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VALORISATION OF GRAPE MARC THROUGH SUPERCRITICAL CO2 EXTRACTION: A SUSTAINABLE APPROACH TO PRODUCING HIGH-QUALITY GRAPESEED OIL IN LA RIOJA

12 PRODUCCIÓN Y CONSUMO RESPONSABLES

Estudiante: Larrazabal Epalza, Andoni

Director/Directora: Herrero Villalibre, Saioa

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Valorisation of Grape Marc Through Supercritical CO2 Extraction: A Sustainable Approach to Producing High-Quality Grapeseed Oil in La Rioja

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Odense, Denmark

Author: Andoni Larrazabal Epalza

Supervisors: Massimiliano Errico, Rime Bahij

Este proyecto busca analizar la viabilidad técnica y económica de la implantación y producción de una planta de extracción supercrítica con CO_2 de aceite de pepita de uva. La pepita de uva es uno de los restos sólidos más abundantes que se producen como producto secundario en el proceso de vinificación. Mediante un proceso de acondicionamiento del orujo de uva y un proceso de extracción semi continuo, se transforma el orujo de uva, un producto poco apreciado y que históricamente se ha quemado o desechado, en aceite de pepita de uva, producto de alto valor tanto para la industria cosmética y farmacéutica como para la industria alimenticia.

This project aims to analyze the technical and economic feasibility of implementing and producing a supercritical CO_2 extraction plant for grape seed oil. Grape seeds are one of the most abundant solid residues produced as a by-product in the winemaking process. Through a process of conditioning the grape pomace and a semi-continuous extraction process, grape pomace, a low-value product that has historically been burned or discarded, is transformed into grape seed oil, a high-value product for the cosmetic, pharmaceutical, and food industries.

Proiektu honek mahats-hazien olioa lortzeko, CO_2 extrakzio superkritikoa erabiliko duen planta baten ezarpenaren eta ekoizpenaren bidegarritasun teknikoa eta ekonomikoa aztertzea du helburu. Mahats-hazia ardogintzan bigarren mailako produktu gisa sortzen den hondakin solido ugarienetariko bat da. Mahats-muxarra prestatzeko prozesu baten eta erausketa erdi jarraitu baten bidez, balio txikiko produktu hau, historikoki erre edo bota dena, mahats-hazien olio bihurtzen da. Produktu hau balio handikoa da kosmetika, farmazia eta elikagai industrietarako.

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1. Introduction

1.1 Context and Justification

The wine industry generates a significant amount of solid waste during the winemaking process. The most abundant solid waste is known as grape marc or grape pomace. Traditionally, this waste has been burned or used as feed for livestock. However, recent studies have shown that these residues contain high-value compounds such as dietary fibres, oils, and polyphenols, which have multiple industrial applications. The valorisation of these wastes presents not only a significant economic opportunity but also contributes to environmental sustainability by reducing the amount of industrial waste.

In the last decade, there has been growing interest in the reutilization of grape residues. For example, the phenolic compounds extracted from grape marc are used for their antioxidant properties, which are beneficial in the prevention of cardiovascular diseases and other chronic conditions. Additionally, grapeseed oil is highly valued in the food and cosmetic industries for its high content of unsaturated fatty acids and natural antioxidants.

1.2 Objectives

The main goal of this project is to evaluate the economic feasibility of a grape seed oil extraction plant that uses supercritical carbon dioxide (supercritical CO_2) as a solvent. This extraction method cold compete with conventional techniques of extractions with organic solvents, offering a higher quality product and eliminating the necessity for additional stages of distillation and solvent refinement. This project intends to focus on the production of this high-quality oil. The implementation of this technology not only enhances the economic value of grape residues but also contributes to the sustainability of the wine industry. The Sustainable Development Goal that this project will enhance the most will be SDG12: Ensure sustainable consumption and production patterns.

1.3 Extraction Method with Supercritical CO2

The CO_2 supercritical extraction is an advanced technique that utilises carbon dioxide in its supercritical state to dissolve and extract valuable compounds from vegetable materials. This method is particularly advantageous due to the non-toxicity of the CO2, the solvent used, which is also non-flammable and easy to eliminate from the final product. Additionally, the supercritical CO2 extraction allows for the production of high purity and quality products, which is especially relevant for applications in the food, pharmaceutical, and cosmetic industries.

1.4 Economic Feasibility and Sustainability

This project will not only focus on the technical description of the extraction process, but it will also analyse the economic feasibility of the proposed production plant. The evaluation will include installation and operation costs. With this economic feasibility, the project intends to find out if producing grapeseed oil at industrial scale with supercritical CO2 extraction can be profitable. For this, the plant should be able to sell the product at a competitive price and have enough income to return the initial investment in the span of 10 years.

2. Life cycle of grapes and their waste

2.1 Description of the Wine Production Process and Waste Generation

The production of wine goes from the planting of the vine to the bottling of the wine. The first phase of wine production starts by planting the vines. Usually, vines are grown in areas with sufficient sunlight and a long growing season, which is why the southern part of Europe has a long winemaking tradition.

The planting of the vines is most frequent in spring, although this may vary depending on the region and grape variety. Once planted, the vines require constant care, such as pruning, irrigation, fertilization, and pest and disease control.

Harvesting the grapes, also known as the vintage, happens once grapes reach the desired maturity level. This can be done manually or mechanically. Once harvested, grapes are transported to the winery to start what is called the vinification process, that is the process by which grapes, more specifically their juice, is transformed into wine.

The first step is the selection of the grapes, where badly damaged grapes are discarded. Then, the grapes are lightly crushed to release their juice, the must, that contains the sugar that will ferment into alcohol.

Here we need to address the difference between red and white wine production. For red wines, the must is fermented without separating the juice from the seeds, skins, and pulp. Conversely, for white wines, the crushed grapes are pressed immediately to separate the juice from the skins and seeds before fermentation.

Then, the must is transferred to fermentation vessels, which are traditionally made of oak but can also be made of stainless steel or concrete. In these vessels is where the alcoholic fermentation happens, where yeasts transform the sugars of the must into alcohol and carbon dioxide. In many cases, an additional malolactic fermentation is carried out, where bacteria transform malic acid into lactic acid.

For red wines there is an additional step called maceration. In the maceration, the must remains in contact with the grape skins and seeds. White wines undergo no maceration or a very little one.

After fermentation and maceration, pressing can be performed to obtain more wine from the skins, seeds, and remaining pulp. In many cases this pressed wine and the wine that was gotten before, called free wine, are mixed in concrete proportions to obtain a specific result.

Next, the wine undergoes an aging process, which can happen in oak barrels or stainless-steel tanks. Then, the aged wine undergoes a clarification and stabilization process. Tartaric stabilization is performed to prevent the formation of tartrate crystals in the bottle, while microbiological stabilization prevents unwanted fermentation and contamination.

The final process is bottling, where wine is sealed into bottles. Before this step, final touches may be given to the wine such as adding sulphites for preservation, or a final filtering (Muhlack, Potumarthi, & Jeffery, 2017).

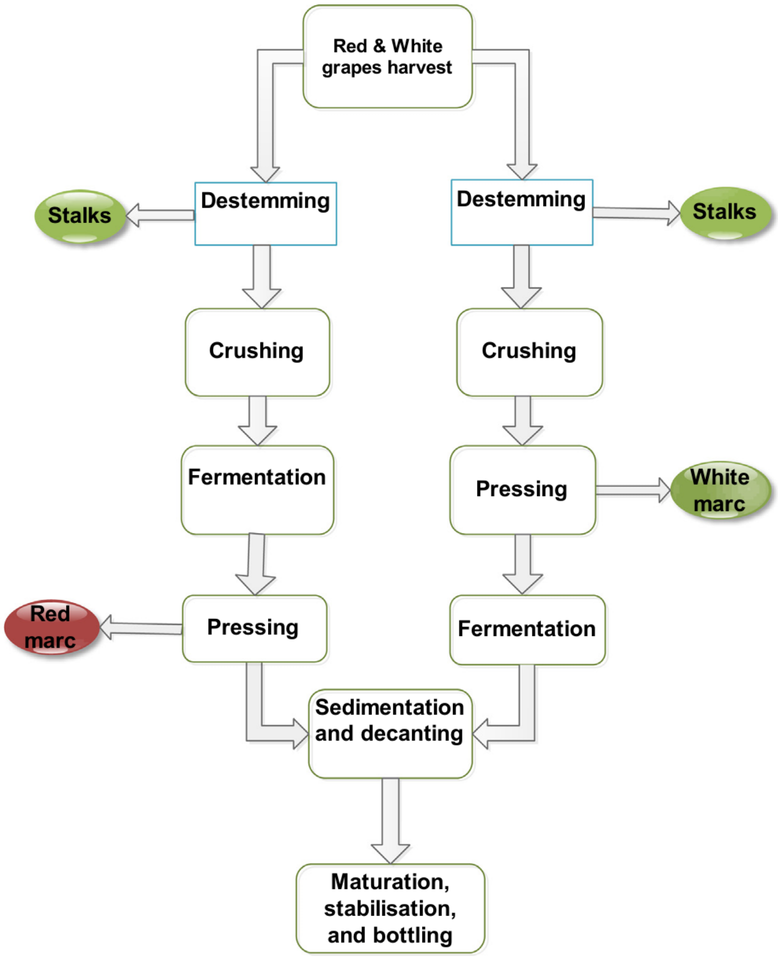


Figure 1. Diagram of the vinification process and the waste generated.

During this lengthy process, big amounts of organic waste are generated. During the maintenance of the vineyard, particularly in the pruning season, great amounts of plant waste are generated from the vine cuttings. This waste can be left to decompose naturally, used as mulch, or composted. It can also be revalorized for bioenergy production.

When grapes are harvested, leaves, stems and damaged grapes are removed. During the sorting process additional grapes are removed. This waste can be composed, used as mulch and some parts can be used to feed livestock. After the destemming process, stalks are removed, which can be used to produce biomass products.

In the vinification process, the main solid waste is the grape marc or pomace. Grape marc is mainly composed of grape skins, seeds, and pulp. It is generated after the crushing and pressing, which happens at different stages for red and white wine. The use of grape marc will be described in detail in the next section, as it is the main waste considered in this project; but it is mainly used as compost, livestock feeding, distillation or grapeseed oil production.

During fermentation, carbon dioxide is generated. Additionally, yeast lees, which are dead yeast cells, accumulate at the bottom of the fermentation tanks. CO_2 can be captured in this process and used for industrial purposes, while lees can be used as fertilizer or added to compost among other uses.

In the clarification and stabilization processes, spent fining agents and precipitated solids are generated. Normally these are composted or disposed.

The next table summarises the waste generated during each step of the winemaking process and its current uses.

Table 1. Summary of the waste generated in the vinifcation process.

