	84.0
Protein	0.7
Ash	0.1
Fat	0.3
Dietary fiber	2.4
Carbohydrates	12.6

From Sinha et al (2012)

Table 4 Nutritional quality of bilberry

Nutritional quality of bilberry	
Component	Percent
Water	86
Protein	0.7
Ash	0.2
Fat	0.8
Dietary fiber	4.6
Carbohydrates	7.7

From Simmonds & Preedy (2015)

3.3 Nutritional quality of the berries

Berries are rich in fiber, vitamin C, vitamin K, manganese and potassium and they only have 80 calories per cup. They are also low in sodium and have virtually no fat. Moreover, they are rich in polyphenols such as anthocyanins, proanthocyanidins, flavonoids, phenolic acids, and tannins. (Zielinska & Danuta, 2019)

3.4 Berry processing

The next diagrams show the sequence for processing the berries with all the different unit operations analyzed in this thesis.

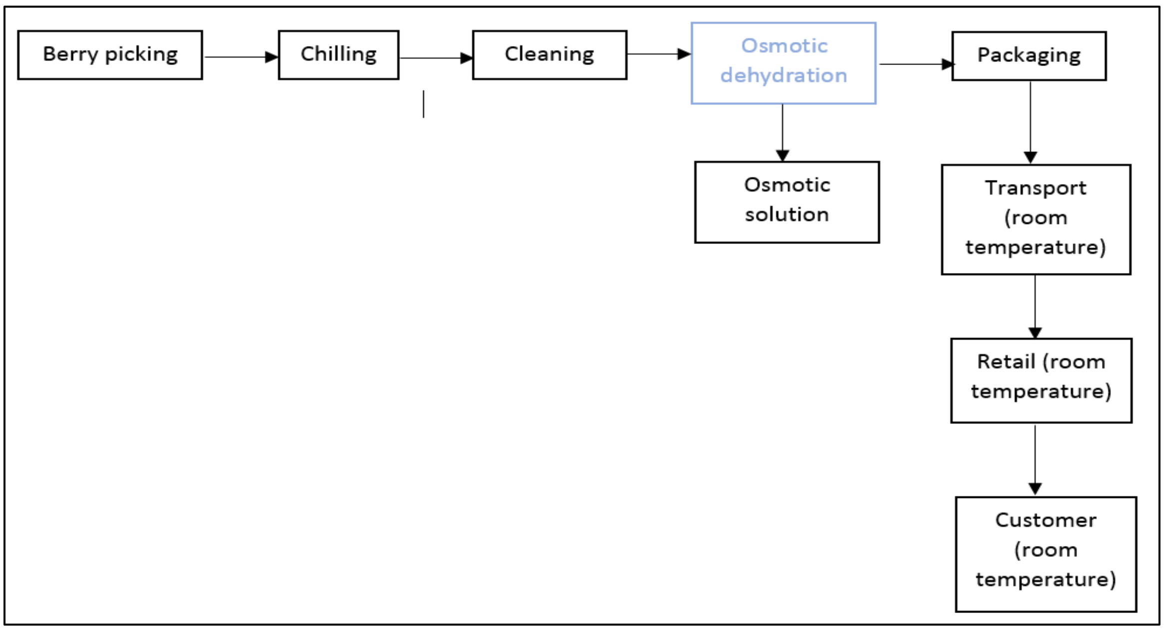

Figure 1 Osmotic dehydration process diagram (Sinha et al, 2012)

