BResilient

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1. Introduction

The B-resilient project “Building the biomass resilience of food producing and processing SMEs through green and digitalized value chain” – has received funding from the EU’s Horizon Europe Programme under Grant Agreement 101074621. Its overall objective is to empower food-producing and processing SMEs (FP² SMEs) to become more resilient by means of an optimum use of biomass. Since biomass is the key component of the agri-food ecosystem and the bioeconomy, the project focuses on maximising usage of available feedstock and the valorisation of side streams into bio-based ingredients in a wide variety of ways, building on zero-waste and circular concepts. The needs and opportunities in the agri-food sector overlap very much with those in other sectors dealing with the formulation of new/improved/more fossil-free and locally-sourced products as a key step; this includes all industrial sectors working with bio-based ingredients, i.e., ingredients and building blocks derived from biomass. The intent of B-Resilient is therefore to link the agri-food ecosystem with key sectors working with bio-based ingredients (with the emphasis on agri-food, cosmetics, green chemistry, and the transversal bio-based economy sector) with the aim of stimulating cross-sectoral fertilization during the quest for new products, meeting customer demand.

B-Resilient brings together clusters with a background in the agri-food industry. Its ambition is to strengthen and develop current and new cross-sectoral industrial value chains within the FP² industries through a combination of direct and indirect innovation actions, as well as support capacity-building measures. B-Resilient organises cross-sectoral, cross-border matchmaking/ business events for SMEs with different innovation actors in biomass resilience support with lump sums to support travelling costs. The project also opens opportunities for food-processing SMEs through a lump sum scheme including innovation lump sums for new (European & international) value chains and for the deployment of new biobased business models and services, continuity plan lump sums for creating business continuity and an internationalisation lump sum to support company development. Besides the consortium network, associated clusters from the S3 platform on I4CE and other networks also support the outreach to SMEs across the EU.

This report is one of the major deliverables of B-Resilient Work Package 1 activities, whose objectives were:

O1.1: Identify partners and establish cooperation between new value chain actors, identify value chains and plans to develop them and translate these plans into actions supporting a resilient agri-food industry;

O1.2: Build up the knowledge and skill capacity of the cluster managers to improve their support and guidance to SMEs

It presents the biomass market analysis conducted on the 5 Value Chains which were selected by the B-Resilient partners, as those offering promising opportunities for valorising side-streams into bio-based ingredients through various pathways. Based on the requests (*i.e.*, needs/priorities) shared by each of the consortium partners at project start, the B-Resilient partnership decided to focus on 6 high-potential biomass value chains (VC):

- Apple
- Diary
- Grape and winemaking
- Brewers' grains
- Wheat bran
- Stone fruits

For each VC, Innov’Alliance prepared a first general overview, and each partner went on building regional VC groups gathering 10 to 20 members. The VC groups provided a framework to the B-Resilient cluster members to identify and exchange with established or new partners, to explore selected common challenges and opportunities in the biomass market.

The partners then decided to evolve the update of the initial study into a specific market analysis per value chain. In addition, due to the large number of fruit and relative by-products covered by the “stone fruits” VC and considering the limited time and resources available under the B-Resilient project, the consortium partners decided not to pursue the investigation there and to focus the efforts on the five remaining VCs. To offer a more in-depth analysis and gather inputs from the actors of the regional value chains, each partner then proposed to contribute to two studies, selected based on the priorities expressed by each of the consortium partners.

Target audiences:

The primary audience is that of companies new to the circular economy market having access to side-streams and by-products and willing to explore opportunities to use them and created higher-value added solutions than brownfield or feed options. The studies are thought as inspiration for innovators that would then revert to their cluster contact point to understand what the best option for them would be to enter the circular bioeconomy market. On that basis, the market analyses – presented in their entirety in the following sections - have been used by the B-Resilient partners in many occasions; for example to inspire acceleration projects during the 2nd C&I event (T2.2), to extract articles and nurture the skills hub (T1.3; https://i4ce.eu/skills-hub/), as well as to provide inputs for regional events as well as to help the designing the FP² SMEs training (T1.3).

Methodology

As reported in more details below, the methodology adopted for each market study was based on the combination of three different sources of information: 1) data extracted from Mintel, a database of product releases in 64 countries; 2) a review of scientific literature available on the valorisation of the major by-products identified in each biomass VCs; 3) two different questionnaires, aimed at collecting views and insights both from companies and research and/or technical centres in each region investigated. By M18, the partners prepared the update market analysis for the “Apple”, “Wheat bran” and Grapes and winemaking” VCs, while the remaining two studies were prepared for M23.

To enable a more in-depth analysis and collect input from stakeholders involved in regional VCs, each consortium partner committed to contributing to two studies. These studies were selected according to priorities identified by the partners—for example, the availability and quantity of biomass for valorisation in a region or the most promising valorisation pathways. As a result, only a limited number of partners were involved in each VC study, which in turn restricted the number of regions covered per study (see table below). All VC market analyses were coordinated and compiled by Innov’Alliance, with contributions from the partners engaged in each respective VC.

Table 1: Regions, B-Resilient Partners and involved actors per identified value chain

Value Chain	Regions covered	B-Resilient Partners involved	Overall N° of VC actors involved in the study
Apple	Sud-Provence-Alpes-Côte d’Azur (FR) Pays de la Loire (FR) Brittany (FR) Normandy (FR)	Innov’Alliance, Wagralim, and Valorial	13 organizations, including different types of companies (SMEs and large companies), apple producers and processing companies, solution providers (e.g., food research labs, biosolution providers, etc), as well

	Wallonia (BE)		as public and private technical centres.
Beer and Brewery by-products	Provence-Alpes-Côte d'Azur (FR) Auvergne-Rhône-Alpes (FR) Galicia (ES)	Innov'Alliance and Clusaga	4 organizations, all companies
Diary	Flanders (BE) Galicia (ES) La Rioja (ES) Central Macedonia (EL)	Flanders' Food, Clusaga, Food+i and ATECluster	9 organizations, including including different types of companies (SMEs and large companies) and research centers
Grape and winemaking	Emilia Romagna (IT) Auvergne-Rhône-Alpes (FR) Sud-Provence-Alpes-Côte d'Azur (FR) Central Macedonia (EL) La Rioja (ES)	Innov'Alliance, C-ER, ATE Cluster and Food+i	11 organizations, including 7 different types of companies (SMEs and large companies), research centres, and one university
Wheat bran	Emilia Romagna (IT) Pays de la Loire (FR) Brittany (FR) Normandy (FR) Wallonia (FR) Flanders (BE)	C-ER, Wagralim, Flanders Food and Valorial	7 organizations, including different types of companies (SMEs and large companies, flour mills, industrial bakeries), a research centre and one university.

Each study followed a consistent methodology, incorporating data and information collected from a variety of sources, including:

- Mintel, a database of product releases in 64 countries. Mintel monitors product innovation, product releases and best sellers in the consumer good market around the world. Each product is broken down according to its main ingredients and is classified according to claims defined by a reference system specific to Mintel. The database also analyses consumption trends in the various economic sectors. Mintel was used to provide an understanding of the apple market as well as general trends about new ingredients/products based on each biomass studied and relative by-products.
- A review of scientific literature available on the valorisation of the selected biomass and relative by-products, carried out both to illustrate the main physicochemical characteristics of the biomass, as well as to identify interesting lines of research.
- Two different questionnaires, aimed at collecting views and insights both from companies and research and/or technical centres in each region investigated. The questionnaires had several objectives: provide a context for the VC selected to explore in each region, identify the current valorisation paths as well as the ones being developed, and explore technical, technological and economic obstacles to the valorisation of the biomass and relative by-products.

Structure of the VC reports

Each VC report provides an overview of the market dynamics related to the biomass studied, with a particular focus on the most significant by-products. The reports also offer insights into the main valorisation pathways currently adopted in the regions covered by each study.

All reports follow a consistent structure:

- **Market Overview**: the first chapter introduces the broader market context, presenting data on overall biomass production and trade at both international and European levels. It highlights the sector's significance for the European market and concludes with a brief overview of biomass production in the regions where consortium partners expressed interest in exploring the value chain.
- **Biomass Characteristics and major by-products**: The following sessions offer a concise overview of the botanical and anatomical characteristics of the biomass under study, along with its key components and chemical composition. In cases where multiple by-products were available—such as in the apple and grape/winemaking VCs—only the most relevant ones were presented, particularly those with the highest quantity and availability. The focus is on highlighting their potential as secondary resources within the VC.
- **Valorisation Pathways**: The final chapter examines the major valorisation methods applied to the identified by-products within the regions studied. It incorporates insights and perspectives gathered through interviews with local VC stakeholders. In many cases, these interviews reveal that while there are many opportunities for by-product valorisation, various challenges—such as technological limitations, regulatory and safety constraints, and insufficient market demand—often restrict the amount of by-product that is effectively converted into valuable products or resources.

Acknowledgments

All market studies of the 5 VCs were enriched with insights and feedback gathered during the interviews carried out by the project partners involved in each VC report. The B-Resilient partnership is most grateful for the time dedicated to this study by the following organizations:

Enterprises:

Vergers d'Upigny, Atelier du Fruit, Agrial, Andros, Charles et Alice, Waste Me Up, GreenSpot Technologies, Ovin'Alp, Upcylink, Maltivor, Galician Brew S.L., De Zuivelarij, Milcobel, Kaasmaakerij Karditsel, Damse Kaasmakerij, Queizuar S.L., Lacteos Martinez, S.L.U., Calidad Pascual, Grap'Sud, Terre Cevico S.C.A, Caviro extra Spa, Bodegas Riojanas, Ktima Gerovassiliou SA, DuranSia, Paulic Meunerie, Upcyclink, La Lorraine, Molens 't Kindt.

***Research centers and labs**:*

Gembloux Agrobiotech, LABEO, CTIFL, Centre for Research and Technology – Hellas (CERTH), Aula de Produtos Lácteos e Tecnoloxías Alimentarias – University of Santiago de Compostela, Institut Français du Vin, UNICATT, CNTA, CERTH, INAB – Center for Research and Technology Hellas, Institute for Applied Biosciences, Gembloux AgroBiotech, CREA-Alimenti e Nutrizione.

(NB: the list only incudes the organizations who gave their consent to be mentioned)

Innov'Alliance is most grateful to Dr. Arnaud HEUMANN, Julian RIOCHER and Solen WEBB for the coordination and compilation of the VC reports.