Step	Waste Generated	Management
Pruning	Vine cuttings	Composting, mulching, bioenergy
Harvesting	Leaves, stems, unripe or damaged grapes	Composting, mulching, animal feed
Destemming	Stalks, unsuitable grapes	Composting, animal feed, biochar
Crushing and Pressing	Grape marc (skins, seeds, pulp)	Composting, animal feed, grape seed oil production, distillation
Fermentation	Carbon dioxide, yeast lees	CO_2 capture, composting of yeast lees
Clarification and Stabilization	Spent fining agents, precipitated solids	Composting, special disposal

2.2 Characterization of Grape Marc and current uses

2.2.1 Composition of Grape Marc

The main solid waste of the vinification process is grape marc or pomace. This waste can account for 20% of the weight of the grapes used for vinification on average. Grape marc is composed of a heterogeneous mixture of different components, which vary in proportion depending on factors such as grape variety, cultivation conditions, and processing methods. Below is a detailed characterisation of the main components of grape marc (Muhlack, Potumarthi, & Jeffery, 2017):

Polyphenols

Polyphenols are naturally occurring compounds found in plants, particularly abundant in fruits and vegetables. They are known for their antioxidant properties and contribute to the colour and taste of many foods and beverages. Polyphenols include flavonoids, phenolic acids, and tannins.

- Flavonoids**:** Include anthocyanins, flavonols, and flavanones. Anthocyanins are responsible for the red and purple colours of grapes and have potent antioxidant properties.
- Phenolic Acids**:** Such as gallic acid, ellagic acid, and caffeic acid, which also contribute to the antioxidant capacity of the grape marc.
- Tannins**:** Astringent compounds found in the skins and seeds, used in wine production and known for their health benefits.

Dietary Fibre

Dietary fibre consists of plant-based carbohydrates that are not fully digested by the human body. It is classified into two types: insoluble fibre and soluble fibre. Dietary fibre is found in fruits, vegetables, whole grains, and legumes.

- Insoluble Fibre: Includes cellulose, hemicellulose, and lignin, which help promote bowel regularity and prevent constipation.
- Soluble Fibre: Includes pectins and beta-glucans, which can help lower cholesterol levels and regulate blood sugar levels.

Oils

Fatty acid composition:

- Linoleic Acid (omega-6): Constitutes approximately 60-70% of grape seed oil.
- Oleic Acid (omega-9): Accounts for around 15-20%.
- Other Fatty Acids: Include palmitic acid and stearic acid in smaller proportions.

The oil content in grape seeds can vary between 10-20% of the dry weight of the seeds. This is the product that this project intends to produce. Its composition varies depending on the extraction method used among other factors.

Proteins

Contains essential amino acids such as lysine, leucine, and valine. Proteins represent approximately 10-15% of the dry weight of grape marc.

Residual Sugars

Includes glucose, fructose, and small amounts of other monosaccharides and polysaccharides. Residual sugars can account for around 5-10% of the dry weight of grape marc.

Minerals

The main present minerals are potassium, calcium, magnesium, and iron. The concentration of minerals can vary, but generally, grape marc is a good source of potassium and calcium.

General composition of grape marc

All the compounds mentioned above are located heterogeneously among the grape marc. The product that this project is seeking to extract is the oil. The oil that is contained in the pomace can be found in the seeds. On a dry basis, grape marc consists of 51% skins, 47% seeds and 2% stalks (Jordan, 2002).

Considering regular grape marc, which is what our plant will be purchasing, seeds account for approximately 25% in weight of the grape marc. This means that 25% of the weight of this waste can be used as raw material for the extraction plant. To be conservative, this proportion will be lowered to 20% during the project. According to H. Sovová et. al, 12.6% in weight of the grape seeds consists of oil. Other authors give similar results (Burg, Vítěz, Turan, & Burgová, 2014). (Sovová, Kučera, & Jež, 1993)

Composition of grapeseed oil

Table 2. Chemical composition of grape seed oil obatained by supercritical fluid extraction.

Table 3
Chemical composition of grape seed oil obtained by supercritical fluid extraction.

	PS[a]					Codex Alimentarius
	S_1^b (60 min)	S_2^c (60 min)	S_1^b (300 min)	S_2^c (300 min)	TC[d]	
HPSEC (%)						
Triacylglycerols + diacylglycerols	97.90	72.14	98.98	97.17	98.27	
Monoacylglycerols + free fatty acids	2.10	27.86	1.02	2.83	1.73	
Fatty acid composition (%, w/w)						
Octanoic C (8:0)		0.23		0.03		ND[e]
Decanoic C (10:0)	0.03	0.71		0.03	0.02	ND
Dodecanoic C (12:0)	0.04	0.74		0.04	0.03	ND
Tetradecanoic C (14:0)	0.14	0.69	0.08	0.12	0.11	<0.30
Pentadecanoic C (15:0)	0.03	0.10		0.04	0.02	
Hexadecanoic C (16:0)	8.57	13.32	7.50	8.56	8.13	5.5–11.00
cis-9-hexadecanoic C (16:1)	0.19	0.57	0.13	0.18	0.15	<1.2
Heptadecanoic C (17:0)	0.07	0.11	0.07	0.07	0.07	<0.2
cis-heptadec-9-enoic C (17:1)	0.02		0.02	0.03	0.03	<0.1
Octadecanoic C (18:0)	3.81	4.21	4.45	4.07	4.05	3.0–6.5
cis-9-octadecenoic C (18:1)	14.75	13.55	15.63	15.28	15.10	12.0–28.0
cis-9,*cis*-12-octadecadienoic C (18:2)	71.23	63.25	70.95	70.39	71.20	58.0–78.0
All-*cis*-9,12,15-octadecatrienoic C (18:3)	0.62	1.67	0.52	0.58	0.57	<1.0
Eicosanoic C (20:0)	0.20	0.26	0.28	0.23	0.22	<1.0
cis-9-eicosanoic C (20:1)	0.15	0.15	0.22	0.16	0.18	<0.3
Docosanoic C (22:0)	0.09	0.26	0.08	0.11	0.07	<0.5
Tetracosanoic C (24:0)	0.06	0.18	0.07	0.08	0.05	<0.4

[a] Pilot scale.
[b] Separator 1.
[c] Separator 2.
[d] Total collection.
[e] non-detectable, defined as <0.05%.

According to the work of A. Molero Gómez et. al., who characterised the composition of grapeseed oil depending on the different methods of extraction, grapeseed oil has different properties depending on the method of extraction. For this project, the extraction method will be supercritical CO_2 with similar temperatures and pressures, which ensure the quality of the oil remains intact and does not leave traces of hexane on the oil. In their work they also characterised the fatty oil composition of the oil (Molero Gómez, Pereyra López, & Martínes de la Ossa, 1994).

Table 3. Comparison of properties of extracted grape seed oils obtained using hexane and supercritical carbon dioxide.

Physicochemical parameter	Extraction method		Standard for refined oil [17]
	CO_2, 350 bar, 40 °C, 3 h	Hexane, Soxhlet, 20 h	
Refractive index	1.475	1.474	1.473–1.475 (25 °C)
Density (g ml^{-1})	0.924	0.928	
Viscosity (cP)	69	66	
Absorbance at 290 nm (IgE)	2.730	3.177	
Free fatty acid (%)	3.4	33.8	⩽0.2 (oleic acid)
Iodine index (g per 100 g)	98	124	125–150
Saponification index	259	289	185–196
Unsaponifiable fraction (%)	0.27	2.89	
Peroxide index (meq per kg)	383	101	⩽10

Table 4. Fatty acid composition of oil extracted using hexane and supercritical carbon dioxide.

Oil	Fatty acid composition (%)					
	Palmitic C16:0	Palmitoleic C16:1	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3
Hexane, Soxhlet, 20 h	8.12	0.15	5.60	19.59	66.16	0.37
CO_2, 350 bar, 40 °C, 3 h	8.03	0.15	5.07	19.06	67.39	0.30
Refined oil [17]	5–10	⩽1.2	3–5	12–26	58–77	⩽1

The study of these investigators showed that with hexane or other organic solvents, the yields that the extraction can get will always be higher because the hexane is non selective for triglycerides, extracting free fatty acids, phospholipids, pigments and unsaponifiable substances together with tryglicerides. They also reported the difference in composition of the oil extracted by SFE depending on the extraction time. However, the conclusion of this study is what makes it interesting for the project. The quality of grapeseed oil extracted by SFE is similar to that of oil extracted by organic solvent and then refined and the refining process is not needed with SFE. This means that the composition of the oil extracted in this project can be considered as good quality oil even without a refining process. Additionally, according to Prado et. al., extracting oil with supercritical CO_2 is more selective for vitamin E extraction, which is a powerful antioxidant (Prado, y otros, 2012).

2.2.2 Current Uses of Grape Marc

Animal Feed:

Grape marc can be used as forage for livestock, providing a source of nutrients and dietary fibre. Including grape marc in the diet of livestock has been shown to improve digestion and overall animal health.

Biofuel Production:

The residual sugars in grape marc make it suitable for producing biofuels such as bioethanol. Additionally, the oils extracted from the seeds can be converted into biodiesel.

Industrial Applications:

The polyphenols and other bioactive compounds extracted from grape marc have applications in the pharmaceutical and cosmetic industries. These compounds can be used in the formulation of antioxidant, anti-inflammatory, and antimicrobial products.

Composting and Soil Improvement:

Grape marc can be composted to produce a nutrient-rich organic fertiliser. This compost can improve soil quality, increase its water retention capacity, and provide essential nutrients for plants.

Functional Food Production:

The dietary fibre and polyphenols present in grape marc can be used in the production of functional foods, which offer health benefits beyond basic nutrition. These include cereal bars, dietary supplements, and bakery products.

2.2.3 Disposal Methods of Grape Marc

Burning:

Burning grape marc releases greenhouse gases and other pollutants into the air, contributing to environmental pollution and climate change. The combustion process emits carbon dioxide, methane, and other harmful gases, negatively impacting air quality and public health. Many regions regulate the burning of agricultural waste to minimise these environmental impacts.

Landfills:

Disposing of grape marc in landfills generates several environmental issues. Transport and landfill fees represent significant costs for producers, making this method less economically attractive.

Composting:

Composting transforms grape marc into organic fertilisers, reducing the need for chemical products. The waste decomposes in a controlled manner, producing compost that can be used in agriculture. This method reduces waste from landfills and recycles it by using it for agriculture.

2.2.4 Current uses of Grapeseed oil

This product is appreciated in various industries. Its demand has been growing the last years as consumers become more and more conscious about which vegetable oils are more harmful and which one are healthier, as it happened with palm tree oil, that has been labelled as unhealthy, while other options such as avocado seed oil or olive oil keep growing in demand.

One of the uses of grapeseed oil is as lubricant. For this cases, lower quality oil is used, so the oil that our project would produce would not cover this market, as the selling price will be higher.

In the pharma and food industry, this oil is known because of its benefits to cardiovascular health. Its high content in the fatty acids omega-6 and fitosterols contributes to reducing LDL and increasing HDL (commonly known as good and bad cholesterol respectively).

In the health industry, specifically in the skin care industry, grape seed oil is used for massages and also as part of skin care routines. In fact, the highest selling prices for grapeseed oil when investigating for this project have been found in skin care webpages, where 100ml recipients can be sold for 13€, which gives a price of 130€/L.

These two markets, the food and pharma industry and the cosmetic industry, are the main targets of our product. The quality of the product needs to be high enough to provide to sellers in these markets, as they have the highest selling prices.

3. Market research

3.1 Current methods of production

Grapeseed oil is produced in different ways. Traditional methods include cold pressing and extraction with organic solvents, such as hexane. The cold pressing method is a mechanic process that requires no heating or chemical treatment, which preserves the original flavour of the oil. This method doesn't have the best efficiency, getting less than 9% in weight. The extraction with solvents is more efficient. It has an efficiency of around 10%, but it requires more extraction time and the use of organic solvents. Additionally, this method can leave traces of the solvent in the oil, which is undesired. It can also be dangerous to produce due to the flammable nature of the solvent.