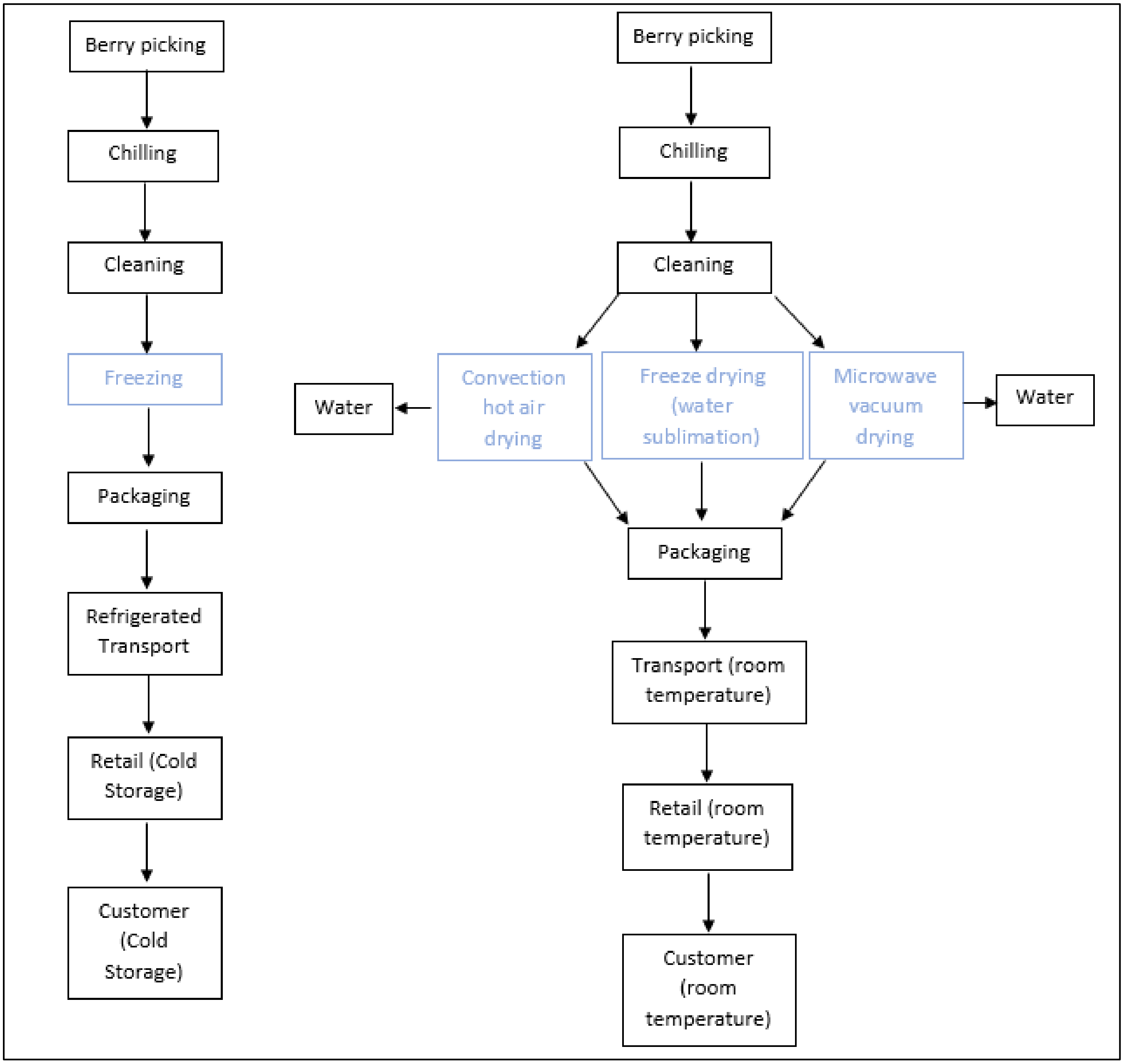

Figure 2 Freezing, hot air drying, freeze-drying, and microwave-vacuum drying process diagram (Sinha et al, 2012)

3.5 Freezing

When freezing a product sensible heat and latent heat of fusion is removed by the exposure to a low temperature medium; these converts water from liquid to ice undergoing three different stages: pre-freezing, phase change, and post-freezing. In the majority of the frozen foods at storage temperatures 10% of water continue in liquid state. Usually, vegetables and fruits are stored frozen to a temperature of -18°C. (Singh & Heldman, 2009)

When the freezing process starts (sensible heat removed) the temperature of water decreases to the freezing point, during this stage ice crystals begin to form (nucleation), then the temperature remains at the freezing point until the phase change completely. The conversion into solid ice occurs as latent heat of fusion is removed from liquid water. The temperature of the ice decreased rapidly when all the liquid water has been converted into solid ice, during this quick temperature decreasing sensible heat is removed. (Singh & Heldman, 2009)

3.5.1 Freezing Berries

Frozen berries are prepared from the ripened fresh fruit of the plant; they are stemmed and cleaned, may be packed with or without packing media, and are frozen and stored at temperatures of -18°C (Hui, 2005). As individual berries, they can be tray frozen or IQF (Individual Quick Frozen) on a belt in an air blast or cryogenic freezer. In order to successfully freeze berries in a large container, the temperature on entering the freezer should be below 15°C (Barrett et al, 2004).

The berries are frozen with air at -30 to -40°C within 3-15 min. The air pass over the berries at 2-5 m/sec through a thick bed of berries (3-14 cm) contained in a trough. Is recommended wetting the berries before passing them through the pre-chilling zone of the freezer to freeze a thin ice layer around each berry, this thin ice layer minimize freezer burn during freezing. (Eskom, 2022)

Effects of Freezing

- Physical changes and quality (for example volume expansion or contraction)
- Color changes
- Flavor and aroma changes
- Textural changes
- Nutritional and antioxidant status changes. (Barrett, 2004)

3.6 Drying

Removing water in different amount and forms is the objective of drying. The structure of the fruit’s changes depending on the manner and amount of water removed, also this will determine the properties of the reconstituted dried product. During drying, the weakest join water (free water) is removed first. In the dehydrated state the properties of the food product aren´t modified by the removal of free water. The water strongly bounded to macromolecules (bound water) is difficult to remove but there is no problem if the bound water is not removed because is difficult that microbials have access to it. (Sinha et al, 2012)

Dehydration of food products makes more efficient the product transportation and storage because reduces product mass and volume (Singh & Heldman, 2009). Hot air drying, osmotic dehydration, vacuum drying, microwave drying, and freeze drying are the most common drying methods in the process of berry drying (Yanan et al, 2019). Compared with freeze-drying the cost of hot air drying have been quantified to be 4-8 times lower (Barbosa, 2019).

3.6.1 Freeze drying

Freeze-drying is accomplished by reducing the food temperature so that most of the product moisture gets frozen, and by decreasing the pressure around the product the ice inside the product can be sublimated. Carrying out these operations requires enormous amounts of energy; however, the final food product have a good quality and preserve its structure resulting from low temperature during sublimation (Singh & Heldman, 2009).