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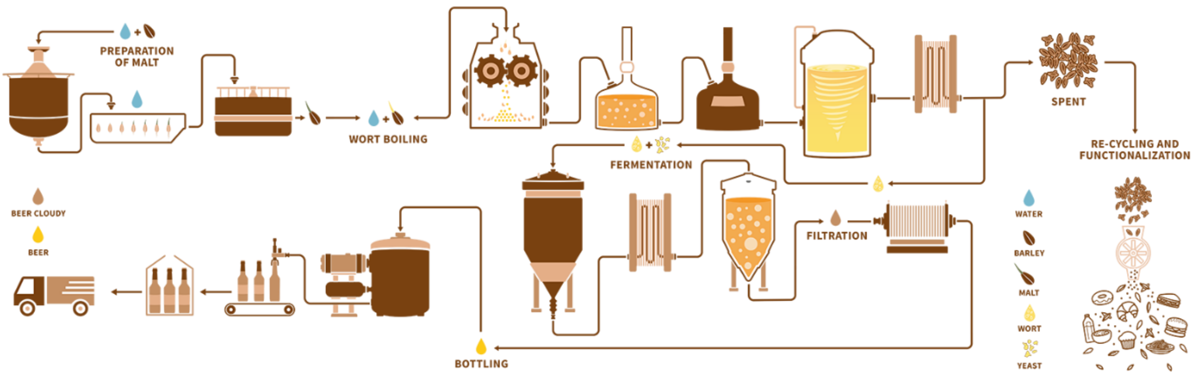
2. Value Chains Reports

2.1. Brewery spent grains

2.1.1. Overview of barley malt and brewery spent grains markets

Brewers' spent grain (BSG) is the most abundant by-product generated in the beer-brewing process. Indeed, it makes up 85 percent of brewing waste (Johnson *et al*., 2010). It is obtained as a mostly solid residue after wort production in the brewing process. The by-product is initially wet, with a short shelf-life, but can be dried and processed.

Figure 1: The beer production process

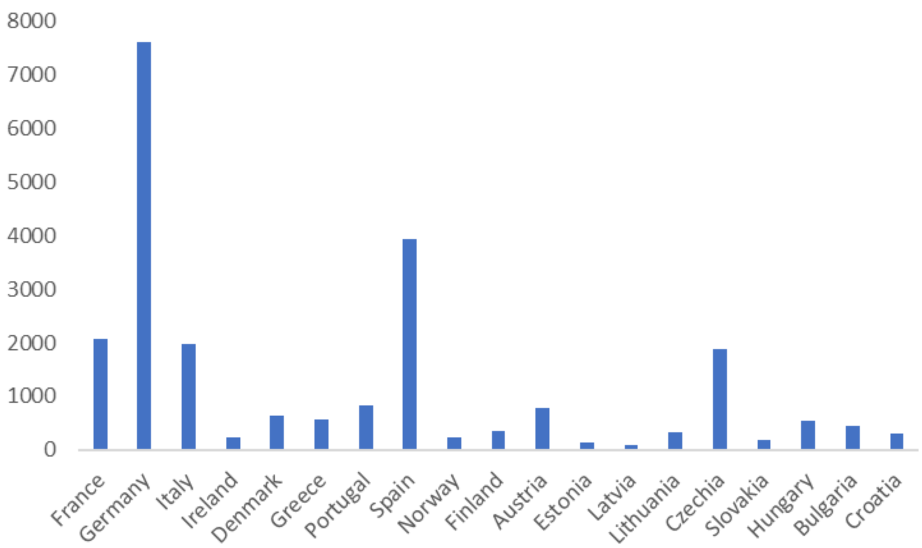


Source: SUSFOOD2, 2024

In 2022, EU countries produced almost 34,4 billion litres of beer containing alcohol and 1,6 billion litres of beer which contained less than 0,5% alcohol or had no alcohol content at all. The EU's total beer (with and without alcohol) production the same year was equivalent to almost 80 litres per inhabitant.

Beer is the fifth most consumed beverage in the world, resulting in an average annual global production of 39 million tonnes of BSG.

Figure 2: Beer production in Europe in 2022 by country (in millions of litres)

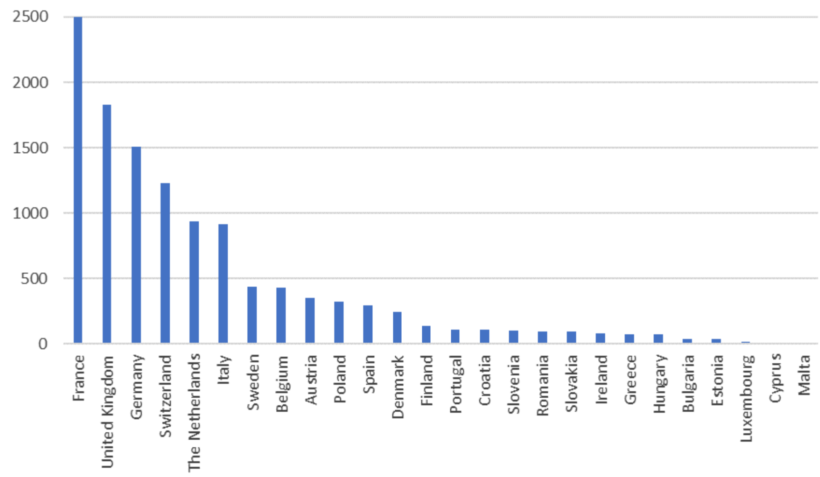


Source: Eurostat, April 2024

In the EU, Germany was the biggest producer in 2022 with 7,6 billion litres produced (22% of the total EU production). Germany was followed by Spain with 3,7 billion litres produced (11% of total EU production).

More than 12.000 breweries are active in EU (Brewers of Europe, 2022). The breakdown by country is as follows:

Figure 3: Number of active breweries in Europe in 2022



Source: Brewers of Europe, 2022

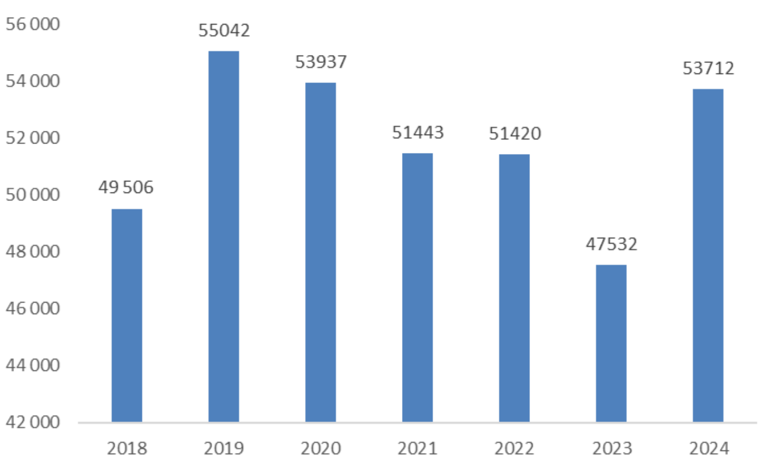
The number of breweries in Europe continues to increase. According to Brewers of Europe, the number of breweries in Europe increased by 2% between 2021 and 2022.

France is the country with the most breweries in Europe. However, 92% are microbreweries which have an annual production of less than 1000 hectolitres. Conversely, microbreweries only represent around 50% of breweries in Germany. Countries like Malta or Cyprus produce little or no beer and consume imported beers, mainly from other European countries.

2.1.1.1. European production of barley malt

Malt is a germinated cereal, usually barley, which is cooked to release its aromas. However, malt can be produced from any cereal: wheat, rye, etc. Barley malt is an important ingredient in the brewing industry, and it also used in the production of whisky and other spirits.

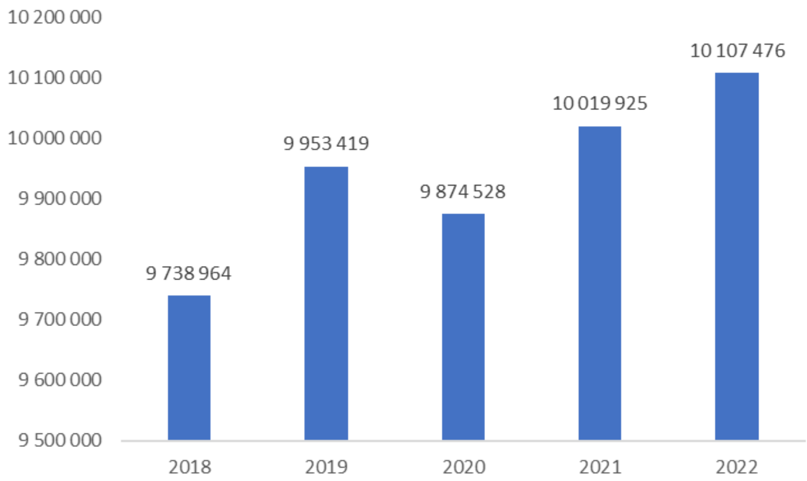
Figure 4: EU barley harvest (in thousands of tons)



Source: Eurostat, 2023; N.B.: 2024 data are Eurostat estimates

Barley malt production in the EU has been falling steadily since 2019. Barley malt is affected by the vagaries of the weather, which have a negative impact on yields.

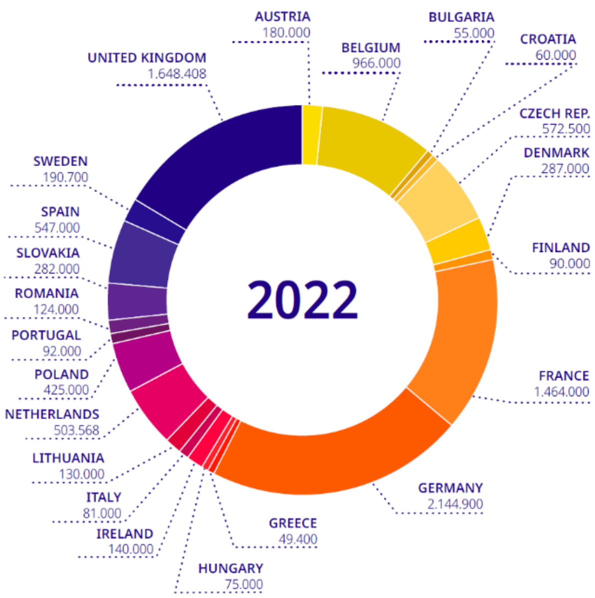
Figure 5: EU Malt production capacity (in tons)



Source: Euromalt, April 2024

Maltification capacity is constantly increasing in Europe. Between 2018 and 2022, it has increased by almost 4%. One of the explanations for the increase in European maltification capacity is explained by the number of breweries which continue to increase.

Figure 6: Share of malt production by European country (in tons) in 2022



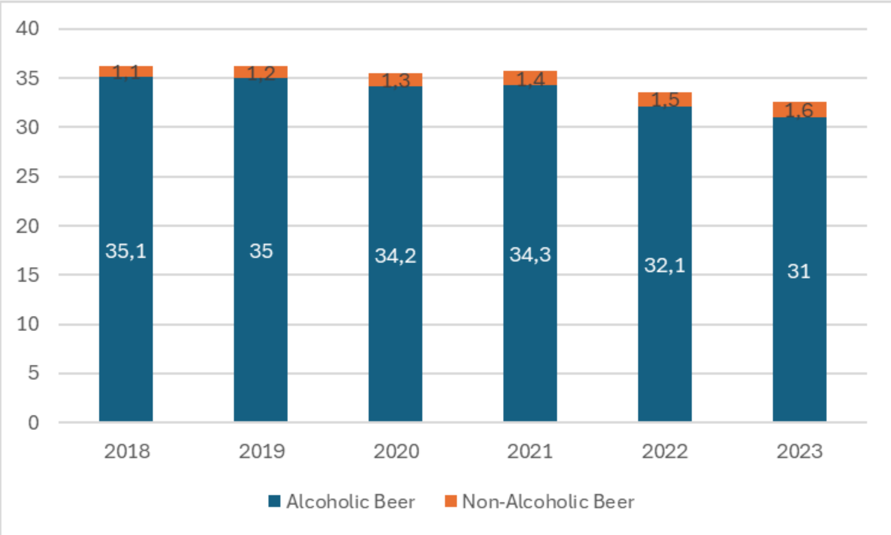
Source: Euromalt, 2024

In 2022, malt production was concentrated in 3 countries, which account for almost 50% of European production: Germany, the United Kingdom and France.