These disadvantages are not present in the supercritical CO_2 extraction method. It is a more advanced method that uses CO_2 as a solvent and not only preserves the biocomponents properly but also leaves no traces of solvent in the oil. This is a more costly and complex method, but it can improve the efficiency. However, the equipment used needs security certifications, as it is a high-pressure process.

There are other not so used methods such as the extraction by microwaves, mechanical extractions other than cold pressing, and enzyme extraction. These are less present in the market but are useful for specific needs; for example, the enzyme extraction is a very selective method as it offers a high specificity in oil extraction.

3.2 Main producers

Although it has been difficult to find specific data regarding the grape seed oil market, according to europages, the most important exporter of grape seed oil is Spain, followed by Italy and France. Although this market is not widely documented, we may take the wine industry and use it as a reference to estimate how much grape pomace is produced. This way we can have an idea of the countries with most availability of raw material for grapeseed oil production. The wine production industry is massive, and the biggest producers are currently Italy, France and Spain. These are the biggest producers according to a report by the "Organización Internacional de la Viña y el Vino" (OIV) and the amount of grape they produce:

Table 5. List of top grape producers and their grape production in 2022.

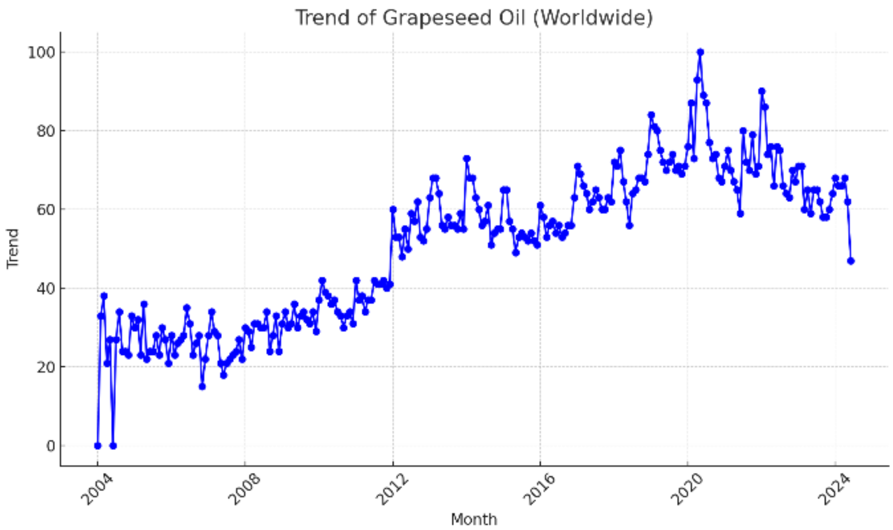
Country	Grape production (tons)
Italy	8,200,000
France	6,900,000
Spain	6,600,000
United States	6,200,000
China	5,800,000
Turkey	4,200,000
Argentina	2,500,000
Chile	2,400,000
Australia	1,700,000
South Africa	1,200,000

With this data in mind, the rough data europages can provide makes sense, as the top producers of wine are the top exporters of grapeseed oil. In fact, these three regions dedicate at least 60% of their grape production to winemaking, which is where grape marc is produced. Therefore, it is logical to think that these countries might be the top producers for this oil.

3.3 Grapeseed oil consumer demand

When researching for this project, every paper that did inquiries around grape seed oil, because they were documenting its process, its composition, or just mentioning it as one of the uses of grape mark to avoid disposal, mentioned that grapeseed oil is a product with growing demand. This has been seen in papers from 2001 and also in more recent papers; however, it has been difficult to find any sources or any conclusive data around the size of the market or the consumption of this oil.

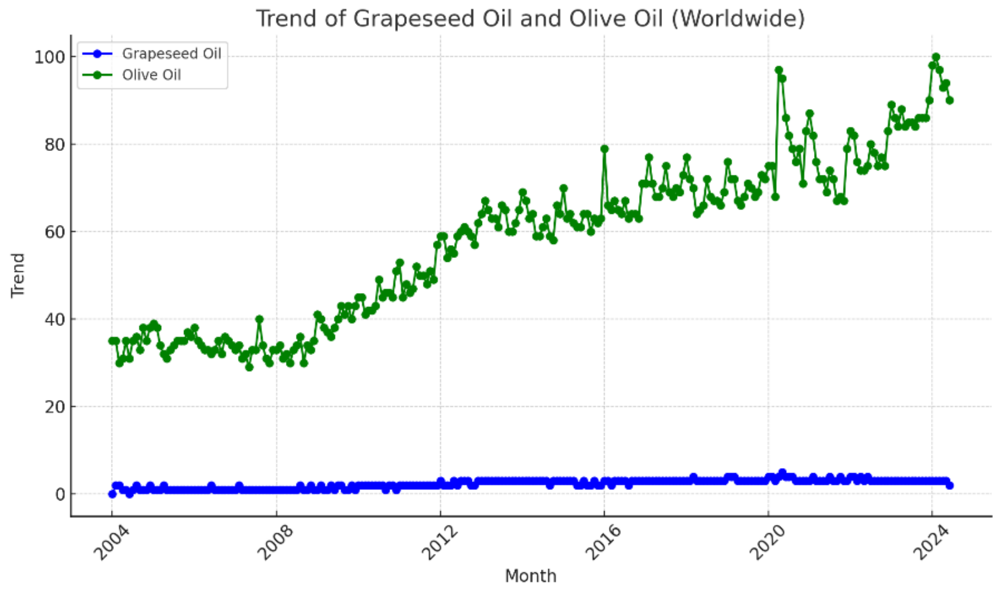
Trying to figure out if this growing demand was real, I decided to find if the searches for "grapeseed oil" around the world were growing or not. By using Google's "Trends" tool, I looked for the popularity of this term from 2004 up to today and elaborated a graph from the csv file[1].



Graph 1. Trend of the term Grapeseed Oil

[1] It needs to be noted that when "Google Trends" gives a score to a term, it is relative to all other searches, which means that it accounts for more and more users looking online. When a term is graphed alone, it measures its most popular point as 100 and gives a score relative to that for the other points.

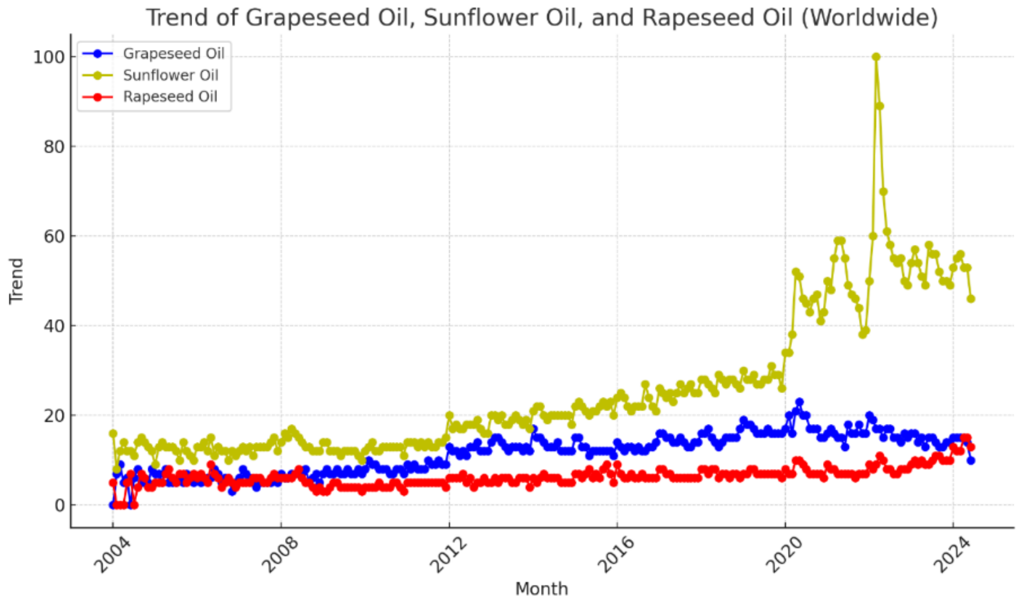
This graph showed that the term “grapeseed oil” has been becoming more popular at least until 2022. However, this needed to be compared to a much more popular term in order to correctly measure the popularity of this search.[2]



Graph 2. Comparison of the trends Grapeseed Oil and Olive Oil

Now, compared to olive oil, which is the most popular cooking oil that is considered healthy, grapeseed oil is a clear loser. Then, I decided to compare the search with other not so popular oils, such as sunflower oil or rapeseed oil, which I felt were less likely to be bought online and more likely to be purchased in a supermarket.

[2] When two or more terms are compared in “Google Trends”, it compares the terms’ popularity with each other.



Graph 3. Comparison of the trend of the terms Grapeseed Oil, Sunflower Oil and Rapeseed Oil

From this graph, it can be seen that, even though the term "grapeseed oil" is less popular than sunflower oil, it is indeed more popular than rapeseed oil. It can also be seen that every vegetable oil has seen some growing over the las 15 years in popularity. Therefore, it can be acceptable to consider that grapeseed oil demand is growing.

4. Supercritical Carbon Dioxide Oil Extraction Plant

4.1 Description of the process

The main goal of the extraction is to obtain the oil that the seeds contain. This oil accounts for 12.6% (w/w) of the seeds. However, our raw product is not seeds but grape marc. In order to perform the extraction, the seeds, which will become the substrate of the extraction, need to be separated from the skins and stalks. Therefore, the process can be divided into two stages:

- Substrate conditioning: This stage wants to separate and grind the seeds in the grape marc. It is divided into three steps.
  - Drying.
  - Mechanical sieving. This means separating the seeds from stalks and skins.
  - Milling.
- Supercritical fluid (CO2) extraction: This stage is where the oil is extracted from the seeds. It has two steps.
  - Extraction. The oil is dissolved in the solvent (CO2).
  - Separation. The oil is separated from the solvent and decanted.

The whole process obtains four products. Stalks and skins from the sieving, and seed powder and oil from the supercritical extraction. In the following more detailed description of the process, this project will mention a purpose for each of these products.

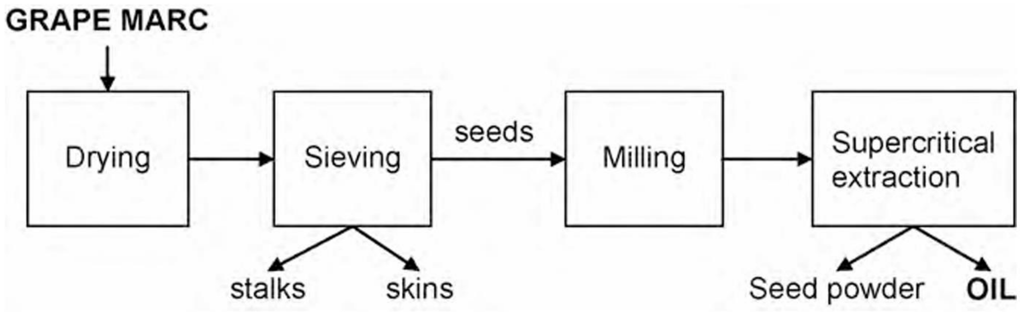


Figure 2. The path of the products through the plant.