It’s important to consider that berries are naturally wrapped by a waxy outer skin that becomes a barrier to water vapor flow during freeze-drying. This mass transfer limitation is usually the phenomenological factor that controls the processing time, energy consumption, and final product quality. A skin rupture or a bursting is frequently observed due to pressure lift just under the berry skin. In summary, berries maintain most of their nutritional quality but their organoleptic characteristics are affected. (Prosapio & Lopez, 2020)

3.6.2 Hot air drying

Is performed in an enclosed and heated chamber. The drying medium, hot air, pass over the product which is placed in open trays (tray dryer). Convection drying is a continuous process and is mostly used for products that have a relatively low water content. Factors that affect the rate of drying are air velocity, humidity, temperature, product geometry, and distribution pattern. Air circulation over the product can be horizontal or vertical to the layer. (Shafiur, 2007) This operation is considered highly destructive because the end products show loss of nutrients and loss of color (Guiné, 2018).

It is challenging dry with this method fruits and vegetables due to their high water content, however is used because extend over long periods the shelf life of the products, however maintaining the maximum temperature gradient between the air and the interior parts of the product will help to carry out more efficiently this operation (Guiné, 2018).

3.6.3 Microwave vacuum drying

Microwave-vacuum drying is a relevant drying process because perform high drying rates at low temperature. Water evaporation by dielectric energy creates a porous structure, which facilitates the mass transfer, however, the heat distribution in the product is not uniform. The vacuum helps to decrease the boiling point of water from 100°C under 1 atm of pressure to a lower temperatures. (Richter, 2014)

Also, vacuum is favorable to the quality of final products because allow temperature-oxygen sensitive components to dry under reduced temperature and oxygen atmosphere. Additionally, water circulation inside the product increases at lower pressures, improving internal mass transfer (Dong & Mujumdar, 2008).

The heat is obtained by electromagnetic radiation, this energy is absorbed by the water molecules present in the food and then is converted into kinetic energy (Richter, 2014). It is necessary use short thickness samples to allow homogeneous heating (Richter, 2014).

A pressure regulator, a microwave oven, a condenser, a glass vacuum desiccator, and a vacuum pump are the most common elements of a microwave-vacuum dryer for foods (Richter, 2014).

3.7 Osmotic dehydration

Osmotic dehydration occurs when through a semi-permeable membrane a solute cross to the other side due to a concentration gradient. The concentration gradient between the intracellular fluid and the osmotic solution is the driving force for water removal. Only in a perfect semipermeable membrane the solute is unable to pass through the membrane in the cells. Nevertheless, due to the internal structure in food products is very difficult to get a perfect semipermeable membrane, generally there is always some leaching out of the food´s own solute and also some solute diffusion into the food. (Shafiur, 2007)

The osmotic dehydration is generally used as a pretreatment for canning because this process does not produce products that can be considered shelf stable, the final moisture content is not low enough. Usually for foods sugar is used as osmotic agent because helps to inhibit the enzyme polyphenol oxidase. (Shafiur, 2007)

Osmotic dehydration consumes less energy than freezing, air drying, and microwave-vacuum drying because it can be conducted at low temperatures. After finishing an osmotic dehydration process the resultant syrup represents a challenge to make the process industrially viable, it can be reused but the microbial contamination of the end product is highly probable, after 8h of continuous use the levels of fungi and yeast can go from 2×10^2 to 10^5 cfu/mL . The unused syrup needs to be adequately treated before disposal in wastewater. (Shafiur, 2007)

3.8 Environmental issues related to food industry

The production of food has an impact on the environment throughout the different stages needed to bring food to the customers. The use of natural resources along with the residues that generates the transport and production of food are current challenges that need to be addressed. (Tiwari et al, 2014)

Freezing berries is a relatively cost-effective way to preserve nutrients and taste, but it also comes with a big energy consumption due to the refrigerated transport and additionally the refrigeration in stores and customers houses. Efforts to reduce this energy cost have typically focused on the refrigeration devices that are used to store the food (Anthropocene, 2021). Globally, per year the electricity consumption of our domestic fridges and freezers to preserve frozen food creates 62 million of tonnes of CO_2 equivalent emissions (The Guardian, 2008).

A common way to preserve berries is by convection hot air drying, but is one of the most energy intensive unit operations in the agricultural and food processing industries, this high use of energy has an impact on the environment, so for a sustainable use of this technology is recommended the development of alternate fuels or renewable sources of energy (Bowser et al, 2011).

The actual food packaging provides a way to make food shelf stable and safe, however most of them is designed to be single use and some of them are not recycled, it is difficult to find unpackaged food, but opportunities to choose packaging less harmful to the environment do exist (FoodPrint, 2020). The big majority of berry producers currently use 100% recyclable packaging (Barrett et al, 2004).

4 Results

4.1 Systematic literature review

Total number of papers found were 40 and 12 were selected for further assessment.