European market for barley malt beer

The beer market in Europe generated a revenue of 148 billion euros in 2023. The market has remained depressed since the beginning of the coronavirus pandemic, although 2023 saw revenue nearly return to pre-pandemic levels. European beer consumption continues to fall, as shown in the graph below:

Figure 7: Volume of the European Beer market from 2018 to 2023, by segment (in billions of litres)

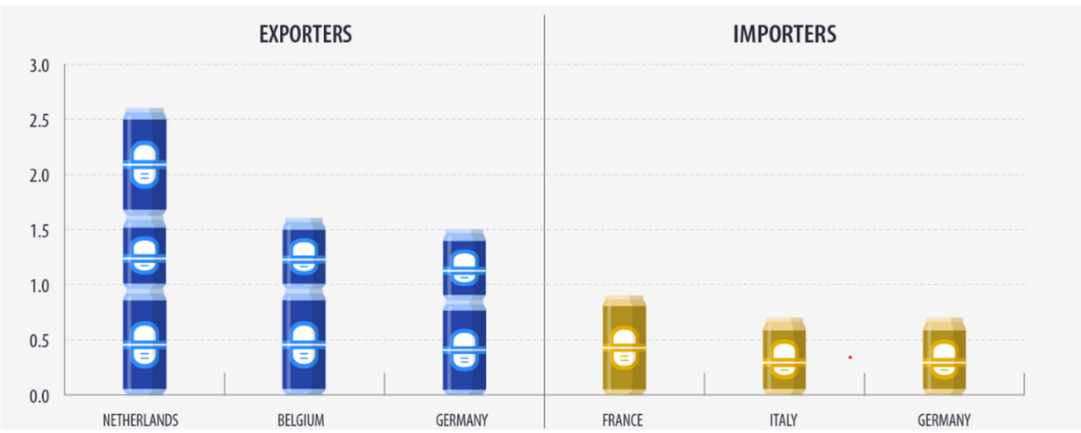


Source: Euromalt, n.d.

European Beer consumption has been falling steadily since 2018. There are many reasons for this. Firstly, the COVID-19 pandemic has brought beer production and consumption to a standstill. Secondly, the war in Ukraine has increased production costs, particularly for raw materials.

Germany was the leading producer of beer in Europe in 2022. However, per capita consumption is highest in the Czech Republic, with 136 litres of beer consumed per inhabitant. Despite this, Germany was not the biggest exporter of beer in Europe. Belgium took the top spot, shipping 16,39 million hectoliters. Europe is the biggest beer producer but not the biggest beer exporter.

Figure 8: Top Beer exporters vs importers in the EU, 2022



Source: Eurostat, April 2024

The Netherlands continued to lead as the top exporter of beer containing alcohol in 2022. The Netherlands exported a total of 2,6 bn litres of beer containing alcohol in 2022, accounting for 27% of the total EU beer exports. Compared to 2021, it increased of 0,7 bn litres in beer exports.

The Netherlands was followed by Belgium (1,6 bn litres; 17%), Germany (1,5 bn litres; 16%), Czechia (0,6 bn litres, 6%) and Ireland (0,4 bn litres, 4%).

France is still the largest importer of beer containing alcohol in 2022, with 0,9 bn litres, representing 17% EU total imports. The other big importers were Italy (0,7 bn litres, 14%), Germany (around 0,7 bn litres, 12%), the Netherlands (0,6 bn, 11%) and Spain (0,5 bn, 10%).

Barley malt production in the B-Resilient partner regions

i. Sud Provence-Alpes-Côte d'Azur

Table 2: Beer production in the Sud Provence-Alpes-Côte d'Azur region

Area	31.400 sq km
Population	5,1 million (2023)
Beer production	55.000 hectolitres (2020)
Number of breweries	138 (2022)
% of national production	5% of French production

Source: Insee, Agreste, interviews

There are around 140 breweries in the Provence-Alpes-Cote d'Azur region, with an estimated production of 55.000 hectolitres in 2022. The region ranks 8th in France in terms of brewery production. 6% of French breweries are located in the PACA region. In 2021, the breakdown by department was as follows:

- Alpes-de-Haute-Provence: 14
- Hautes-Alpes: 11
- Alpes-Maritimes: 27
- Bouches-du-Rhône: 29
- Var: 20
- Vaucluse: 27

The number of breweries in the PACA region is growing more slowly than in other French regions.

ii. Auvergne-Rhône-Alpes

Table 3: Beer production in the Auvergne-Rhône-Alpes region

Area	69.711 sq km
Population	8,7 million
Beer production	Around 500.000 hectolitre per year
Number of breweries	At least 400 breweries
% of national production	Almost 25 %

Source: Insee, Agreste, interviews

The Auvergne-Rhône-Alpes region is France's leading region in terms of the number of breweries, with nearly 350 spread throughout the region - of these, 160 are craft breweries. There is a real shortfall in regional hop production. In Auvergne-Rhône-Alpes, 62.635 ha of winter barley and 5.037 ha of spring barley were grown for all outlets (2019 data). Barley requirements in the region are estimated by the industry at 6.000 tonnes, including 2.000 tonnes for organic production. There are also four malting plants in the Auvergne-Rhone-Alpes region, mostly processing organically farmed products (Chambre d'Agriculture Auvergne-Rhône-Alpes, 2024).

iii. Galicia

Table 4: Beer production in the Galicia region

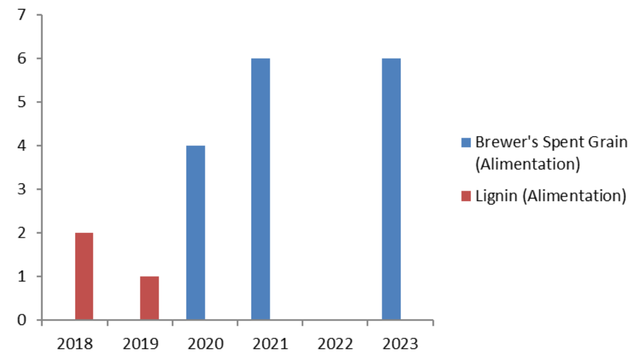
Area	29.574 sq km
Population	2,7 million
Beer production	Data non available
Number of breweries	29
% of national production	12%

Source: interviews

Spain is a major producer of barley and, according to the latest available data, between 2,4 - 2,5 million hectares were cultivated in 2022, of which 770.000 tonnes of barley were used for malting. More than 90% of the total hops are produced in the region of Castilla y León, with the rest distributed among Galicia, Catalonia, La Rioja, Navarre, the Basque Country and Andalusia. The cultivated area in Spain in 2022 amounts to some 580 hectares, with an estimated 1.000 tonnes of hops (in flower form) being harvested overall. Galicia is the third region in terms of the number of breweries (29). The autonomous community is home to one of the country's largest breweries, Corporación Hijos de Rivera, which produces approximately 12% of the country's total output.

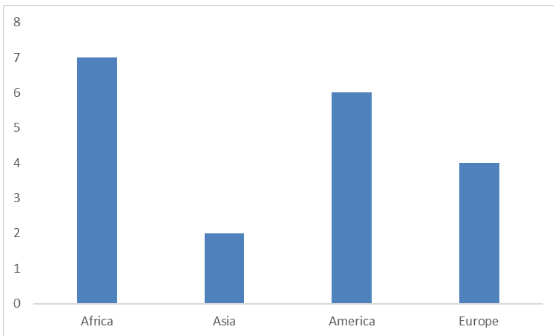
2.1.1.2. BSG-based products launched in Europe

Figure 9: Brewery spent grain and lignin product launches in Europe, per year



Source: Mintel, April 2024

Figure 10: BSG product launches by continent between 2018 and 2023

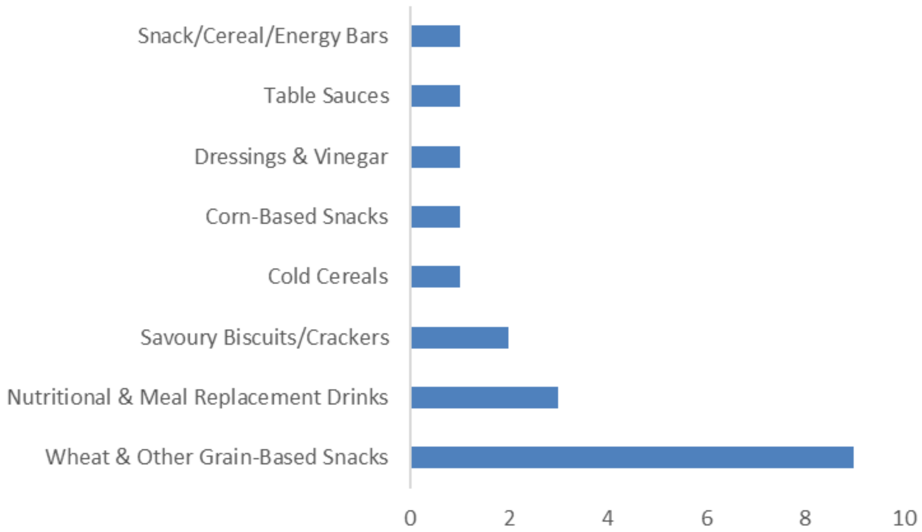


Source: Mintel, April 2024

The BSG-based product market is not experiencing any particular trends. Only around twenty products are listed in the Mintel product database in April 2024, with Europe being an important market. The companies questioned in this study indicated that business-to-business trade was the preferred method for adding value to brewers' grains.

Brewers' grains can replace wheat flour, particularly for bakery products, and this is especially evident in the search of Mintel's database for food BSG-based products, as shown below:

Figure 11: BSG product launches by category between 2018 and 2023



Source: Mintel, April 2024

A limitation regarding the use of Mintel and its ensuing results was identified during the development of this study. Indeed, not all products including brewery spent grains are included in this database. Furthermore, Mintel does not allow for the differentiation between molecules (or specific components) derived from BSG versus these same molecules, but derived from other sources. One cannot, *for example*, search for BSG-derived hemicellulose – results for hemicellulose derived from all possible sources will be shown. As such, there is a limit in the exploration of potential valorisation of brewery by-products.

2.1.2. Botanical and anatomical data

2.1.2.1. Botanical information of barley

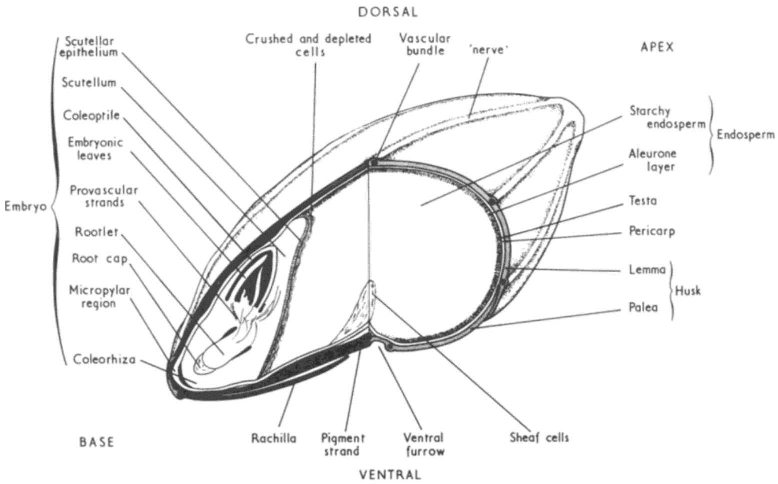
Barley (*Hordeum vulgare*), a member of the grass (*Poaceae*) family, originated from North Africa and Western Asia. Two main cultivars exist today, the 'six-row barley', made up of a cluster of three sessiles (fertile spikelets), and 'two-row barley', with one singular fertile spikelet (the lateral spikelets being sterile) (Native Plan Trust, 2024).