4.1.1 Substrate conditioning

The first step is receiving the grape marc into the storage unit. The transport will be performed by trucks, and the pomace will be stored in an industrial area that is not enclosed so that the air can flow. For this reason, the plant needs a truck bay, to perform the loading and unloading operations.

Then, the grape marc, consisting of seeds, stalks, and skins, needs to be dried. This step is crucial, because if the humidity is not low enough the separation will not be effective. This step can be done in two ways. The first option is to partially dry the pomace in the sun and then finish the process in the oven. The second option is to dry the grape marc directly in the oven. Due to the location of the plant, which is in the region of La Rioja, the second option is more attractive. The climate in the north of Spain is rainy and humid, so drying the pomace in the sun is not a guarantee.

Figure 3. Location of La Rioja in Spain

The equipment to perform the industrial drying will be a rotating drum dryer. This machine needs a source of heat. The key point here is using the grape stalks and skins that will be separated from the grape marc in the next step as fuel for the furnace. This way, the totality of the stalks can be disposed while taking advantage of them. Some part of the skins also needs to be used to feed the furnace. Therefore, the heat source of the dryer will be a biomass combustor that will use the residues from the mechanical separation as fuel. It needs to be noted that the combustor will need to be started by gas and that at the beginning of the process, as none of the marc will be ready to burn, the first dying operations need to be performed using other fuels.

The next step is to separate the seeds from the stalks and the skins. The current product is dry grape marc. To perform the separation the plant will use mechanical sieves, which are vibrating screens that have different diameter holes and will let through the items depending on their size. This will separate the three components of the pomace into different streams, to use them as needed. In this case, the totality of the stalks will be directed to the biomass combustor with the number of skins that become necessary. The exceeding skins can be used to feed livestock. The seeds will continue their conditioning journey into the mill (Duba & Fiori, 2014).

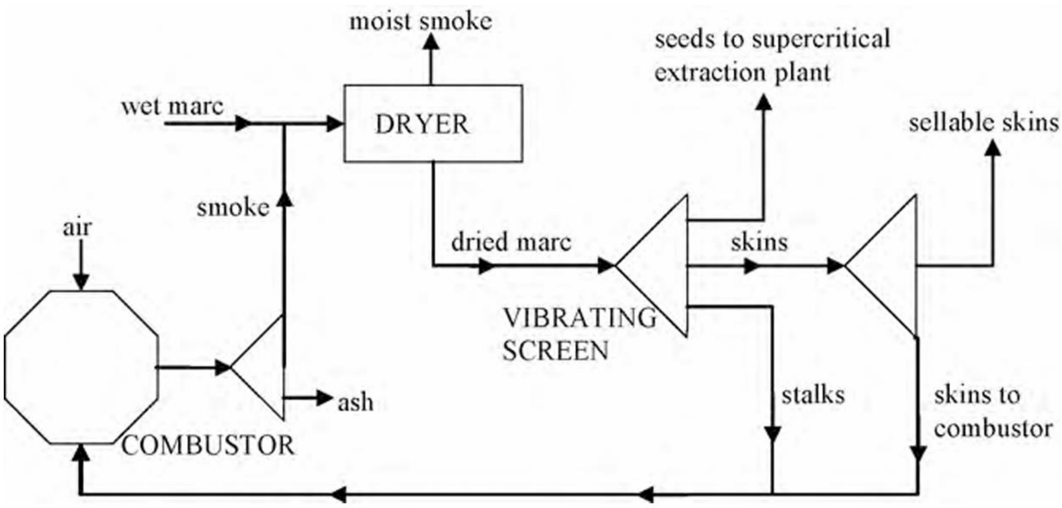


Figure 4. Diagram of the drying and separating operations of the plant.

The mill will produce seed powder. This will be the substrate of the extraction. This will not only help break the cells but also ensures better contact with the solvent and an overall better yield for the extraction.

4.1.2 Supercritical Fluid Extraction with CO2

Once the substrate has been conditioned it will arrive to the extraction plant. Here is where the oil will be extracted from the grinded grape seeds. Supercritical extraction is a batch process, which means that it must be done in batches and not in a continuous way. To maximise productivity, supercritical extraction plants usually use double, triple, or quadruple extraction systems, in order to obtain a semi-continuous process. This plant will use a triple extraction system.

The supercritical CO_2 extraction is a method used to extract compounds from materials, typically plants. The aim is to dissolve the compounds, in this case the oil, into the CO_2. This is possible because in its supercritical state, CO_2 combines characteristics of gases and liquids: it can diffuse through solids as if it was a gas, but it will dissolve the compounds as a liquid would. This is interesting because it is able to solubilize a wide range of compounds while benefitting from enhanced penetration thanks to the diffusion.

This is the equipment needed to perform the triple extraction:

- 3 extraction vessels.
- 2 separators.
- 3 heaters.
- 1 condenser.
- 1 cooler.
- 1 CO2 pump.
- 1 CO2 supply vessel.
- 1 CO2 storage tank.

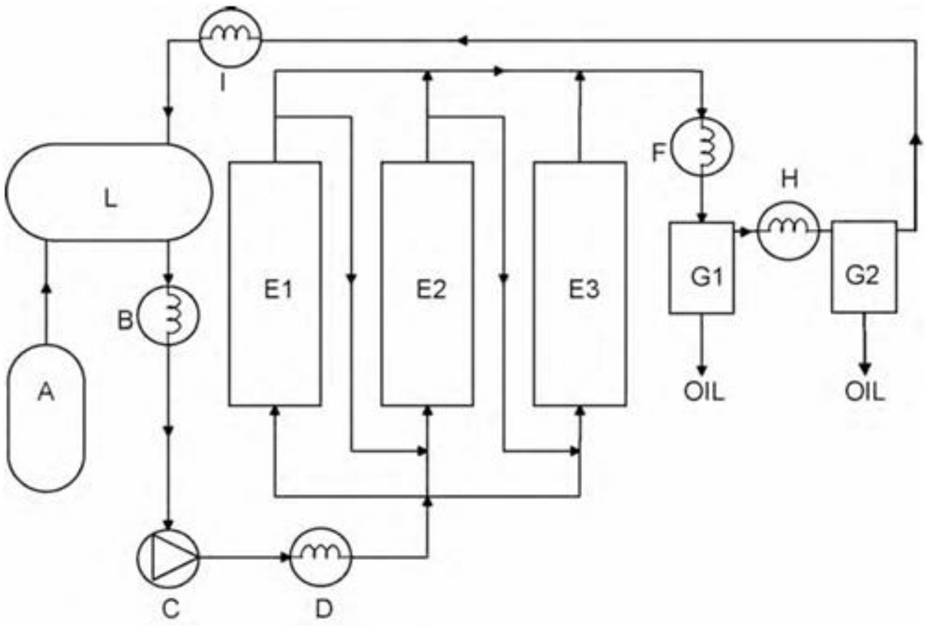


Figure 5. Diagram of the supercritical extraction unit.

To perform the extraction, the seeds will be placed into the extraction vessels. They will be transported by a convey or mechanical system. Once the extraction vessel is filled, it is closed and the pressure inside is increased. To explain the rest of the process it is interesting to follow the path of the CO_2.

First, the CO_2 exits the tank. This CO_2 is in liquid state. Therefore, it is first cooled and then pumped to increase its pressure. Then, the CO_2 is heated to the right temperature. This temperature needs to be high enough to ensure solubility but not so high that it compromises the quality of the compounds in the oil. After the CO_2 is heated, it goes into the extraction vessels, where the substrate is located.

Here, the solvent passes through the milled seeds and dissolves the oil. Then, the solution is cooled and transported to the separators, where the oil is separated from the CO_2. To completely eliminate the oil from the solvent, there is a two-step separation process. The second separator works at 60 bar, a low pressure where the solvent nature of CO_2 disappears. The oil is decanted and stored.

Then, the CO_2 leaves this evaporator in a gaseous state thanks to the previous heating in a gaseous state. From here, it is transported to a condenser, where it becomes liquid again and then it arrives to the storage tank again. Here the cycle is closed.

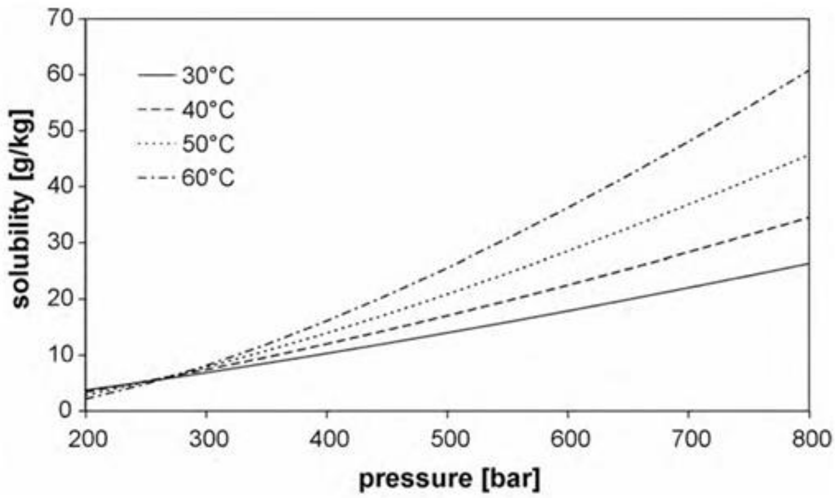
When the extraction vessels are depressurised and opened to insert the milled seeds and extract the exhausted substrate, some CO_2 is lost in the process. To account for such loses, the CO_2 storage tank is connected to a CO_2 supply tank, that will provide any lost CO_2. To minimise these loses, a small compressor transports the CO_2 to the storage tank, and therefore depressurises the vessel, prior to its opening.

Finally, once the extraction process is over, the extraction vessel is opened, and the exhausted seed powder is substituted by new substrate.

The process has been described for a batch. However, this plant will have three extractors working simultaneously. At a given time, two of them will be performing the extraction. Meanwhile, in the other extractor, other tasks will be performed, such as depressurising the vessel, opening it to extract the substrate and filling it up again, and pressurising again. Then, while this third extractor enters the extracting cycle, one of the other two will have concluded the extraction, and the refilling tasks will begin again. And of course, when this second extractor finishes the refilling tasks, the remaining extractor will have concluded its cycle. This way the worker responsible for the machine will be active the whole time and the extractors will be paused for as little time as possible. Each extracting cycle will take two hours, while the depressurizing, refilling and pressurising will take one hour.

4.1.3 Process details

Supercritical extraction can be done in a range of pressures and temperatures. For vegetable oils rising the temperature of the extraction can improve the yield and lower the extraction time. However, the temperature needs to be lower than a threshold in order to obtain oil of maximum quality. This is because rising the temperature ruins some bioactive compounds of the oil. In the next figure, the solubility of vegetable oils in CO2 as a function of pressure and temperature is shown (del Valle & Aguilera, 1988).



Graph 4. Effect of temperature and pressure in oil sulibility in supercritical carbon dioxide.