Table 5 Considered studies about berry processing

Author	Reference	Publication year	Berries	Technologies assessed
Giovanelli et al, 2012	Effects of blanching pre-treatment and sugar composition of the osmotic solution on physico-chemical, morphological and antioxidant	2012	Blueberry	Osmotic dehydration

	characteristics of osmo-dehydrated blueberries.			
Yanan et al, 2019	Berry Drying: Mechanism, pretreatment, drying technology, nutrient preservation, and mathematical models	2019	Blueberry/Cranberry	Osmotic dehydration Hot air drying Freeze-drying Microwave drying Vacuum drying
Zielinska & Danuta, 2019	Effects of freezing, convective and microwave-vacuum drying on the content of bioactive compounds and color of cranberries	2019	Cranberries	Freezing, convective hot air drying, and microwave-vacuum drying
Zielinska et al, 2018	Effects of freezing and hot air drying on the physical, morphological, and thermal properties of cranberries	2018	Cranberries	Freezing and hot air drying
Lachowicz et al, 2019	Comparison of the effect of four drying methods on polyphenols in saskatoon berry	2019	Blueberry	Freeze-drying, convective hot air drying, and microwave-vacuum drying
Zhou et al, 2021	Microwave-vacuum assisted drying of pretreated cranberries: Drying kinetics, bioactive compounds, and antioxidant activity	2021	Cranberries	Microwave-vacuum drying

Sunjka & Raghavan, 2004	Assessment of pretreatment methods and osmotic dehydration for cranberries	2004	Cranberries	Osmotic dehydration
Sadowska et al, 2017	Influence of freezing, lyophilization and air-drying on the total monomeric anthocyanins, vitamin C and antioxidant capacity of selected berries	2017	Bilberry	Freezing, freeze-drying, and convective hot air-drying
Perez et al, 2022	Environmental behavior of blueberry production at small scale in northern Spain and improvement opportunities	2022	Blueberries	Freezing
Arteaga et al, 2021	Postharvest freezing process assessment of the blueberry structure in three acts: bioimpedance, color, and granulometry analysis	2021	Blueberry	Freezing
Prosapio & Lopez, 2020	Freeze-drying technology in foods	2020	Blueberry	Freeze-drying
Yang et al, 2021	Osmotic dehydration kinetics of fresh and frozen blueberries considering volume shrinkage in a novel ternary solution	2021	Blueberry	Osmotic dehydration

Table 6 Results of the systematic literature review

Technology	Operational procedure conditions	Shelf life	Sensory properties	Nutritional quality
IQF Freezing	15 min, – 40°C (Arteaga et al, 2021)	Not available	Volume reduced of 30-40% (Zielinska et al, 2018)	Little reduction of polyphenols and anthocyanin (Zielinska et al, 2018)
Convection oven hot air drying	310 min at 60°C (Zielinska & Danuta, 2019)	Not available	Shrinkage (Yanan et al, 2019)	Total polyphenols and anthocyanin content are significantly reduced (Yanan et al, 2019)
Freeze-drying	-60°C during 24h (Prosapio & Lopez, 2020)	Not available	Berries became porous, berries get an airy texture (Prosapio & Lopez, 2020)	Least loss of phenolic substances (Yanan et al, 2019)
Microwave-Vacuum drying	450 W with 5+/- 1 kPa during 8-10 min. (Zielinska & Danuta, 2019)	Not available	Similar to freeze-drying (Yanan et al, 2019)	Significant degradation of bioactive compounds (Yanan et al, 2019)
Osmotic dehydration	Osmotic solution 20°C for 22 h (Yang et al, 2021)	Not available	Shrinkage (Sunjka & Raghavan, 2004)	Significant degradation of bioactive compounds (Sunjka & Raghavan, 2004)

4.2 Interviews

Roger Uddstål explained all the different technologies assessed in this thesis, which match the description written in the background. He also showed me a map with the distribution of berry companies in Sweden. The main companies are Polarica AB, Olle Svensson AB, Skogsmat AB, and Blåtand AB. Additionally we analyzed that a possible future business in Sweden is the creation of a factory to extract the aroma and antioxidants of the berries because these are products that currently Sweden import (Uddstål personal communication, 2022).

Jan Vanbart told me that for this current year will come to Sweden 1700 Thailand's to collect berries and in total they hope to collect 5000 tons of berries. He also explained me that he manages the documentation to comply with KRAV regulations which stands for food produced without artificial chemical pesticides, good animal welfare, reduced climate impact, more biodiversity and better working conditions (Vanbart personal communication, 2022).

4.3 Energy consumption

According to the articles reviewed, the energy consumption for IQF berries is 410 kJ/kg with an air velocity of 6 m/s and a temperature of -43°C inside the freezer (Korotkiy, 2014). For microwave vacuum drying berries, the energy consumption is 5020 kJ/kg at 5.33 kPa and 500W (Yongsawatdigul & Gunasekaran, 1996). For convective hot air drying the energy consumption is 489500 kJ/kg keeping the oven at 50°C for 15 hours (Pavkov et al, 2017). For freeze-drying berries the energy consumption is 937177.4 kJ/kg at -60°C for 48 hours (Pavkov et al, 2017). In none of the publications reviewed, the energy expenditure for osmotic dehydration was mentioned. Roger Uddstål told me in the interview that lyophilization has the highest energy expenditure, then microwave-vacuum drying, in third place convection hot air drying, then freezing but without considering the cold supply chain, and finally osmotic dehydration (Uddstål personal communication, 2022).

4.4 Operational process conditions

According to the articles reviewed to freeze cranberries the time registered is 15 min and the temperature is -40°C (Arteaga et al, 2021). For freeze-drying blueberry, a temperature of -60°C was applied for 24 h (Prosapio & Lopez, 2020). For hot air drying cranberries, a temperature of 60°C for 310 min was applied (Zielinska & Danuta, 2019). For osmotic dehydration of berries, the osmotic solution had a temperature of 20°C and the operation lasted 22 h (Yang et al, 2021), and for microwave vacuum drying the operation lasted 8-10 min at 450W and 5+/- 1 kPa (Zielinska & Danuta, 2019).