This terrestrial plant is a diploid; self-fertilising, the male plant will fertilize its own or adjacent flowers. Each node on each plant will be able to produce three flowers; the placement of kernels will defer according to the cultivar. Each cultivar can also produce different flavour profiles, important during the brewing process.

The plant's germination time can vary (between 1-3 days); its growing season is short, with maturity that can be reached at three months. Perennial barley will bloom both in spring and summer (Egbert, 2008).

The barley grain is made up of a round shape with tapered ends, and comprises a shallow wrinkle across its ventral side. The husks of chaffs (flowering glumes) tend to adhere to the grain, but this is not necessarily the case of all barley varieties. The caryopsis (a fruit) is found within the husk (Briggs, 1978). A base/dorsal/ventral/apex view of the barley grain can be found in the figure below.

Figure 12: "Idealized diagram of a barely grain, with a sector removed, to show the disposition of the tissues"

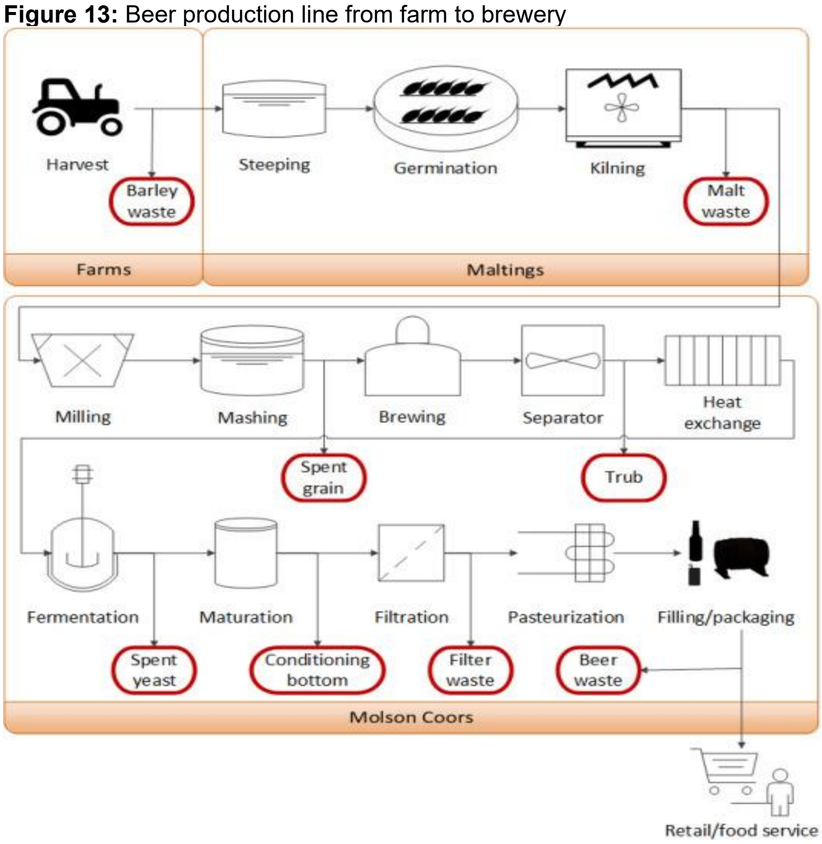


Source: Briggs, 1978

2.1.2.2. BSG Composition

During beer production, barley (the major grain of production) is turned into malt during the 'malting process' (composed of the steeping, germination and kilning steps). Following the malting process, the malted barley briefly goes through milling before entering the mashing phase, where the milled malt is mixed with water, and then undergoes through an enzymatic process where the starch and proteins are broken down. Following this process, both non-

Figure 13: Beer production line from farm to brewery



Source: Garcia-Garcia et al., 2019

degraded and extracted ingredients (in water) are obtained; brewery spent grains are the solids obtained (with wort being the aqueous solution) (Zeko-Pivač *et al*., 2022).

The main by-products arising from the production of (barley malt-based) beer include spent grain (which accounts for 85% of the total by-products), spent hops and yeast (Johnson *et al*., 2010). Other beer-making by-products include (as shown in the Figure 13 above) trub, conditioning bottom, filter waste and beer waste occurring post-packaging (Garcia-Garcia *et al*., 2019).

Brewery spent grains are generated in part from the beer waste production (41%), and from malt materials (31%) (Garcia-Garcia *et al*., 2019; Nigam, 2017); for every 100 L of beer produced, 20 kg of BSG are obtained (Naibaho & Korzeniowska, 2021).

Brewery spent grains (BSG) are a majority lignocellulosic material (other than protein, dietary fibre is a major component of BSG, as outlined in the Table 5 below), also containing non-cellulose polysaccharides, notably arabinoxylans and lignin.

Chemical composition of BSG will depend on a variety of factors, notably the specific grain variety, the harvest time, the conditions in which it was malted, and the conditions of mashing of the grain. Further changes in composition can arise during the brewing process, where adjuncts are added to the production. The three tables below (Table 5, Table 6, and Table 7) outline the (average) composition of BSG, including the constitutional composition, phenolic acid and sugar composition, and mineral, vitamin and amino acid composition.

Table 5: Composition of germinated barley foodstuff

Composition	% weight
Water	7,8
Protein	46,0
Lipids	10,2
Ash	2,0
Dietary fibre:	34,0
(Cellulose	8,8)
(Hemicellulose	17,0)
(Lignin	8,2)
Minor components (ferulic acid, coumaric acid, etc…)	<1,0

Source: Mitsuyama et al., 1998

Table 6: Total phenolic acid and sugar composition of brewer's spent grain

Phenolic acid composition	Mole fractions (%)
Trans-p-Coumaric acid	27,72
Cis-p-Coumaric acid	4,52
Trans-Ferulic acid	51,00
Cis-Ferulic acid	6,16
8, 5´-Diferulic acid	2,21
5,5-Diferulic acid	2,03
8-0-4´-Diferulic acid	6,36
Sugar composition	**Mole fractions (%)**
Arabinose	15,36
Fucose	0,11
Rhamnose	0,20
Xylose	29,84
Mannose	1,24
Galactose	2,00
Glucose (non-cellulose)	25,71
Glucose (cellulose)	12,60
Uronic acid	12,95

Source: Jay et al., 2008

Table 7: Minerals, vitamins and amino acids found in brewer's spent grain

Minerals (concentration < 5 %)	Vitamins (ppm)	Proteins
Calcium, cobalt, copper, iron, magnesium, manganese, phosphorus, potassium, selenium, sodium and sulphur	Biotin (0,1) Choline (1800) Folic acid (0,2) Niacin (44) Pantothenic acid (8,5) Riboflavin (1,5) Thiamine (0,7) Pyridoxine (0,7)	Leucine, valine, alanine, serine, glycine, glutamic acid and aspartic acid in the largest amounts, and tyrosine, proline, threonine, arginine, and lysine in smaller amounts. Cystine, histidine, isoleucine, methionine, phenylalanine, and tryptophan.

Sources: Huige, 2006; Mariani, 1953

The various uses and/or advantages of the components of BSG are outlined in the Table 8 below.

Table 8: Possible uses and/or advantages of components of BSG

Components of BSG	Possible uses/advantages of component	Source(s)
Lignocellulosic components	Main raw material for pulp and paper industries Bio-processing can produce fuel-grade ethanol Production of fermentable sugars by enzymatic hydrolysis Isolated lignin can be starting material for activated carbon, vanillin, emulsifying and chelating agents, benzene, dispersant, antioxidants, pesticides, phenols, fertilisers, polymers, adhesives, concrete additives	Mussatto *et al.*, 2010 Mussatto *et al.*, 2008 Gan et al., 2002 Mussatto *et al.*, 2007 Santos & Curvelo, 2001; Gargulak & Lebo, 2000
Phenolic acid compounds	Strong antioxidant properties (significant role in human health) Ferulic acid and *p*-coumaric acid have useful role in food industry	Graf, 1992 Graf, 1992
Carbohydrate fractions	Manufacture of food-grade chemicals Energy sources in microbial fermentations Sweetener or stabilizer in foods	Mussatto et al., 2006 Mussatto et al., 2006 Saito *et al.*, 1993; Serghat *et al.*, 1992
Proteins	Food products	Diptee *et al.*, 1989

Source: Innov'Alliance

2.1.3. Examples of valorisation of BSG

Several issues arise during the production of beer regarding the disposal of the major by-products; indeed, these are generally considered to be bulky (in terms of absolute quantity of product), have a relatively low market value, and are difficult to store due to their high moisture content (Johnson *et al*., 2010). In-depth analyses of the molecular composition of brewery spent grains (BSG) – the most significant, by quantity, by-product of beer production, have permitted researchers to identify major areas of application for BSG (see Table 8). The main use areas of BSG are outlined in the table below.

Table 9: Specific areas of application of BSG

Uses of BSG	Comments
Animal nutrition	Cattles, poultry, pigs, fish, rats and hamsters
Human nutrition	Flakes, whole-wheat products and extruded snacks
Energy production	Direct combustion or fermentation to produce biogas
Charcoal production	BSG charcoal
Biotechnological processes	Substrate for cultivation of microorganisms, as a substrate for production of enzymes
Brewing process	As an additive or carrier in brewing process
Brick constituent	Production of high-porosity bricks
Adsorbent	Pyrolysed spent grains can be used as an adsorbent for removing volatile organic compounds from waste gases
Paper manufacture	Paper towels, business cards and coasters
Agronomic application	For improving the productivity of fragile soils

Source: Johnson *et al*., 2010

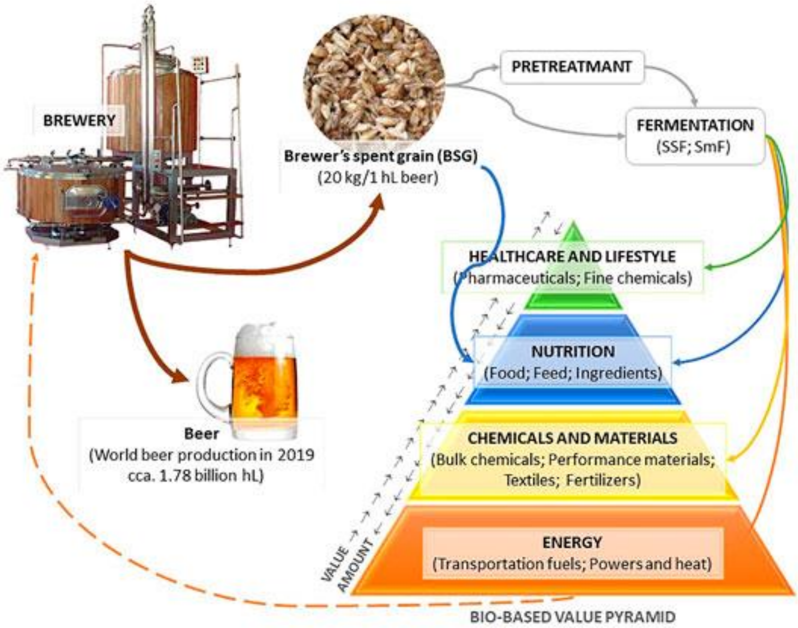
Some projects or possibilities for the valorisation of spent malt are being evaluated by the University of Santiago de Compostela, derived from the possible prebiotic potential that some of its molecules may have (Reis *et al*., 2014). Other models of biorefinery of brewery waste for the production of other molecules with bioactive properties, such as bacteriocins and biosurfactants, are being investigated by the University of Vigo (Outeiriño Rodriguez, 2022).