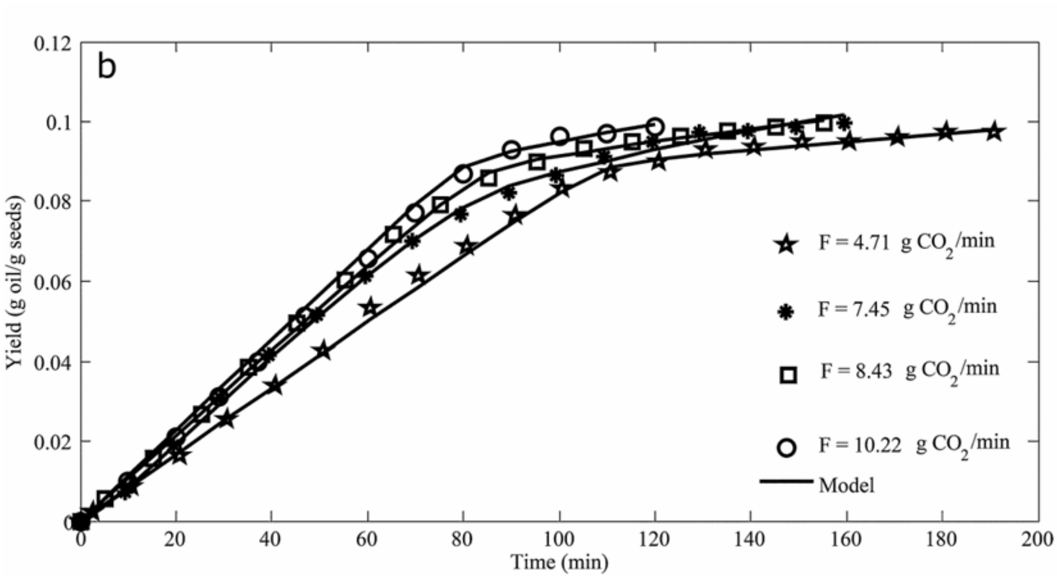
According to Sievers, the most efficient temperature and pressure energy wise to extract oil from soybean is 100ºC at 500 bar, the highest pressure they tried. However, the article also mentions that this temperature is excessive if the quality of the oil wants to be preserved. The author mentions that lowering the extraction temperature to 40ºC increases energy costs greatly. Therefore, taking this research into consideration, the temperature will be set at 60ºC (Sievers, 1998).

Duba and Fiori tried different operating conditions for grapeseed oil and get to similar conclusions[3]. It is mentioned that there is a positive effect on the extraction rate by increasing the pressure; there is a consensus about this in all the articles. The increase in pressure at constant temperature makes the density of the supercritical CO2 increase, which enhances its solvent power and ultimately the extraction rate when the rest of the parameters are kept constant. The maximum pressure that this research tested was 500 bar, so this

[3] This report analyses the extraction downwards, while the plant that is being designed will have the solvent flowing upwards. There is no firm consensus of which flow is better, but most papers read in the making of this project recommended an upward flow.

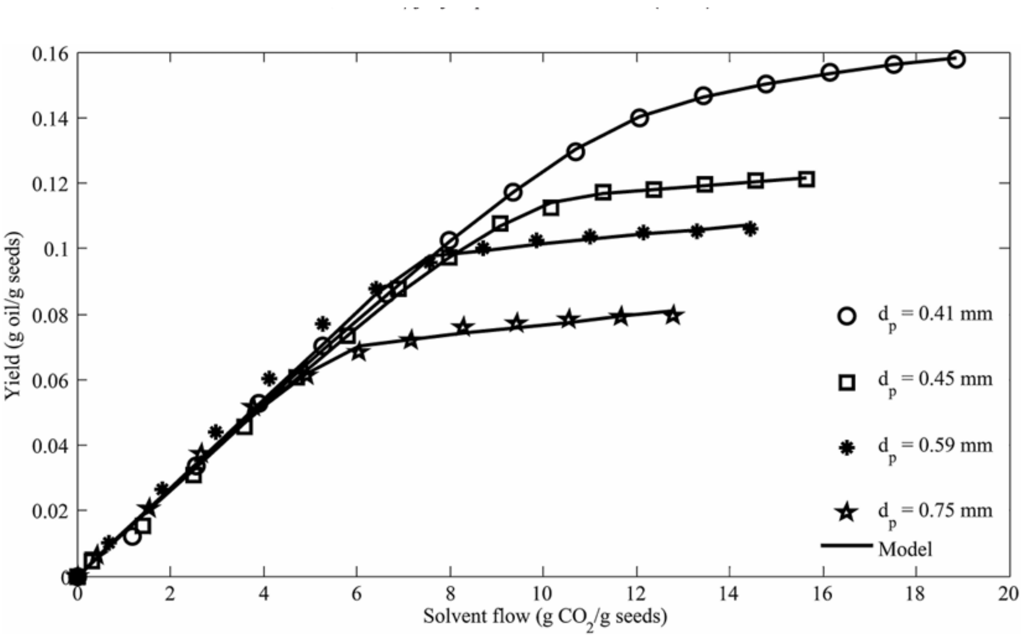
will be the temperature at which the plant will extract the oil (Duba & Fiori, 2014).

The study also concluded that an increase in flow rate increases the yield.



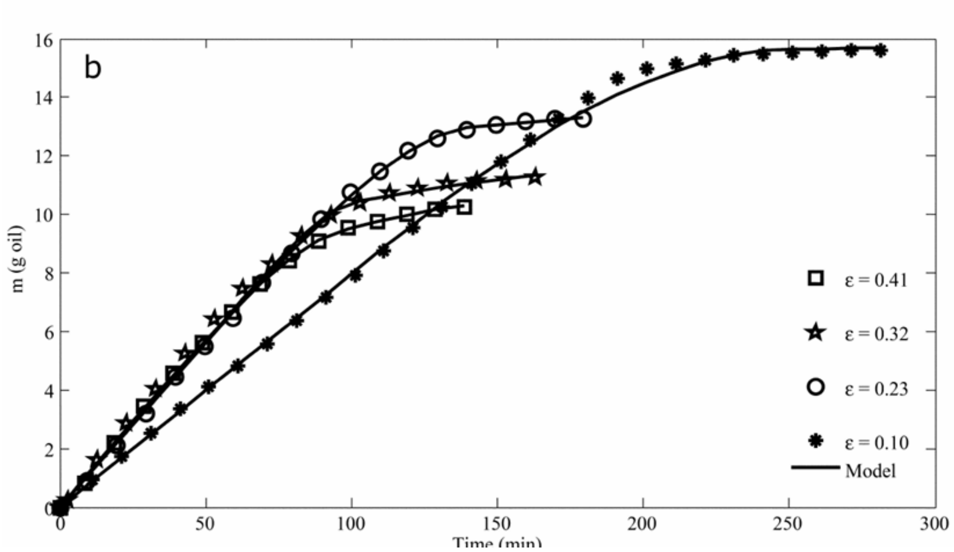
Graph 5. Effect of flow rate in yield.

This study also studied the effect of particle diameter. This is an important parameter that can be controlled, as the seeds will be milled in the plant. The yield clearly decreased with the increase of particle size, so grinding the particles finer will give better yields.

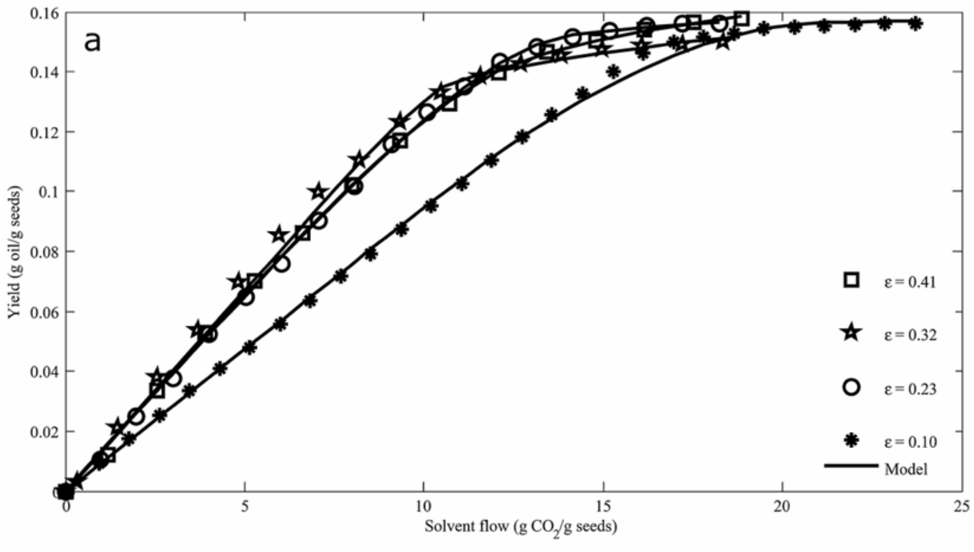


Graph 6. Effect of particle sice of the substrate in the yield.

Another factor the study researched on was bed porosity. For all their experiments, the extractors were fully filled with grinded seeds. Then, the seeds were compacted. For ε = 0.41 the seeds were not compacted at all.



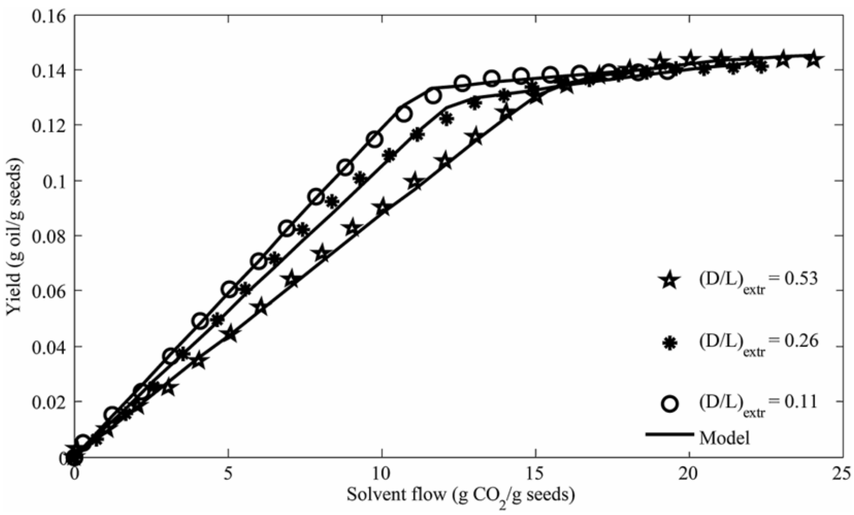
Graph 7. Effect of substrate compression on the extraction.



Graph 8. Effect of substrate compression on yield.

According to the study, in the range of ε between 0.23-0.31, the yield does not change significantly, but compacting the substrate further lowers the yield of the extraction.

The study also researched on the D/L diameter-length ratio. It concluded that the extraction rate increased when D/L decreased, which means that the longer the extraction vessel, the lower the specific solvent consumption.



Graph 9. Effect of the D/L relationship on the yield.

In this project a commercial extractor will be considered for the feasibility, so this parameter can not be changed. However, later in the document, a mention will be made to building the supercritical extractor. In that case, this parameter would be important.

These would be the factors to consider at the time of choosing the operating parameters for the plant. With these parameters, the aim is to determine a yield of extraction to determine the oil production. With this number, a first economic feasibility analysis can be performed to set a selling price and decide whether the extraction process would be economically viable or not.

Most laboratory research set the yield of grapeseed oil extraction at around 10% (w/w). This number changes depending on the grape variety, operating conditions, and other factors, and can go from 5% to over 13%. Furthermore, it is not reasonable to just assume a big extraction plant would have the same yield and the same efficiency as a laboratory scale model would.