4.5 Investment cost

Accordingly, to Alibaba website the price of the equipment's (examples) are. IQF Freezer cooling capacity 500 kg/h - 47500 USD (Alibaba, 2022), hot air dryer 50kg capacity - 3500 USD (Alibaba, 2022), freeze dryer 10kg/batch - 105000 USD (Alibaba, 2022), and microwave vacuum dryer capacity 5 kg/h - 45000 USD (Alibaba, 2022). For osmotic dehydrator equipment there is no available producer. Additionally, to these prices we must consider the cost of the unboxing, installation, commissioning, and the connection to the automation system.

4.6 Impacts on nutritional and sensory quality

- Freezing: volume reduced to approximately 30-40% of the original volume of raw fruits (Zielinska et al, 2018). Freezing most probably resulted in the formation of large ice crystals inside the fruit (Zhou et al, 2021).
- Freeze-drying: retains almost all the nutritional value. Food became porous, an airy texture (Prosapio & Lopez, 2020).
- Convective hot air drying: the volumetric shrinkage of dried fruits depended on the drying temperature, and it was significantly higher in

cranberries dried with hot air at 80 and 90°C than in those dried with hot air at 60 and 70°C (Zielinska et al, 2018). Volume reduced to approximately 30-40% of the original volume of raw fruits. The highest content of total polyphenols in blueberries dried at 70°C, 80°C, and 90°C was using hot air at 90°C, lower air temperature and prolonged exposure to oxygen contributed to greater degradation of polyphenols and reduced antioxidant capacity (Zielinska et al, 2018).

- Microwave-vacuum drying: present shrinkage of whole cranberry, however the overall appearance was more desirable than that of cranberries subjected to hot air drying (Zhou et al, 2021). Microwave vacuum drying resulted in reduced losses of polyphenols comparing with hot air drying (Zhou et al, 2021).
- Osmotic dehydration: a lot of vitamins, minerals, and hydrophilic compounds are lost in the process, the berry gets shrinkage and a crystallized texture. (Giovanelli et al, 2012), (Yang et al, 2021), (Sunjka & Raghavan, 2004)

4.7 Shelf life

None of the articles reviewed have information about the shelf life, however on the books they mention that freeze-drying and microwave-vacuum drying get the longest shelf life for fruits, on second place convection hot air drying and freezing get long shelf life but less than freeze-drying and microwave-vacuum drying (Shafiur, 2007). Finally osmotic dehydration increases the shelf life of fruits but is recommended better as a pretreatment before applying some of the previous mentioned technologies (Shafiur, 2007).

5 Environmental Assessment

The aim of this section is to compare qualitatively through a checklist based on a Life Cycle Approach (LCA) the preservation technologies discussed in the previous chapters to see which one has more environmental impact. The elements evaluated are water used in the processing stage, energy used in the processing stage, packaging, transport, and storage. First is compared Individual Quick Freezing (IQF) against osmotic dehydration (Table 8) and secondly is compared IQF against lyophilization, hot air drying, and microwave vacuum drying (Table 9). The tables are placed in appendix A.

When IQF is compared to osmotic dehydration I could see that osmotic dehydration has the disadvantage of requiring large amounts of water to prepare the osmotic solution, which is one of the hotspots identified thanks to the checklist. In terms of packaging, it is not possible for either unit operation to re-use the packaging material during the processing stage, but consumers can do so while they finish the product. Berries are typically packaged in single-use plastics, but the plastic can be recycled if made of polypropylene (Robertson, 2013) or biodegraded if made of polylactic acid (Mihai & Holban, 2018). Regarding energy consumption during the processing stage, IQF consumes more energy than osmotic dehydration because osmotic dehydration is performed at 20°C (Yang et al, 2021), which is another hotspot identified by the checklist. Concerning transport and storage, osmotic dehydrated products have the advantage of not requiring cold transport or cold storage, this would be the third hotspot identified by the checklist.

Comparing IQF against the drying technologies when it comes to the use of water in the processing stage only IQF use a small amount of water to wet the berries before passing them through the pre-chilling zone (Eskom, 2022). About the use of energy during the processing stage, the drying technologies expend more energy than IQF according to the information obtained from the articles (Section 4.3), however all these unit operations can be supplied by energy coming from a renewable source (Spellman, 2016) this is a hotspot identified thanks to the checklist because the difference of energy expenditure between them is high. About packaging, for both unit operations is not possible re-use the packaging material in the processing stage, but consumers can do it while they finish the product. Berries are packaged in single-use plastics mostly of time, however the plastic can be recycled if is used polypropylene (Robertson, 2013) or can be biodegraded if they use plastic packages made of polylactic acid (Mihai & Holban, 2018). Concerning the transport and storage is an advantage for dried products that they don´t need cold transport or cold storage, this is another hotspot that could be identified thanks to the checklist.

6 Analysis and discussion

The berry processing is a challenge because the fruit has a waxy peel that makes difficult to remove all the steam generated with all the drying techniques analyzed on this thesis (Prosapio & Lopez, 2020). The peel has a few pores. Considering this aspect that is why freezing is the best technology to preserve the original shape of the berry, otherwise all the drying techniques burst the peel at some point during the drying process (Prosapio & Lopez, 2020). This waxy peel of the berries makes very slow the osmotic dehydration process (Yang et al, 2021).