Projects such as the Life Brewery project (LIFE16ENV/ES/000160) have emerged as an innovative and sustainable technological solution to make the most of beer by-products. As a result of this project, six new ingredients have been developed for application in nutraceutics and as alternative raw materials for aquaculture feeds. It is worth noting that this has been done on a pre-industrial scale for the production of flours and feeds for aquaculture, so that the valorisation scheme applied to the case study of the project can be subsequently replicated and transferred to the European level (San Martín *et al*., 2023).

From the major sector uses outlined above, and supported by ongoing research/projects, five sectors of valorisation of BSG were selected in this analysis to provide more in-depth descriptions of possible valorisation. Animal nutrition and agronomic applications were grouped together, as were energy and charcoal production, with human nutrition/food and packaging/paper remaining in their respective solo categories. A final category grouping cosmetics, biotechnology and other biochemical processes has been included: industrial production. These aforementioned categories and ongoing projects also align with Zeko-Pivač *et al*.'s (2022) economic valuation of uses of BSG, as shown in the

Figure ***14*** below.

Figure 14: Bio-based value pyramid for the uses of BSG from brewery



Source: Zeko-Pivač et al., 2022

2.1.3.1. Feed & Agriculture

Feed

The main way in which BSG is valorised is through transformation for animal feed (Mussatto *et al*., 2006). Indeed, the use of BSG as animal feed has been ongoing for many years (Szponar et al., 2003). The lignocellulosic components of BSG (*i.e.*, cellulose, hemicellulose and lignin), as well as the presence of carbohydrates (notably sugars) and amino acids make BSG a highly advantageous source of nutrients for ruminants (Bisaria et al., 1997). Beyond this high fibre and protein content, the low-cost and wide availability of BSG make it a highly interesting substrate for animal feed (Mussatto, 2013).

As cattle feed, BSG can be found in both wet and dry material forms (Mussatto, 2013); beyond its nutritional and cost advantages, BSG has also been found to increase (bovine) milk production (actual milk yield), milk fat content, milk fat yield, and content of total solids (Belibasakis & Tsirgogianni, 1996).

Milk Stout, from the *Estrella Galicia Beer Factory*, is born from a totally innovative circular process: it is made from lactose from milk from cows from Galician farms fed with bagasse, the main by-product obtained from the production of the brand's beers. For this project, Estrella Galicia Beer Factory has had the collaboration of several Galician companies. *Galacteum* developed the process, an innovation whereby lactose is incorporated in the form of whey, provided by the *Celega* cheese factory. Milk from Galician farms under the coordination of the Aira agricultural cooperative is used to obtain it; one of these farms is *Pena Guisande*, whose cows are fed with bagasse supplied by Estrella Galicia (from Estrella Galicia interview by Clúster Alimentario de Galicia).

Agriculture

BSG also has interesting applications in the realm of agriculture, notably as a soil amendment. Nutrients within the BSG residues are highly valuable, including phosphorus or even potassium, important sources of nutrients for crops (Dessalew *et al*., 2017).

Spent grain has also been tested as an alternative to traditional compost, with one study showing enhanced plant germination and increased soil organic matter in calcareous soils. This same study found a reduction pH, increased “soil water holding capacity, organic matter, macronutrients, [and] micronutrients” (Aboukila *et al*., 2018). BSG can also be effective in reducing soil sodicity and increasing soil fertility (Aboukila, 2019).

2.1.3.2. Energy

Cellulose is a major “renewable natural biological resource” – its presence in barley, and so in the brewery industry, makes BSG a very interesting feedstock source to produce bioethanol (Aliyu & Bala, 2010). Bioprocessing BSG can produce fuel-grade ethanol (Mussatto *et al*., 2008); indeed, the lignocellulosic components of BSG, and more specifically the hemicellulose and cellulose fractions, “can be used for ethanol production” (Mussatto, 2013; Aliyu & Bala, 2010).

One study on the valorisation of BSG using a “novel microwave-assisted, catalysed, hydrothermal process” has demonstrated a promising approach. This environmentally friendly method of valorisation of the spent grains assisted in the production of bio-oil and bio-char (both biofuels) and sugar-rich aqueous solutions (platform chemicals). This single unit biofuel is an interesting development in the context of innovative biorefinery of BSG (Lorente *et al*., 2019).

There also exists a strong potential for transformation of BSG into (fuel) pellets for heat production, achieving technological and economic advantages, notably relative to other, non-BSG pellets (Sperandio *et al*., 2017).

2.1.3.3. Food

The composition of BSG, notably its carbohydrate fractions, proteins, phenolic acid compounds but also lignocellulosic components offer great variety for valorisation pathways in the domain of food and drink.

BSG can be used in the manufacture of food-grade chemicals (Mussatto et al., 2006). Lignin – when isolated – can be transformed into vanillin, emulsifying and chelating agents and antioxidants (Mussatto et al., 2007; Santos & Curvelo, 2001; Gargulak & Lebo, 2000). The strong antioxidant properties of BSG can have a significant role in human health if included in food products; the ferulic and *p*-coumaric acids found in BSG can also be useful in the food industry (Graf, 1992).

Spent grains can also be used in the manufacture of food products (Diptee et al., 1989), notably as a sweetener or stabilizer (Saito et al., 1993; Serghat et al., 1992). Indeed, various food products have been tested with an inclusion of BSG in various degrees, with different effects. It can be used “to enhance or upgrade the fibre contents of certain food items; such as breads and snacks” (Aliyu & Bala, 2010). Indeed, a few studies highlight the impact of BSG on the fibre content of foodstuffs; adding BSG (in the ranges of 25-35% by weight of the foodstuff) was found to increase the protein, and 15% additional BSG was found to double dietary fibre in snacks (Ktenioudaki et al., 2012). In a study of baked snacks, adding just 10% by weight of BSG “increased the fibre content two-fold” (Ktenioudaki et al., 2013). One French Company, *Maltivor*, revalorises brewery spent grain as flour, then destined for industrial use, either by bakeries or biscuit manufacturers. Once the raw material is obtained, it is then dried and milled; and, as is the case with Maltivor, if the brewery spent grains come from different breweries, a homogenisation process is required.

According to Maltivor, brewery spent grain flour can replace wheat flour up to 30 % - beyond its partial substitution quality, this flour also possesses interesting organoleptic qualities according to the different malts. There is, however, a need for caution in adding BSG into foodstuffs to avoid excessively changing organoleptic qualities of said foods beyond the consumers' level of acceptability for it. Limiting the added quantity of BSG helps to avoid perceived changes in taste of food, baking characteristics such as structure and texture, and maximizing acceptability to consumers (Ktenioudaki et al., 2012; Ktenioudaki et al., 2013). Maltivor also highlights the risk of consumers' perception of brewery spent grains as a 'waste' material.

2.1.3.4. Packaging and paper

The fibrous nature of brewery spent grains, owed to its lignocellulosic characteristics, makes it an interesting main raw material for the pulp and paper industries, but also for packaging (Mussatto *et al*., 2010; Mussatto, 2013). Spent grains have a variety of uses in the packaging and paper industry, having been used in the manufacture of "paper towels, business cards and coasters, conferring high-grade texture on these products" (Ishiwaki *et al*., 2000), but also plates, cups, cutlery.

Indeed, French start-up *Waste Me Up* collects brewery spent grains, transforms them and revalorises them for daily use, making for an interesting alternative to 100 % plastic versions. The spent grains go through a double drying process (mechanic and air drying) before being mulched. This mulching allows for the separation by size, and the final obtention of brewery spent grains flour. The fibres from the spent grains can then be integrated into plastic. At this point in time, bioplastics cannot be 100% made from the brewery spent grains and require a minimum of petrochemical-based plastic product.

Packaging, and in particular food packaging, where packaging is in direct contact with food, is faced with strict constraints and norms. The potential presence of pesticides and/or other phytosanitary products means the usage of brewery spent grains as packaging is strictly regulated, and innovation in the subject limited. Research in the area is nevertheless promising. Indeed, one study explored the preparation of nanocomposite films prepared with arabinoxylans extracted from brewery spent grains. These films were found to be homogenous, with demonstrable thermal stability and "good mechanical properties". As a result, the brewery spent grain film is endowed with UV-barrier properties, as well as anti-oxydant and antimicrobial activity. As such, there is strong potential for these types of films in food packaging systems (Moreirinha *et al*., 2020).

2.1.3.5. Industrial production (other than energy)

Other than in the domain of energy, brewery spent grains have interesting valorisation pathways to be explored in industrial production.

Multiple processes requiring separation and purification of products, whether it be for the treatment of effluents, or processes requiring adsorption capacities, use activated carbons (Montané et al., 2005). The chemical activation of brewery spent grains' lignin can create activated carbon. These BSG-derived activated carbons have shown to have a high adsorption capacity, especially for metallic ions such as "nickel, iron, chromium, and silicon". The adsorption rate of these activated carbons is similar to commercially-found rates, making them interesting for industrial use (Mussatto *et al*., 2010).

Brewery spent grains also make for interesting energy sources in fermentation (Mussatto et al., 2006). Various characteristics of BSG, including its "polysaccharide, protein content and high moisture contents" make for an ideal substrate for "microbial growth and degradation" (Robertson et al., 2010). It has also been found to be useful as a substrate for solid state fermentation. Indeed, one study inoculated nine different species of fungi onto BSG, resulting in solid state fermentation "without chemical adjustment or supplementation" (Khidzir et al., 2010).

Due to its characteristic as a waste by-product, BSG is seen as a low-cost substrate; this makes it particularly interesting as a substitute substrate for enzyme production, resulting in lower enzyme production costs (Aliyu & Bala, 2010).

2.1.4. Limitations and Recommendations

High moisture values of BSG means its management must be timely and precise to avoid fermentation of product spoilage (Mukasafari *et al*., 2017); this applies to its use as a feedstock for agricultural purposes (feed and soil amendments), as well as industrial uses (energy/petrochemical). This limitation is therefore applicable to most potential valorisation pathways of brewery spent grains. Brewery spent grains, arising from a process of fermentation, require stabilisation. Indeed, these grains may contain elements decomposing into alcohol, which can be problematic in the development of food products.