The most common grape species used for wine production is *Vitis Vinifera*. The most common grape in La Rioja, Spain, is tempranillo, which is a specific variety comprehended inside this species. To decide on a number for the yield, this project will focus on research on *Vitis Vinifera*.

Prado et. al._proposed a scale-up criterion to predict the behaviour of the supercritical fluid extraction process. This was tested by predicting a pilot scale extraction from a lab scale process, which was 17-fold scale-up. This research was conducted at 40ºC, which is a lower temperature than the one this project intends using, but the extraction time was also longer (Prado, y otros, 2012).

The authors propose maintaining the solvent to feed ratio (S/F) constant to approximate the behaviour of the scaled-up extraction. This study states that, according to other studies in the literature, increasing the scale of production lowers the yield, while equipment manufacturers defend that scaling up increases the yield. This study concludes that scaling up improves the yield. The yield this study found for extracting at 40ºC and 350 bar was as the figure shows.

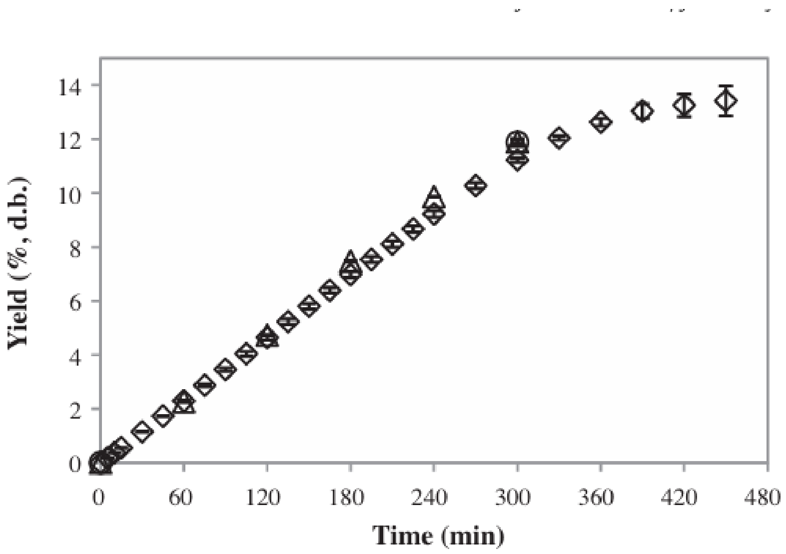


Fig. 2. OECs of grape seed SFE at 313 K/35 MPa for laboratory (◇) and pilot (△) scales, and total collection yield at pilot scale (○).

Graph 10. Comparison of yields obtained in lab and pilot scale.

According to this method, if the solvent to feed ratio is maintained, the yield can be predicted. I decided to use the numbers proposed by Luca Fiori. He considered a seed oil content of 12% and an extraction efficiency of 85% for a plant bigger than the one proposed in this project. His solvent to feed ratio was of S/F = 4.8. The overall yield of the process for this author would be of 10.2% (Fiori, 2010).

Considering that the seed content reported for *Vitis Vinifera* in the waste characterization section was 12.6% and taking a bit more conservative approach, the overall yield for the plant to perform the viability analysis will be an of 10%, which would imply that the efficiency of our process would be of 79.37%.

To sum up, the extraction process will be performed with the following operating conditions:

- Temperature 60ºC
- Pressure: 550 bar
- S/F = 4.8

The yield for this process will be considered of 10%. This is, the oil production will be considered as 10% of the mass of grape seeds introduced to the extractor.

- Overall yield: 10%

4.2 Plant sizing

The first approach to determine the size of the plant for this project, was choosing a winery that produced great amounts of grape and trying to design a plant that would be able to transform the grape mark it produced to extract the seed oil.

The summary of this calculations is presented here. After consulting some supercritical extraction suppliers, the cost of a triple extractor that consisted of 3 extraction chambers of 40 net litres each was set to 500.000€. Then, after calculating in a conservative but realistic manner, the yearly production of oil was estimated to be above 5 tons per year. These numbers were estimated with the information granted by the extractor supplier. The winery that was taken into account could provide a bit more than twice as much grape marc needed for this rhythm of extraction, so 2 of these extractors (or one that would be twice as big) were considered. However, the potential income that was calculated was just not enough to cover the grape marc conditioning expenses and the work force expenses, because more than 3 shift workers were needed to operate the machinery 24 hours per day.

Therefore, the plant was approached in a bigger way. The production of grape in a whole region was considered. La Rioja, in Spain, is one of the most appreciated winemaking regions in the country. Even though the area is not very large, the wine production is very intensive, and most if not all the grape that is planted in the region is dedicated to winemaking, due to its designation of origin.

Figure 6. Stamp of Designation of Origin of La Rioja.

The new approach was to design a bigger plant that would feed from the grape marc of some of the winemakers in this region. It also comes with some advantages. For example, the proximity of the wineries. As the region is not very large, it takes less than 1 hour drive to go from one end of the region to the other.

Additionally, the region prides itself on having the most advanced technologies when it comes to winemaking while embracing tradition and respect for nature, so a plant to these characteristics would possibly seduce different bodegas. Many winemakers use the grape mark to produce other liquors besides wine, but this exhausted grape marc is also usable for the purpose of this project. In fact, it has a lower humidity content and the seed content in weight is higher.

In the first approach, that had a triple extractor with a total net capacity of 120 litres, the economies of scale were playing against the plant. For this one, I decided to make the extraction volume over ten times bigger. I decided to go for a triple extractor, each having a net capacity for substrate of 500L per extraction.

The first step to calculate the size of the plant would be to consider the availability of the substrate for the extraction.

Volume of each extractor [L]	Extractions per hour	Working days	Extractions per year
500	1	300	7200
Seed density [kg/L]	Needed seeds [kg]	Needed seeds [Tonm]	Needed marc [Tonm]
0,6	2160000	2160	10800

(Burg, Vítěz, Turan, & Burgová, 2014)

Using the seed density and the volume of extractions, we can determine the weight of seeds needed yearly for oil production. With the conservative number of 20% of the grape marc in weight base being seeds, a bit over 10.000 tons of grape marc would be needed yearly to supply our plant.

According to the data from the "Regulatory Council of the Rioja Designation of Origin", over 400.000.000 kg of grapes were produced and received by wineries in the region under the Designation of Origin. Considering that around 20% of the weight of grape used to produce wine is converted into grape marc, that means there would be 80.000 tons of grape marc produced in the region every year (RiojaWine, 2024).

With that amount of pomace, our plant would need less than 15% of the grape marc produced in the region to satisfy its needs. Our plant could be designed to use all the grape marc in the region, but it is also unlikely that all the wineries would be willing to sell their grape marc to us, and some of this marc might have different properties than the ones required for this project or come from different grape species. Therefore, this capacity of production seems reasonable for the location of the plant.

4.3 Design of the plant

This section will describe the equipment needed for the extraction plant and the requirements the location needs to have in order to perform the substrate conditioning and the extraction.

4.3.1 Location

As stated before, our plant will need 10.800 tons of grape marc per year. This grape marc needs to be stored before it is processed. Therefore, the location must have a big storage area with a truck bay so transportation can be done efficiently. This area should be an open-air disposal where trucks will unload the pomace coming from wineries until it is directed to the substrate conditioning area.

For the storing purposes, an area of around 3.000 square meters needs to be dedicated. This area does not need special requirements other than mentioned above, such as ground levelling or heating or cooling for employees. This big storing space is needed due to the seasonal nature of grape harvesting.

The location needs a second area, where the substrate will be conditioned. This area should be separated from the storage area not only for safety reasons, but also because it needs to be comfortable for workers to operate the machines. The location for this work is estimated to 400 square meters.

Finaly, the plant needs the extraction area. The commercial supercritical extraction system, which includes most of the extraction machines, takes up 10x5 meters of ground floor and it is 6.4 meters high. However, the manufacturer recommends operating it in a large room. Therefore, between the office, storage space for the extracted oil, and the extraction plant, another 500 square meters should be considered. This section of the plant is the most delicate one, so the location should be levelled, at ground floor and with no columns in the middle.

With all the above, the space needed for the extraction plant will be set at 4.000 square meters.

4.3.2 Equipment

The equipment needed for this plant is divided into transportation around the facility, substrate conditioning and supercritical extraction.

For transportation around the facility, mechanical ramps will be used. These will transport the grape marc and seeds from one part of the plant to the other.

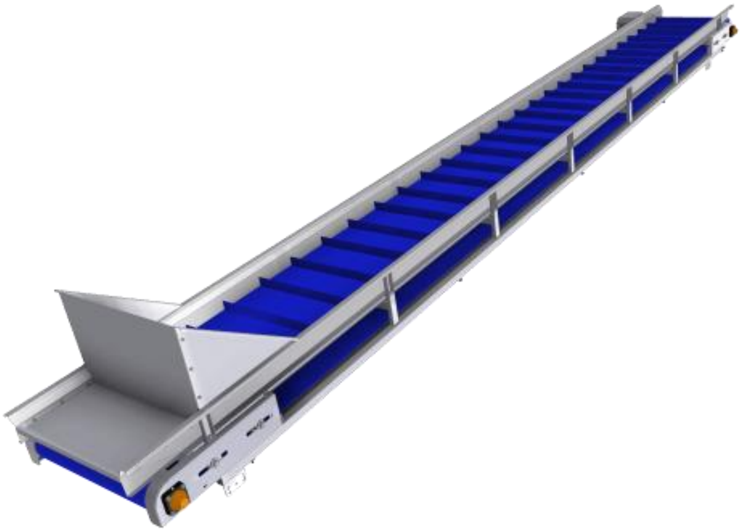


Figure 7. Mechanical transporting line.

For substrate conditioning, the plant needs a drum dryer that is fuelled by a biomass combustor, a mechanical sieving machine and a mill for the seeds. All of these items are common in the agricultural industry and can be found in the area.

The rotary drum dryer is a commonly used machine, but for this plant it needs to be heated by a biomass combustor in order to take advantage of the stalks and grape skins separated in the mechanical sieves.

Figure 8. Drum dryer.

The screening needs to be designed for each particle size. At least 3 screens would be needed. It is a common process that has many options in the market.

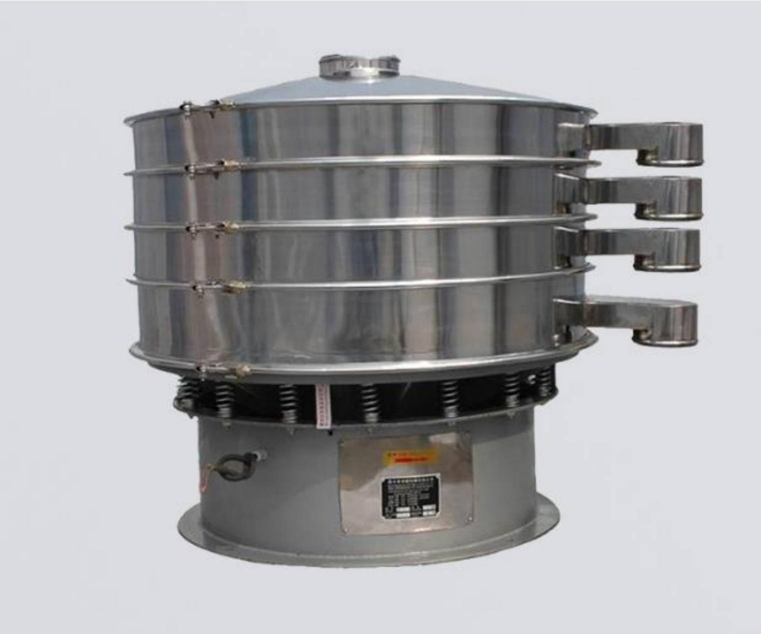


Figure 9. Mechanical sieves.