Throughout my literature review I observed that many experiments weren´t carry on in a commercial/industrial size equipment but in equipment's that simulate them, this makes hard compare between the different technologies.

Is important to consider that regardless the drying technique the berries must be chilled all the time before being processed so besides the energy consumption of each technique the energy expenditure during the chilling stage will be an additional cost that´s why is important choose the fasted method. The quick method is the microwave-vacuum drying (8-10 min) and the slowest is the freeze-drying (24 hrs), but during my investigation I saw that these times vary considerably if small holes are done in the peel with CO_2. (Prosapio & Lopez, 2020)

About osmotic dehydrator equipment there is no available producer, looks like the process is simply carry on in a big container, so the producer has to make its own container with the dimensions according to the production he will have.

The method that allows preserve the biggest amount on antioxidants is the freeze-drying followed by microwave-vacuum drying (Lachowicz et al, 2019), and the one that keep the lowest amount is the convective hot air drying, however the freeze-drying equipment is very expensive and also the energy consumption due to the vacuum system and the very low temperatures needed to be carry on the operation implies a big expenditure on energy. However, microwave vacuum drying at 480 W could give product with the quality similar to the obtained by freeze drying (Lachowicz et al, 2019).

About the environmental impact of berry processing is in the stages after being packaged is where we can see noticeable difference between freezing and the rest of the methods reviewed on this thesis. All the drying technics and the osmotic dehydration don´t need cold storage or cold transportation, moreover due to the volume decrease of each berry there is more space to transport more product per trip. Additionally, the customer can keep the product at room temperature, however since there are a lot of food products available in the market that need to be stored in the freezer in the customer houses (like fish, ice cream, etc) there is no big difference between have berries that need or not need keep cold.

In my opinion, to contribute to the development and innovation of the berry processing system in Sweden the investment on microwave-vacuum drying can help to get a more sustainable berry industry, because the cold transportation and storage could be avoided while having a product with nutrients. Also, the development of factories that commercialize berry as dehydrated puree can help a lot because is easier to process, use less energy and the product keep more nutrients than try to sell dehydrated or freeze berries (Barbosa, 2019). On the other hand, the main reason of the enormous berry utilization in Sweden is that the current system to collect berries is inefficient (Vanbart personal communication, 2022), I would recommend make programs to motivate people in the communities surrounding the forest to find profitable collect berries or invest in the acquisition of robots to collect the berries. Currently companies must expend a lot in bringing foreigners to collect the berries, but even with them there still being a lot of problems to collect the berries (Vanbart personal communication, 2022).

7 Answer to the research questions

- How much energy require the drying and the osmotic dehydration comparing with freezing?

Is difficult to compare the energy consumption because in each article they don´t process the same amount of berries and they don´t finish the process until get the same percentage of moisture or the same aw. Comparing the energy consumptions obtained from the articles, the unit operation that expends more energy to process berries is freeze-drying (937177.4 kJ/kg), then convective hot air drying (489500 kJ/kg), then microwave vacuum drying (5020 kJ/kg), and lastly Individual Quick Freezing (410 kJ/kg), but considering that osmotic dehydration is carried out at 20°C I could say that osmotic dehydration is the one that uses less energy. From my interview with Roger Uddstål I can see that his opinion match with the information obtained from the articles except for how he sorts microwave vacuum drying and convective hot air drying.

- How long could be the shelf life of the berries after a drying/osmotic dehydration process comparing with freezing?

In the articles I couldn´t find a specific period of shelf life for each treatment applied to berries, however on the books they mention that freeze-drying and microwave-vacuum drying get the longest shelf life for fruits, on second place convection hot air drying and freezing get long shelf life but less than freeze-drying and microwave-vacuum drying. Finally osmotic dehydration increases the shelf life of fruits but is recommended better as a pretreatment before applying some of the previous mentioned technologies.

- Which of the mentioned technologies (drying, osmotic dehydration and freezing) has less impact on the sensory properties of the berries?

Freeze-drying because retain to a great proportion the characteristics of fresh fruit after being rehydrated, compared with the other methods of dehydration. Berries maintain their color, the majority of phenolic, anthocyanin, vitamins, and volatile compounds. Damage to the hydrophilic groups responsible for the interaction with water is lower than that of other methods, so freeze-dried berries rapidly rehydrate and regain water content and organoleptic properties similar to the fresh berries.

- Which of the mentioned technologies (drying, osmotic dehydration and freezing) have less environmental impact considering processing, transport, and storage stages?

I couldn´t say a specific one because it depends on the specific conditions that make up a production process, however if the energy that supplies the processing of berries comes from a renewable source this will help to have a less environmental impact. Additionally, is recommendable use the unit operation that best allow have a balance in the energy expenditure between processing, transport, and storage. Looks like avoid the use of cold supply chain would have less environmental impact, however many dried products are transported over long distances, and this can contaminate more due to the use of fuel in the transport.

8 Conclusions

Comparing all the technologies no one is better than the other, rather it depends on the type of product you want to obtain. All the technologies have their advantages and disadvantages. Freeze drying has one of the longest shelf life and less impact on nutritional and sensory properties, however the equipment is very expensive, time consuming, and therefore consumes a lot of energy which makes a product with high cost and less accessible to the consumer.