According to Galician brewers *Galician Brew, S.L.*, the main obstacles to the valorisation of brewery spent grains are the necessary financing of research, and the investment for the purchase of machinery for the evaluation of by-products. One study found that the difficulties in management and storage of the biomass material of BSG offset its advantages (high volume, low acquisition price, availability) (Buffington, 2014). One potential solution in the domain of the (energetic) industrial use of BSG is in its transformation into pellets (once moisture content has been controlled and reduced); this solution is technologically and economically feasible – and offers potential for circular bioeconomy when re-utilized by the breweries producing the BSG (Sperandio *et al*., 2017).

The inherent 'difficulties' related to moisture values in BSG do not pose a problem in the context of solid-state fermentation, where high moisture values are advantageous – there is no need to add substrates to accelerate fermentation (Robertson et al., 2010; Khidzir et al., 2010). In order to respond to this issue of high moisture values, Maltivor focuses on rapid access to the raw material, and its subsequent fast drying. Reducing both the distance and travel time of the raw material to its drying location (or drying on site of malting) is of primary importance.

2.2. Grapes and winemaking

2.2.1. Overview of grapes and winemaking market

Grapes have a long history of cultivation in Europe. According to Eurostat, there were 2.2 million vineyards holdings for wine in the EU in 2020, the vast majority of which were very small. Indeed, 83.3 % had less than 1 hectare of vineyards. Grapes have 2 traditional uses:

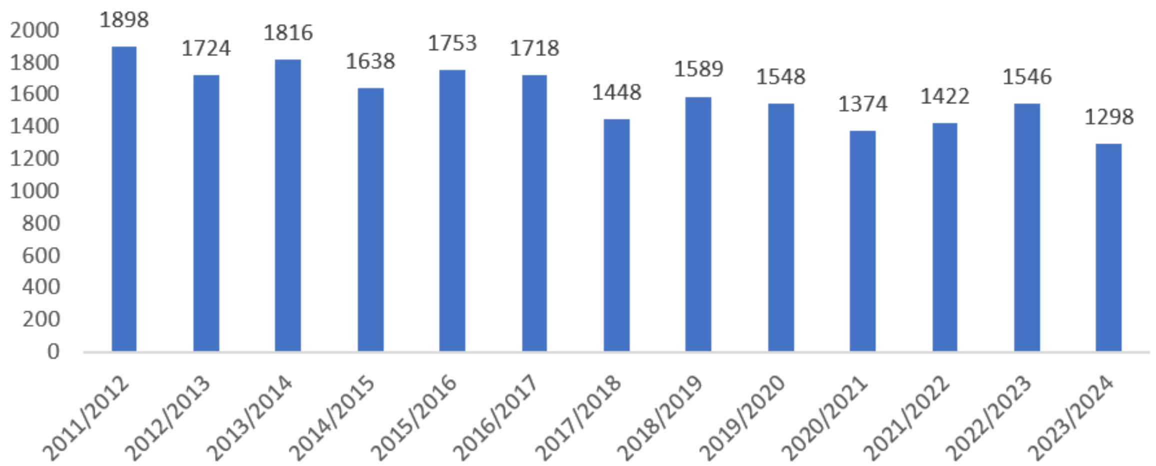
- Unpressed grapes or “fresh grapes”: referring to all kind of uses concerning the fresh fruit, such as table grapes and dried grapes (raisins)
- Pressed grapes, mostly “wine grapes”, which refers to grapes transformed into wine

Fresh grapes are amongst the most popular fruits in European consumption. The market is mature, with large volumes and relatively stable demand the whole year. Totalling 1.6 billion euros in 2021, table grapes have the highest import value (after bananas and avocados). Since 2000, the share of unpressed grapes has risen considerably, mainly due to the increase of table grape production, which has almost doubled in twenty years (31.5 million tonnes of table grapes in 2022, i.e. +3% compared to 2021).

2.2.1.1. European production of grapes

This section is to provide a short overview of the European grapes production, pointing out the main producing countries, as well as the main trends in terms of grape trade between Europe and the rest of the world.

Figure 15: EU-27: Annual volume of grapes produced from 2011 to 2024 (in thousand tons)



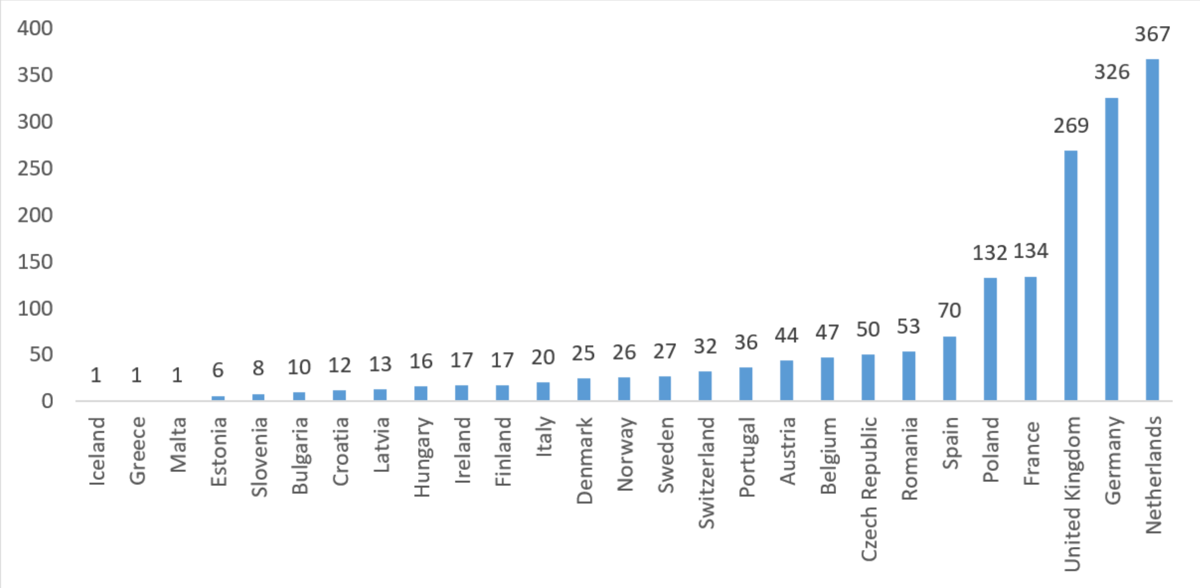
Source: Eurostat, data extracted in January 2024. NB: Data for 2023-2024 are Eurostat estimates.

Europe is one of the largest (table & wine) grape producers in the world, and a top five producer of table grapes. In 2021, China was by far the world’s leading producer of table grapes ahead of Iran and Turkey. However, the world’s main exporters are Chile, Italy, the United States and South Africa. The same year, table grape production in the 28-member European Union (EU) totalled 1.7 million tonnes, with Italy accounting for 57% of this volume. The EU is also the world's leading market for table grapes, with cumulative imports from its members reaching over 1.6 million tonnes (data for 2021), or almost 40% of the total volume traded worldwide each year (4 million tonnes).

The increase in production prices in the past 5 years creates opportunities for non-European suppliers that are more competitive. Most imports from non-European suppliers are registered by the United Kingdom and the Netherlands. The peak of (table & wine) grape consumption in Germany and France takes place during the European summer season (about June to

October). Off-season imported grapes find their way into mainland Europe through the Netherlands. France, Italy and Spain are the largest producers in the EU.

Figure 16: Total imports of fresh grapes per European country in 2022 (in thousand tons)



Source: Eurostat, data extracted in January 2024

Italy, Spain and Greece account for most exports of grapes. In the European grape season, Italy and Spain are the main competitors. They have a local advantage, and as long as their supply is abundant, it will be difficult to be in the market at the same time. Their peak supply is in August and September. On the other hand, European production of table grapes is becoming expensive and competition from nearby regions, such as Egypt and Morocco, is increasing**.**

The Netherlands is Europe's most important logistical hub for long-distance table grapes and its main entrance point for table grapes into Europe. From there, a large volume (80 % of grapes) is re-exported to the rest of the European Union. Germany is the main market for Dutch re-exported grapes and the largest consumer market in Europe (93 % of the imports stayed in the country). Germany sources the largest part of its grapes from Italy and Spain and through logistical hubs in the Netherlands.

With the decline of European consumption, international trade is seen by winemakers as an important issue. In the past two decades, wine has become popular in parts of the world that traditionally had lower demands. Outside the EU, the largest markets in terms of wine consumers are the US, UK, China, Russia, Argentina and Australia.

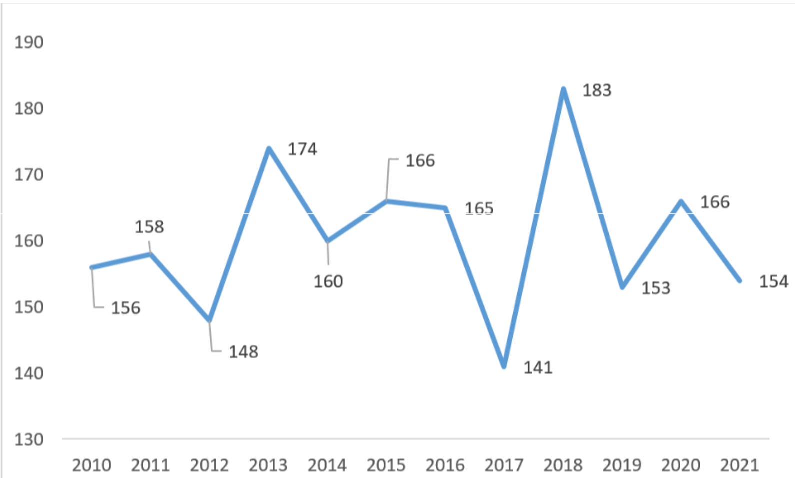
Global wine exports reached 111,6 million hL and 34,3 billion euros in 2021. In volume, the biggest exporter in Europe was Spain (23 million hL), while France led exports in terms of value (11,1 billion euros). The same year, Spain, Italy and France accounted for 54 % of world wine exports in terms of volume and 61 % in terms of value. The main EU exports markets for the EU were the US (4,7 billion euros) during the 2021-2022 period, followed by the UK (3,4 billion euros), Switzerland (1,3 billion) and Canada (1.15 billion). Two thirds of the wine imported by the US came from Italy and Frace. Germany is the biggest importer in terms of volume (14,5 million hl). In 2021 and 2022, the EU imported wine primarily from the US (440 million euros), Chile (379 million euros), Australia (241 million euros) and South Africa (239 million euros).

2.2.1.2. European wine production

For centuries, wine has been deeply rooted in European culture. Most European regions have traditionally considered wine a refined product. The EU legislation (Reg. (EU) 1308/2013) defines wine as "a product obtained exclusively from the total or partial alcoholic fermentation of fresh grapes, whether or not crushed, or of grape must".

According to *the Comité Européen des Entreprises Vins* (CEEV, European Committee Wine Enterprises), the EU is the first producer, consumer, exporter and importer of wine in the world. The average annual production between 2016 and 2020 was 165 million hectolitres (source: Eurostat). In 2020, the EU accounted for 45% of global wine-growing areas, 64% of production and 48% of consumption. The EU also accounts for half of world's production, with three quarters of EU wine produced in Spain, France and Italy.