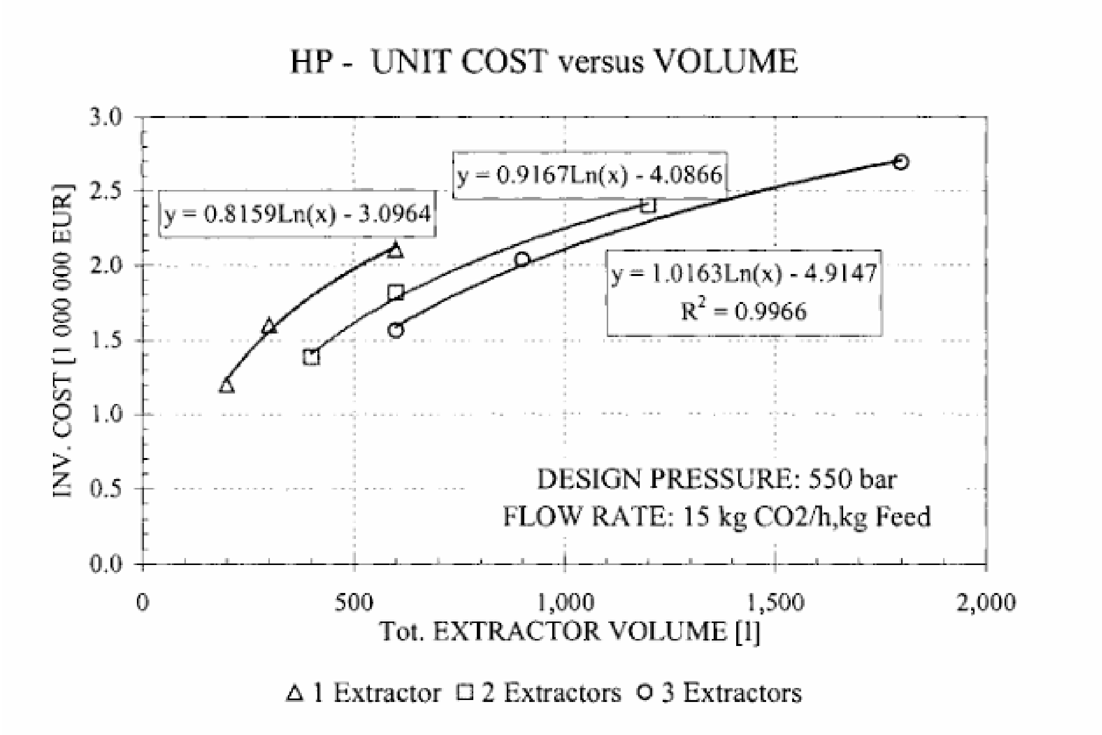
The mill has to be a mill that is ready to grind oilseeds to the required particle size (d_p = 0.41 mm). One option would be the "High-capacity Buhler cracking mill OLCB". This mill is capable of milling all kinds of seeds. The model in the picture is the bigger version, but there are smaller versions that suit the needs of our plant.

Figure 10. Seed mill.

For the supercritical plant, the equipment that has been chosen is a triple extractor provided by SpareCo. This company has been supportive and has provided indicative prices and production rates for their products so I could make these calculations. The extractor chosen has been their "Triple 580L Supercritical CO2 Extractor". With the data they provided, this extraction system has a capacity of 1500L between their 3 extractors. The system has the certifications to operate at high pressures.

Figure 11. Triple supercritical extractor.

The company sells a bigger extraction system with 4 extracting vessels. This could be an option if after consulting winemakers for the availability of grape marc and testing the grape seed oil market the production estimated needed to be increased. There is also the option to build our own supercritical extractor to fulfil our specific needs. This option will not be considered in this project, but according to E. Lack, the cost in million euros can be calculated for a supercritical fluid extraction plant according to this equation (Lack, Gamse, & Marr, 2001).



Graph 11. Cost of a supercritical extractor unit versus volume.

$$Cost\ in\ M€ = 1.0163 \cdot Ln(V_T) - 4.9147$$

Where V_T is the total volume of extraction in litres. For the commercial plant that was chosen for this project, where V_T=1500L, the cost would theoretically be of 2.5M€, and the approximate retail price provided by the manufacturer for this project was of exactly 2.5M€. Therefore, this equation proposed in 2001 could still be useful to determine the initial investment for the plant. Consequently, if the needs of the production of the plant were bigger than this, the approach to foresee an initial investment would be to use this equation.

5. Economic feasibility

5.1 Introduction

The objective of the economic feasibility analysis will be to determine if the installation and operation of the plant that was suggested in the previous section of the project would be financially feasible. This analysis will not only evaluate the price of the final product to recover the investment in a premeditated time frame, typically 10 years, but will also explore different financial alternatives to fund or run the project.

5.2 Implementation costs analysis

Building an extraction plant means a significant initial investment. The amount of money needed for this plant will be great specially because of the equipment needed for the extraction. Fortunately, the plant does not take a huge amount of space comparing with other industries, so the building costs will not be as high as they could be.

5.2.1 Building costs

In the section of this project called location, the area that as estimated necessary to locate the plant and the storage was set at 4.000 square meters. It was divided into three sections, one for storing the grape marc, one for conditioning it, and a last area to perform the supercritical extraction. It also needed to allocate the office in one of the sections.

The cost of this infrastructure should be comprehensive of the next points:

- Renting or buying the unit.
- Conditioning the smaller unit for the process.
- Conditioning the smaller unit for the workers.

To estimate the cost of this infrastructure, the real state website "Idealista" was consulted. In this page, industrial units with the following characteristics were searched:

- More than 4.000 square meters.
- Located in the middle portion of the region of La Rioja.
- Truck bay for unloading operations.
- Conditioned ground floor level.
- Column-free industrial warehouse.

Realistically, the storage would not need to have these characteristics and only some portion of the warehouse would need these requirements. However, it is more conservative to make calculations this way and it simplifies the search as it will account all the areas in the same warehouse.

The cost of buying a warehouse per square meter with such characteristics went from 150 to 400€. Renting these locations went from 1 to 1,70€ per square meter. Because these locations already met most requirements, such as having office areas, parking spots for workers, floor levelling or truck bays, building costs to remodel the location can be minimised. The costs of remodelling the location were considered as 200€ per square meter.

Table 6. Cost of buying, renting and remodelling a suitable location.

4.000 [sq m]	Buying	Renting	Building
[€/m^2]	275,00 €	1,50 €	200,00 €
[€]	1.100.000,00 €	6.000,00 €	800.000,00 €

By taking middle prices for both renting and buying and considering the costs of remodelling the location as 200€ per square meter, this is the cost we would get from buying, renting, and building the infrastructure. If we chose to buy the location, the initial investment on infrastructure to locate the plant would be of 1.900.000€.

5.2.2 Equipment costs

The equipment needed for the plant will be the following:

- Mechanical transporter
- Drum dryer (with a biomass combustor)
- Mechanical sieves
- Mill
- Supercritical extractor

The cost for the transportation system of seeds and grape marc around the plant was estimated in 50.000€. This includes transportation of the pomace to the dryer, of the seeds to the mill and other material transportations.

The cost of the substrate conditioning system was estimated in 100.000€. This includes the drying system, the sorting system and the seed grinder.

The last piece of equipment will be the supercritical extraction system. The company "SpareCo", which is an Italian company that has been producing equipment for supercritical fluid extraction since 1995, shared approximate prices for their extractors for this project. As mentioned in the plant sizing section of this project, the approximate cost of the chosen extractor was 2.500.000€. To account for modifications or other costs related to fitting the extractor to our needs, the cost of purchasing the extraction system was set to 3.000.000€.

The next table summarises the costs of purchasing the equipment for the plant.

Table 7. Cost of equipment.

Equipment	
Biomass combustor and dryer	500.000,00 €
Vibrating screen	300.000,00 €
Seed miller	200.000,00 €
Plant transport	50.000,00 €
Supercritical plant	3.000.000,00 €
Total	4.050.000,00 €

5.2.3 Initial investment

Adding up the cost of buying and remodelling the location and purchasing the required equipment, we get the initial investment needed to set up the oil extraction plant. The supercritical extractor supplying company mentioned the possibility to lease the supercritical extracting system for 12 years. However, they did not provide details of the pricing for that option, so purchasing the equipment will be the option considered. The possibility of renting the location will also be regarded.

Table 8. Total initial investment.

Initial Investment	
Location	4.050.000,00 €
Equiment	1.900.000,00 €
Total	5.950.000,00 €

5.3 Operating costs

The operating costs of the plant have been divided into the following categories:

- Raw materials
    - Grape marc
    - CO_2
- Transportation
- Substrate conditioning (drying, sorting, and grinding the seeds)
- Extraction
- Work force
- Administrative costs
- Capital costs
- Rent of the facilities

5.3.1 Raw materials

As stated before, the sizing of the plant has been designed regarding the volume of the extractor and the availability of grape marc.

Table 9. Yearly cost of raw materials.

Grape marc	
kg/year	10800000
Cost [€/ton]	1
Cost [€]	10.800,00 €
CO_2	
kg/year	864000
Cost [€/ton]	300

The pricing of grape marc has been set to 1€ per ton, which is considered a conservative price. This price does not include transportation of the material to our plant, so this cost will be considered in the transportation section (Fiori, 2010).

For CO_2, a price of 0.25€/kg has been used. The amount of CO_2 needed has been set to be 4.8 times bigger in weight than the seeds. And, as the CO_2 is recirculated, a loss of 10% has been decided to account for the amount of gas that is lost in the operations of changing the substrate for the extraction. Again, this should be a conservative approach, as authors account for a 2% CO_2 loss. Seeing the cost of the solvent, depressurising the vessel before opening it to change the substrate becomes of critical importance (Bertucco) (Prado, y otros, 2012).

5.3.2 Transportation

To calculate the transportation costs per ton of grape marc, the following formula has been used:

$$CT = \frac{(t_t \cdot 2 + t_{l\&u}) \cdot C_{th}}{W_t}$$

Where:

- CT: cost of the transportation per ton of transported grape marc.
- t_t: travel time. Due to the short distances of the region, the time was set to 0.8 hours.
- $t_{l\&u}$: loading and unloading time. The time is set to 1 hour.
- C_{th}: cost of the truck per hour, including the driver, fuel, and other costs. 60€/h is a reasonable price.
- W_t: maximum weight capacity of the truck. 20 tons.

This calculation gives a result of 5,4€/ton of grape marc. The only factor that can be influenced in this equation would be the closeness to the wineries, so choosing a fitting location is of outmost importance. The time of 0.8 hours is a conservative approach, since in 1 hour drive a car can cross the longest section of the region.

5.3.3 Substrate conditioning

The cost of this step includes drying the grape marc, separating the seeds from the stalks and skins of the grapes, and milling the seeds. As stated before, the fuel for drying the grape marc will be the totality of the stalks and the amount of skins that become necessary. Therefore, the cost of this step will be drastically reduced, as it will only need natural gas (methane) to start the combustion.