Microwave vacuum drying has less impact on the nutritional and sensory quality of the berries than freezing, osmotic dehydration and hot air drying, but no better than freeze drying. The equipment is high cost, and the procedure is complicated because the heat doesn´t distributes uniform in all the berry. Is one of the quickest technologies but requires a lot of energy, which makes a product costly and less accessible to the customers.

Osmotic dehydration is a very old technique that uses little energy but is very time consuming, the berry can easily contaminate, and basically the berry lose a lot of water soluble nutrients. The final product has a texture that people likes and also the berries get a sweet taste if the osmotic agent is sucrose.

Hot air drying is one of the common techniques to process berries. It makes a product with a long shelf life. Also has a good texture and flavor widely accepted by consumers, but it is very time consuming and energy demanding, however the equipment is cheap and is easy to build. One disadvantage is that the product lose many of its nutrients but not that much as the osmotic dehydration.

Freezing is in the middle of the way when comparing nutritional and sensory quality, microwave-vacuum drying and freeze drying are better, but hot air drying and osmotic dehydration are worst. The same situation happens with cost of the equipment. The biggest disadvantage is the storage and the transport because requires cold chain which is energy consuming and therefore not environmentally friendly.

9 Future research

My suggestion for future research is to compare the energy consumption but setting a common Aw value to get using all the drying methods investigated in this thesis, then will be more accurate the comparation of energy consumption, after this make a sensory and nutritional analysis of each product obtained to see which technology allow keep the majority of nutrients and the best texture, and finally keep a sample during a long time to see the shelf life. Depending on the degree of specificity wished the investigation could be applied to each berry. Additionally, it is important make a technical description of the machines used in the experiments.

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Appendix A: Qualitative Sustainability Checklist

Table 7 Checklist to assess sustainability performance with a life cycle perspective

1. Raw materials	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Is it possible to reduce the amount of raw material required by the process?							
Can the process result in reducing or eliminating…pesticides…fertilizers…biogenic emissions…used in primary production?							
2. Water	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the amount of water used be reduced?							
Can cleaning operations be optimized?							
3. Energy	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the electricity and/or heat needed for production treatment be reduced?							
Can the electricity and/or heat needed for cleaning operations be reduced?							
Is it possible to use energy coming from renewable resources?							
4. Packaging	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the process reduce the use of packaging material for primary packaging?							
Can the process reduce the use of packaging material for secondary packaging?							
Can the process reduce the use of packaging material for tertiary packaging?							
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in re-usable material?							
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in recyclable material?							
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in bio-degradable material?							
5. Transport	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	No	
Is it possible to decrease or eliminate…airfreight...cold...transports?							
Is it possible to reduce transport distances?							
6. Storage	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the need for cold storage be reduced or eliminated by products volume decrease thanks to the process?							
Can the need for cold storage be reduced or eliminated by storage duration decrease thanks to the process?							
7. Waste	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Is the process likely to reduce waste in relationship with perishable nature of food?							
Is the process likely to reduce waste in relationship with packaging?							
Is the process likely to reduce waste in relationship with cleaning operations?							
Is the process likely to reduce waste in relationship with production planning?							
Is the process likely to reduce waste in relationship with storage conditions?							
Is the process likely to reduce waste in relationship with consumer behavior?							

Is the process likely to reduce waste in relationship with supply chain coordination?							
8. Spatial planning	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	No	
Can the process prevent the establishment of new roads and/or factories on agricultural land of significance?							
Can the process prevent the transformation of natural land to agricultural land?							
Can the process lead to investment of new infra-structure in the community?							
9. Work	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the process contribute to better working conditions in terms of … working hours…air pollution…noise…smell…for employees?							
Can the process increase skills and level of knowledge among the employees?							
Can the process lead to the creation of new jobs?							
10. Health	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the process make the food healthier?							
Can the process improve food safety?							
11. Economy	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the process lead to new investments in the food chain?							
Can the production cost per kg of product be decreased by the process?							
Can the process improve the European export market?							
Can the process lead to an increased independency on imported raw materials?							
Can the process lead to an increased independency on imported energy?							
Can the process improve food security?							

Individual Quick Freezing vs Osmotic Dehydration

Table 8 Individual Quick Freezing vs Osmotic Dehydration Qualitative Sustainable Checklist