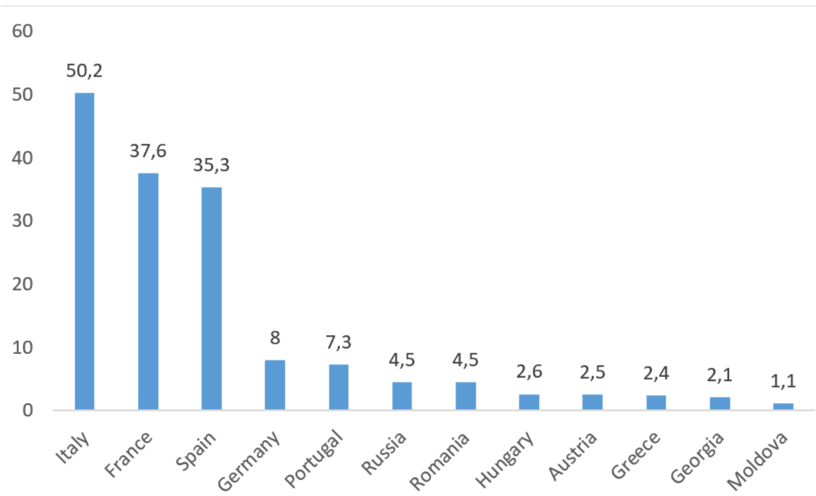
Figure 17: European Wine production (in millions of hectolitres)



Source: International Organisation of Vine and Wine, data extracted in January 2024

An increase in wine production took place in 2022 following the climatic events of the year (spring frost, hail, excess heat and drought). However, preliminary estimates for 2022 wine production in EU countries indicated quite a heterogeneous situation. The 2022 production of wine expected to increase by approximately 3.5 million hectolitres.

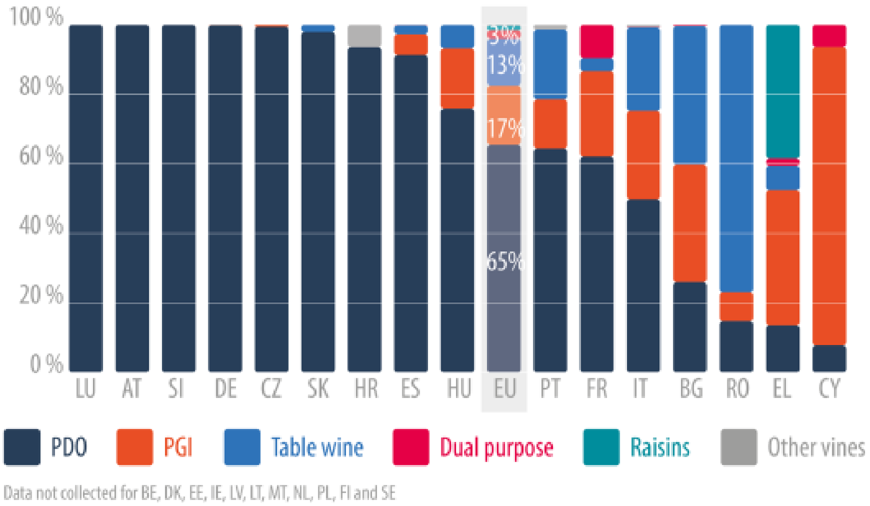
Figure 18: Volume of wine produced in wine producing countries in 2021 (European continent) (in millions of hectolitres)



Source: International Organisation of Vine and Wine, data extracted in January 2024

Italy is the richest European country in terms of wine varieties: there are several hundred official varieties in the country. Italy produces a large amount of table wine, vermouth, and cooking wines (such as Marsala). Three major regions produce high quality table wines: Veneto (18% of production), Tuscany (17%) and Piedmont (11%). In France, wine is commercially produced in every region, except the North coast. France produces 3000 different wines on more than two million hectares of vineyards. The main French wine areas are Bordeaux, Burgundy, Languedoc, Champagne, the Loire Valley, Alsace, Rhône, Provence and Corsica. All seventeen of Spain's administrative regions produce wine. The greatest concentration of vineyards is in Castilla-La Mancha, but the most famous come from Galicia, Catalonia, Andalucia and La Rioja.

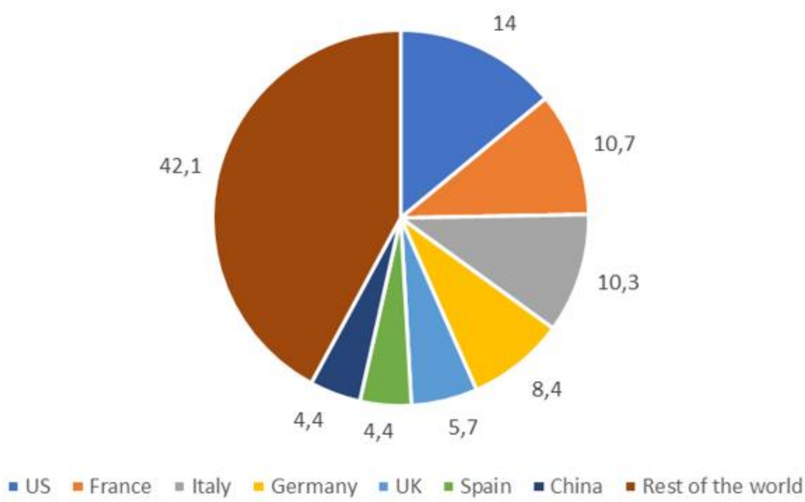
Figure 19: Vine surface area, by type of production



Source: Eurostat, data extracted in January 2024. Note: PDO: Protected Designation Origin; PGI: Protected Geographical Indication

Wine production in Europe is centred on PDOs products, which account for 65% of the total wine production. However, production varies from country to country. Romania is the only European country with a majority of vine grown for use in table wine. The other countries tend to focus on PDO or PGI.

Figure 20: Share of global wine consumption in 2021



Source: International Organisation of Vine and Wine (IOV)

The EU accounted for 48 % of global wine consumption in 2021. The same year, the largest consumption in the EU was in France (25,2 million hectolitres) and Italy (24,2 million hectolitres). Both countries are also the main wine producers. However, consumption in the European Union has declined since 2008; wine consumption has declined by 24 % in the 2010-2020 period. Forecasts for the 2020-2030 period point to a decline in wine consumption by 0,2 % per year.

Grapes production in the B-Resilient partner regions

The B-Resilient consortium partners decided to focus the market analysis of the grapes and winemaking VC on 5 regions where grapes and wine are important for the regional economy. As such regions are important grapes and wine producers, there is a specific attention for the valorisations of the by-products resulting from the transformation processes. The regions covered by this study are Sud-Provence-Alpes-Côte d'Azur and Auvergne-Rhône-Alpes in France, Emilia Romagna in Italy, La Rioja in Spain, and Central Macedonia, in Greece.

i. Sud-Provence-Alpes Cotes d'Azur

Table 10: Grape production in Sud-Provence-Alpes-Côte d'Azur

Area	31.400 sq km
Population	5,1 million (2023)
Grape production	32.000 tonnes of table grapes and 1,974 million hectolitres of wine (2023)
% area	34% of agricultural surface is destinated to viticulture
% of national production	5% of French vineyards

Source: Insee, Agrest, interviews carried out by Innov'Alliance

Sud-Provence-Alpes-Côte d'Azur (or PACA) is France's leading producer for table grapes (around 46.000 tonnes of table grape were produced in 2022). The departments of Vaucluse, Var and Bouches-du-Rhône are the main producers. Several varieties are produced: red grapes (Prima, Cardinal, Muscat, etc.), white grapes (Chasselas, Danlas, Centennial, etc.) and rosé (Rubi, Suffolk, etc.).

The climate is favourable to grape-growing: warm temperatures in summer and mild in winter, average humidity, little frost in winter, etc. PACA region also produces wine (nearly 1,97 million hectolitres in 2023), and rosé wines make up the most of its production (75% of the regional wine production). The PACA region is also the biggest producer of rosé wine in the whole of France. Red wine (20%) and white wine (5%) are also produced, but to a lesser extent.

ii. Auvergne-Rhône-Alpes

Table 11: Grape production in Auvergne-Rhône-Alpes

Area	69.711 sq km
Population	8.708.652 inhabitants
Grape production	2,3 million hl of wine
% area	48.000 ha
% of national production	Data non available

Source: Insee, Agrest, interviews carried out by Innov'Alliance

The Auvergne-Rhône-Alpes region produces several grape varieties: Chardonnay, Grenache Blanc and Muscat for white wine, Syrah, Muscat noir for red wine, etc. The region is the fourth-largest wine-producer of France. The regional wine industry covers 8.000 hectares and 2,3 million hectolitres. The largest wine variety produced in Auvergne Rhône-Alpes is Beaujolais (850.000 hl).

iii. Emilia-Romagna

Table 12: Grape production in Emilia-Romagna

Area	22.446 sq km
Population	4.426.629 inhabitants (2023 estimate)
Grape production	806.228,4 tonnes + 6,7 million hl of wine (data 2022)
% area	53.235 hectares (31/07/2022)
% of national production	Data non available

Source: ISTAT, interviews carried out by C-ER

Emilia-Romagna showed a production of 806.228,4 tonnes of grapes for wine production (data based on Istat). Considering the last 5 harvests, the situation is overall steady. The regional surface area consists of 5.,235,87 ha (data as of 31/07/2022). In the last 5 years, there has been an increasing trend in the number of cultivated hectares. Emilia-Romagna is characterized by 16.514 firms of different size: from small producers to big companies (e.g., Caviro). Designations of Origin generated 490 million euros of revenue (data from 2022). In 2021, Emilia-Romagna had 16.514 wine producers, for a total wine production of 6.700.000 hl. In the region, several projects are ongoing regarding the use of by-products of oenology. For example, small farmers generally use lees as a fertilisation medium. Historically, these products were used by distilleries for the production of grappa (an Italian grape-based pomace brandy).

There are also several projects on the use of grapevine products for the production of cosmetics, focusing, for instance, on the importance of antioxidant compounds (stilbenes, polyphenols etc.).

iv. La Rioja

Table 13: Grape production in La Rioja

Area	5.045 sq km
Population	323.377 inhabitants (2023)
Grape production	419.475,8 tonnes (in 2022)
% area	66.798 ha (mainly dedicated to the production of red grapes)
% of national production	Nearly 70%

Source: interviews conducted by food+i

La Rioja is an autonomous community in the north of Spain. The autonomous community is renowned for its very important wine industry. In fact, it is one of Spain's most productive wine-producing communities. Its most important product is red wine, which accounts for almost 90% of the region's wine production. Rioja has more than 500 winegrowers who mainly harvest Tempranillo grapes, renowned for their early ripening. However, this is not the most common grape variety in Spain; Grenache is still the most widely harvested grape variety in Spain.

Over the period 2018-2022, 2018 was the best year in terms of grape production (485.854.620 kg). Though it shrunk to 385.810.919 kg in 2019 and has been increasing since, grape production hasn't reached 2018 values yet. The regional vineyards surface area was 66,798 ha in 2022, and it has been increasing in the past 5 years. La Rioja hosts 637 wineries, with a wine production around 93.770 hectolitres.