For the cost of maintenance, 5% of the initial price of the machinery will be considered. These machines will work at full capacity from time to time and store the conditioned substrate. Therefore, they will not be working the same amount of time as the extractor, that will be running all year around. The total annual cost of conditioning the substrate will be considered 80.000€.

5.3.4 Extraction

According to SpareCo, their extractor has a power consumption of 110kW. Their biggest extraction system, consisting of 4 extractors of 700L net each, has a power consumption of 180kW. Just to be super conservative, the cost of the extraction in terms of power will be calculated with this number, in case any additional power is required to operate the extractors plus other non-considered costs. Choosing this consumption also intends to cover possible unexpected raises in electricity costs. Another cost that will go into this part will be a 5% of the cost of the extractor as annual maintenance and spare part changing.

According to data from the Spanish government, the electricity for industrial purposes had a cost of 0,13€/kWh in 2023 (Government, 2024).

Table 10. Yearly extraction costs.

Extration costs	
Power consumption [kWh]	1.296.000
Electricity cost [€]	168.480,00 €
Maintenante cost [€]	125.000,00 €

5.3.5 Work force

In order to operate this plant, 2 workers need to be present on site to operate the extractor and control other duties. Consulting what the labour cost per hour is in the region of La Rioja in the national institute of statistics in Spain, the cost of industrial labour is 22,25€ per hour. This includes all the costs of employment. To be more conservative, a labour cost of 25€ per hour of use (INE, 2024).

With the plant working 300 days per year all day around, then having two workers on site to operate the plant would have a cost of 360.000€ per year. If we account for the starting and stopping operations, which could be the labour costs of 10 workers working for 2 weeks 12 hours per day, we get an expense of 42.000€. Adding it to the labour cost of the regular functioning and rounding up, we set on a cost of labour of 450.000€ per year to operate and maintain the plant. This should account for any other expenses related to work force such as training the workers or other issues.

Table 11. Yearly cost of the work force.

Work force	
Labour cost [€/hour]	25
Simultaneous workers	2
Worker costs [€]	360000
Rounded up costs [€]	450.000,00 €

5.3.6 Administrative costs

The plant will need to have an administration to pay the salaries to its workers and other issues. For those expenses an annual quantity of 50.000€ will be considered (Bertucco).

5.3.7 Rent of the facilities

The possibility of renting instead of acquiring the location was a possibility mentioned before. Therefore, if the location was to be rented, the annual cost of renting the facilities would be of 7.500€ per month, resulting in 90.000€ per year.

5.3.8 Total operating costs

After adding up all the costs associated with the production of grapeseed oil, we end up with an annual cost of 926.184€. For the rental approach, the annual cost increases to 998.184€. It is interesting to observe that most of that cost (450.000€) comes from labour costs, then followed by the extraction and substrate conditioning costs. This means that a plant with higher production capacity that was able to function with the same amount of workers would be more cost effective.

Table 12. Initial investment and operation costs for the options of buying and renting the location.

	Buying	Renting
Initial investment	5.950.000,00 €	4.850.000,00 €
Operation costs	926.184,00 €	998.184,00 €

5.4 Income

After analysing the costs of the plant, we need to address the potential income from production. The main (if not all) income of the plant will come from selling grapeseed oil. The following section will be used to calculate at which price we would need to sell the oil to get the initial investment back.

The plant will produce two by products that could be sold to livestock farmers. Grape skins and the exhausted seed powder are used to feed animals. However, this residual income will not be taken into account, and in this project only the grapeseed oil sales will be considered as potential income.

Considering the approach where the location was bought, we calculate the price of the oil to get back the initial investment in 10 years.

$$\begin{aligned} &Initial\ investment + 10 \cdot Operational\ Costs \\ &\quad = 10 \cdot Production \cdot Selling\ Price \end{aligned}$$

Considering a yield of 10% and a capacity of extracting 2.160 tons of seeds per year, the yearly production is set to 216.000 kilograms. For a production of 216.000 kg per year, we get a selling price of 7€ per kilogram or 7.000€ per ton. To correctly address this selling price, I contacted Agralco. Agralco is a cooperative that manages winemaking by-products, and produces alcohols, tartaric acid, enocyanin, grape seed meal, and grape seed oil in a region not so far from La Rioja. I asked about an approximate selling price for grapeseed oil. They informed that non-refined oil was selling at around 1.800€/ton and the refined oil at 3.700€/ton. This meant that the price to get the investment back in 10 years is clearly too high.

However, after researching and asking about their production methods, I discovered that this oil was being extracted using organic solvents, specifically hexane. Considering that the quality of the supercritically extracted oil is more resemblant to cold pressed oil rather than oil extracted by organic solvents, the higher price could be plausible. With less conservative numbers for many aspects of this project, the selling price could be lowered. Just by changing the lost CO_2 to 2%, not rounding up the costs of labour and using 402.000€ per year, and using the real electric consumption of the extractor, the selling price to return the investment in 10 years lowers to 6,44€/kg, and if we consider the return of the investment in 12 years, which was the time lapse for the lease of the equipment, it further lowers the price to 5,99€/kg.

However, the initial price will be used as the result of the project, 7.000€/ton.

5.5 Funding options

This project is a very costly initiative that needs to secure the necessary funds to establish and operate the grapeseed oil extraction plant. Some funding options are available, each coming with advantages and disadvantages. This section will explore some alternatives and will try to determine the most viable path to fund the project.

5.5.1 Equity Financing

Self-funding

Self-funding would be the best option to maintain control and to have no obligations due to debt. It would also leave the owner with all the profits. After adding operating costs, the investments plus expenses of the first year almost reaches 7 million €, which seems a very high personal financial risk.

Angel investors

This would share the risks and profits of the company among different investors. This comes with loss of control and dilution of ownership. However, this looks like a viable alternative.

Considering that this plant is meant to revalorise winemaking waste from different companies, it is not hard to imagine a situation where these companies could form a cooperative company to reduce their waste, earn some profit over that waste and improve their image by adopting more sustainable and environmentally friendly practices.

Wineries from the region could form this cooperative or an association and divide profits according to the amount of capital invested. By adopting this measure, they would ensure all their grape marc will be bought from them, lowering their environmental impact and improving their yearly results.

Venture capital

Venture capital is an option that is usually used by startups or rapid growing companies. This plant being a longer term slowly growing industry, venture capital might not be a viable solution.

5.5.2 Debt Financing

Debt financing would be an option to buy some of the machinery. However, debt financing comes with a cost. The interests that need to be paid for this money have not been considered in this project. However, is very likely that even if the plant was to be funded by wineries, these would need to borrow some money from the banks to purchase the equipment, in which case those costs should be considered. This option would lower the initial investment.

In conclusion, gathering the necessary funds for the extraction plant from one institution only would be difficult, as the needed investment is high. However, it is more likely to work if the advantages from the project go beyond the economical. Therefore, I believe a joint venture among the winemakers of the region could be beneficial.

The economic feasibility of the project can not be more than hypothesised, as the selling price of such an oil is to be determined. The required investment is very high to jump to conclusions, and the market for the product may not be big enough to sell the whole production.

However, I believe this project might be feasible if the market is big enough. Checking the retail prices of grapeseed oil online, there is a huge difference in the price comparing it to the price the association Agralco provided. Therefore, the must be a difference in quality or perception of the product comparing it to the grape seed oil extracted with organic solvents.

6. Potential risks

It has been made clear that the projects feasibility is very sensitive of the sales of the product and the selling price of it. This section wants to identify potential risks that may affect the project and develop mitigation indications to minimise their effects.

6.1 Technical risks

The supercritical CO_2 extraction process relies on high-pressure equipment. Any malfunction in the system could disrupt operations and lead to a significant loss of time. This is why maintenance was added to the operational costs, as it will be cheaper to prevent these risks. Maintaining the system regularly will minimise the risk of technical failure.

6.2 Energy supply and costs

The extraction process is energy intensive. The last 5 years the energy supply market has fluctuated significantly. Production of grape seed oil will always be tied to energy prices and ensuring maximum efficiency of the process is the only possible strategy.

6.3 Market demand and price fluctuations

Even though the market of grape seed oil seems to grow, the investment needed for this plant is large. The demand for quality grape seed oil needs to be big enough to justify such an investment. The same goes for the selling price, if the final consumer does not prefer the oil extracted without organic solvents, selling the product will become impossible.

6.4 Supply chain disruptions

Although the supply chain for this plant is not large, a bad harvesting season can ruin the plants supply of grape marc. Just like winemakers, the effect of a bad season will affect a whole year of production. Stablishing long-term contracts with multiple suppliers can reduce the impact of this risk.

7. Impact

7.1 Environmental impact

The proposed grape seed oil extraction plant offers some environmental benefits. By utilising grape marc, a by-product of the wine industry, the project addresses a waste management issue. It converts grape seeds into a valuable product, therefore reducing the environmental footprint of the wine industry.

Furthermore, the supercritical CO_2 extraction method is more environmentally friendly than other extraction methods using organic solvents, as CO_2 is a non-toxic recyclable solvent. By burning the stalks and seeds, the plant does not rely on fossil fuels.

However, burning these residues to fuel the dryer has a negative environmental impact, as it releases harmful particles to the air, affecting air quality. Therefore, the substrate conditioning has a negative impact in the quality of the air. Additionally, the extraction is energy demanding, and the electric power may or may not come from green sources.

7.2 Social impact

The establishment of the plant will have positive social implications. The plant will create job opportunities, both from operating the plant as direct workers and from transportation of the grape marc. Additionally, by reducing the environmental impact of grape marc disposal, the project improves the quality of life for local residents.

7.3 Sustainable Development Goals

This plant has its advantages and its considerations. However, the outcome would be a positive one, and I believe it would align with these specific goals regarding the SDGs, especially number 12, *Responsible consumption and production* (SDGs, 2024).

- 12.2: *By 2030, achieve the sustainable management and efficient use of natural resources*. By revalorising a product that is traditionally disposed, this plant will help using the resources more efficiently.
- 12.4: *By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment*. This plant will improve the life cycle of the grape that is destined to winemaking.

Figure 12. Logo of SDG 12.

8. Conclusion

The proposed project to establish a grapeseed oil extraction plant in La Rioja presents an interesting opportunity to revalorize grape marc using supercritical CO_2 technology. By taking advantage of this extraction method, we do not only improve the economic value of a grape residue, but also contribute to environmental sustainability.

I believe this project is justified by the substantial benefits it offers. It mitigates waste management issues by transforming grape seeds into valuable products, thus reducing the winemaking industry's footprint. The use of this extraction method might be a good choice to produce high quality grape seed oil.

Economically, the feasibility analysis is not completely conclusive, but despite the high initial investments and operating costs, the project has the potential for profitability, provided the market for high-quality grapeseed oil continues to grow. I want to remark the idea of local wineries embarking in a joint venture to tackle this issue. I believe the region would strongly benefit from such an advanced plant, and that it could be the opportunity to test industrial scale grapeseed oil production. However, the price sensitivity is still an issue, underscoring the importance of reducing production costs.

In conclusion, the establishment of a supercritical CO2-based grapeseed oil extraction plant in La Rioja is an innovative initiative that integrates economic, environmental, and social benefits. Even if there are risks involving the project, I believe the plant could not only achieve financial sustainability, but also contribute significantly to the sustainable development of the wine industry, specially if different producers cooperated and aligned their efforts.

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