1. Water	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the amount of water used be reduced?			x				For IQF is recommended wetting the berries before passing them through the pre-chilling zone of the freezer (Eskom, 2022). However, osmotic dehydration requires the preparation of large quantities of osmotic solution to dehydrate the berries. (Shafiur, 2007)
Can cleaning operations be optimized?							This question will not be answered because cleaning operations are out of the scope of this thesis.
2. Energy	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the electricity and/or heat needed for production treatment be reduced?			x				To process berries osmotic dehydration is carried out at 20°C for 22 hours (Yang et al, 2021) while IQF is carried out at -40°C during 15 min per batch (Arteaga et al, 2021).
Can the electricity and/or heat needed for cleaning operations be reduced?							This question will not be answered because cleaning operations are out of the scope of this thesis.
Is it possible to use energy coming from renewable resources?			x				Yes, both unit operations can be supplied by energy coming from a renewable source (Spellman, 2016).
3. Packaging	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the process reduce the use of packaging material for primary packaging?				x		x	Primary packaging is the packaging that is in direct contact with the food (Mavinkere et al, 2021). It cannot be reduced neither in the process nor in downstream with either of the two methods.
Can the process reduce the use of packaging material for secondary packaging?				x		x	Secondary packaging includes boxes containing primary packages (Mavinkere et al, 2021). Compared technologies do not influence the amount of secondary packaging.
Can the process reduce the use of packaging material for tertiary packaging?				x		x	Tertiary packaging is used to protect secondary packaging, includes pallets and containers for warehousing (Mavinkere et al, 2021). Compared technologies do not influence the amount of tertiary packaging.
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in re-usable material?				x	x		For both unit operations is not possible re-use the packaging material, they use single-use plastics mostly of time, however the plastic can be recycled. (Robertson, 2013) On customer stage is possible re-use the single-use plastic until the product is finished. (Robertson, 2013)
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in recyclable material?			x				Yes, for both unit operations the most common package used is made of polypropylene (PP) which is fully recyclable (Robertson, 2013)
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in bio-degradable material?			x				Yes, for both unit operations is possible use biodegradable plastic packages made of polylactic acid (PLA). (Mihai & Holban, 2018)
4. Transport	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	No	
Is it possible to decrease or eliminate…airfreight...cold...transports?					x		Osmotic dehydration doesn´t need cold transport (Shafiur, 2007). So, this is an advantage of using osmotic dehydration.
Is it possible to reduce transport distances?							The reduction of the distances involves factors out of the scope of this thesis.
5. Storage	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the need for cold storage be reduced or eliminated by products volume decrease thanks to the process?					x		Osmotic dehydrated products doesn´t need cold storage (Shafiur, 2007). So, this is an advantage of using osmotic dehydration.

	Upstream yes	Upstream no	Process yes	Process no	Downstream yes	Downstream no	Comments
Can the need for cold storage be reduced or eliminated by storage duration decrease thanks to the process?					x		Osmotic dehydrated products doesn´t need cold storage (Shafiur, 2007). So, this is an advantage of using osmotic dehydration.

Individual Quick Freezing vs Drying Technologies (freeze-drying, microwave vacuum drying, convection hot air drying)

Table 9 Individual Quick Freezing vs Drying Technologies Qualitative Sustainable Checklist

1. Water	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the amount of water used be reduced?				x			Drying technologies don´t need water to work. For IQF is recommended wetting the berries before passing them through the pre-chilling zone of the freezer (Eskom, 2022).
Can cleaning operations be optimized?							This question will not be answered because cleaning operations are out of the scope of this thesis.
2. Energy	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the electricity and/or heat needed for production treatment be reduced?			x				Freeze-drying is an energy intensive unit operation because it requires a lot of energy to carry out the product freezing and the vacuum requirements (Singh & Heldman, 2009). To freeze-drying berries is needed a temperature of -60°C for 24h (Prosapio & Lopez, 2020) For use microwave vacuum drying with berries is needed 450 W with 5+/- 1 kPa during 8-10 minutes while hot air drying needs 60°C for 310 minutes (Zielinska & Danuta, 2019). IQF is carried out at -40°C during 15 min per batch (Arteaga et al, 2021).
Can the electricity and/or heat needed for cleaning operations be reduced?							This question will not be answered because cleaning operations are out of the scope of this thesis.
Is it possible to use energy coming from renewable resources?			x				Yes, the unit operations analyzed of this table can be supplied by energy coming from a renewable source (Spellman, 2016).
3. Packaging	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the process reduce the use of packaging material for primary packaging?				x		x	Primary packaging is the packaging that is in direct contact with the food (Mavinkere et al, 2021). It cannot be reduced either in the process or in the downstream with any of the compared technologies.
Can the process reduce the use of packaging material for secondary packaging?				x		x	Secondary packaging includes boxes containing primary packages (Mavinkere et al, 2021). Compared technologies do not influence the amount of secondary packaging.
Can the process reduce the use of packaging material for tertiary packaging?				x		x	Tertiary packaging is used to protect secondary packaging, includes pallets and containers for warehousing (Mavinkere et al, 2021). Compared technologies do not influence the amount of tertiary packaging.
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in re-usable material?				x	x		For these unit operations is not possible re-use the packaging material, they use single-use plastics mostly of time, however the plastic can be recycled. (Robertson, 2013) On customer stage is possible re-use the single-use plastic until the product is finished. (Robertson, 2013)

Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in recyclable material?			x				Yes, for these unit operations the most common package used is made of polypropylene (PP) which is fully recyclable (Robertson, 2013)
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in bio-degradable material?			x				Yes, for these unit operations is possible use biodegradable plastic packages made of polylactic acid (PLA). (Mihai & Holban, 2018)
4. Transport	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	No	
Is it possible to decrease or eliminate…airfreight...cold...transports?					x		Frozen berries must be stored at -18°C (Hui, 2005). Dried food products don´t need cold storage (Sinha et al, 2012).
Is it possible to reduce transport distances?							The reduction of the distances involves factors out of the scope of this thesis.
5. Storage	Upstream		Process		Downstream		Comments
	yes	no	yes	no	yes	no	
Can the need for cold storage be reduced or eliminated by products volume decrease thanks to the process?					x		Frozen berries must be stored at -18°C (Hui, 2005). Dried food products don´t need cold storage (Sinha et al, 2012).
Can the need for cold storage be reduced or eliminated by storage duration decrease thanks to the process?					x		Frozen berries must be stored at -18°C (Hui, 2005). Dried food products don´t need cold storage (Sinha et al, 2012).