Considering the importance of the wine industry in the region, several regional companies have cleverly harnessed the potential of winemaking by-products, transforming them into valuable resources and making significant contributions to sustainability and innovation within the industry. New products and ingredients issued from winemaking by-products developed by regional companies can be found in different sectors, such as beverage (ex. the production of gin infused with natural aromas from Rioja wine), natural cosmetics (i.e., from processed lees, a wine paste is obtained for making masks and wraps, along with an extract used in creams and lotions); nutraceuticals (through the extraction of enocyanine), etc (Ros, 2023).

v. Central Macedonia

Table 14: Grape production in Central Macedonia/Thessaloniki

Area	18.811 sq km
Population	1.782.630 inhabitants (2023 estimation)
Grape production	50.901 tonnes of wine, 24.110 for table use and 48 tonnes in raisin (2021)
% area	Data not available
% of national production	8% in 2021

Source: Elstat, n.d.

Central Macedonia is one of the thirteen administrative regions of Greece. Thessaloniki is at the heart of Central Macedonia, and the fourth largest prefecture in Northern Greece. The most important variety in Central Macedonia is Xinomavro, which is considered to be one of the “noblest” red grape varieties of Greek viticulture. As data on wine industry in the region of Central Macedonia are not readily available, the main features, importance and evolution of the sector must be inferred though broader data.

Greece is a small country where its approximately 1,500 wine-making enterprises (statistics of 2020) are mostly small and medium-sized or even family-owned and responsible for less than 0,9% of the world's wine production: about 2.283 thousand hl (harvest 2021), with relative stability compared to the average of the last twenty years, which have a value of €355 million. However, these companies mostly have high technology, good know-how and reputation, while producing a wide variety of “good” to “very good” wines with good value for money. The bottled ones number about 7.500 different labels, most of them white wine (67,3%) without designation of origin (2020).

Greek PDO and PGI wines, in terms of their share in the total Greek wine production, show a significantly increasing trend over the last two years and the estimate is that from 25,2% in 2021 they will reach 32,9% in 2022.

According to industry statistics, during the period:

- 2015-2021: the total number of grape producers (for wine) in Greece was approximately 193.000 (2,3% increase over the six year period) while the respective land used was of approximately 1.030.000 ha (0,1% decrease over the six year period).
- 2020-2021: 2.284 thousand hl of wine were traded in the Greek market of Greece, just 0.9% below the average of the last 220 years. 55% of this is estimated to have been traded in bulk or in a bag (bag-in-box), while due to the special conditions of the Covid-19

pandemic, 35% through HORECA and various entertainment venues, 45% through Super Markets, 15% in wineries and 5% online. The trade in these aforementioned categories for 2019-20 were 65%, 25%, 7% and 3%, respectively.

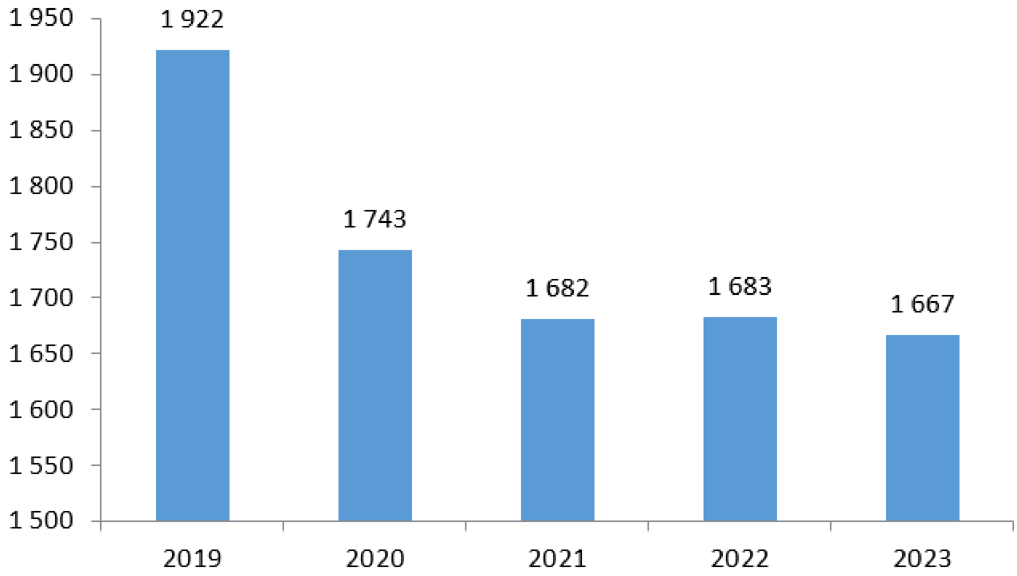
- 2015-2021: the N. Greece (including Region of Central Macedonia) accounted for about 148,000 ha of land used to produce grapes (for wine).
- 2020-2021: the N. Greece's wineries treated approximately 550.000t of grapes, accounting for about 14%-16% of the treated biomass.

Although the overall wine production is not very high, wastes and by-products form wineries are important for other SMEs. Most of the pomace is used for distillation, compost, or animal feed. Pilot efforts are in progress in different wineries to extract high value compounds or products such as essential oils from grape seeds, anthocyanins for the food industry and compounds such as resveratrol for the cosmetic and pharma industry. Most of them have been or are funded from research programs and cooperations between SMEs and Research/Academic entities.

2.2.1.3. Grape-based products launched in Europe

Grape-based products are frequent on the European market. Nearly 8.700 new products have been launched between 2019 and 2023.

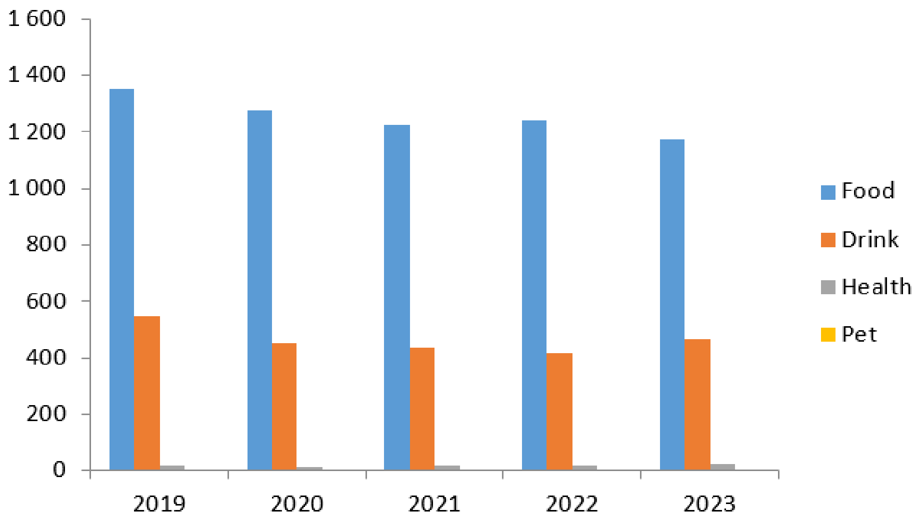
Figure 21: Evolution of grape-based products launched by year between 2019 and 2023



Source: Mintel, extracted January 2024

However, the number of grape-based product launches has been declining over the period considered. The peak of the grape-based products trend seems to have passed.

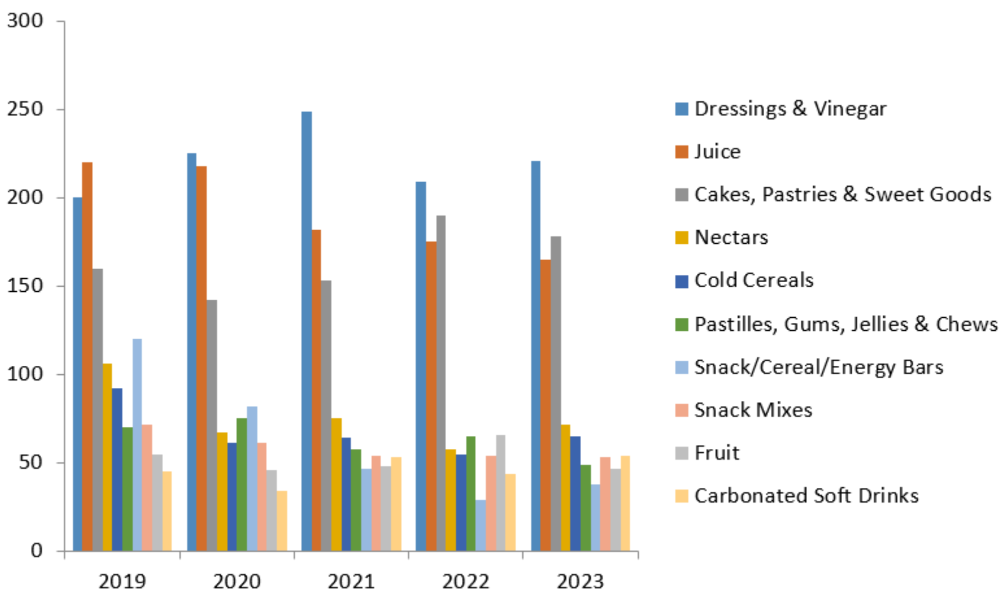
Figure 22: Evolution of grape-based products by category and by year between 2019 and 2023



Source: Mintel, extracted on January 2024

Launches of new grape-based products between 2019 and 2023 were primarily in the food and drink sectors. The molecules extracted from grapes are exploited also in different markets, such as cosmetics, in the form of seed oil, or as an antioxidant.

Figure 23: Evolution of grape-based products by sub-categories and by year between 2019 and 2023



Source: Mintel, extracted January 2024

The food industry mostly exploits grapes in liquid form (vinegar, juice, nectars). Raisin-based products are also very popular in new launches. This is because both liquid and raisin processing enable grapes to be preserved longer.

2.2.2. Botanical and anatomical data

Grapevine (*Vitis vinifera L.*) is a worldwide cultivated fruit crop with a high economic value. Grape berries can be used as fresh fruit (raisin), or they can be fermented to produce wine (most of grape-fruit production). Wine production is an ancient human activity that generates several by-products.

2.2.2.1. Botanical information

Grape is a grafted perennial woody plant that differs from annual crop plants on several aspects. Many perennial crops are clonally propagated, allowing to keep the genetic combinations that have been selected. Grape plants are grafted in many countries. Grafting consists of combining graft scions (shoots of a plant) to rootstock (root system) of a different plant with the aim to improve the robustness of the graft partners. This method is widely used in vineyards. Perennials, including grape plants, exhibit recurring cycles of growth and dormancy. The grapevine's seasonal development involves bud break in spring, followed by leaf and cluster formation, blooming, fruit set, and ripening in summer. Leaf fall occurs in autumn, leading to bud dormancy in winter. This entire cycle spans about 7 months, subject to environmental factors and management practices. The grape plant's life cycle is meticulously divided into 47 growth stages, serving as a management guide. Despite the existence of numerous grape cultivars worldwide, a small percentage, mainly 12 varieties, constitutes a significant majority of vineyards in certain countries.

2.2.2.2. Composition

Composition of grapes depends on variety, season, ripeness, cultivation conditions, etc. Grape berries are rich in sugar, pigments, aroma and polyphenolic compounds which are beneficial to human health. The table below represents an estimate of the nutritional composition of white and black grapes.

Table 15: Nutritional composition of black and white grapes (per 100g of raw product)

Fresh grapes	Grapes (black)	Grapes (white)
Energy value (kcal per 100 g)	90,1	79,1
Water (g)	76,7	79,4
Fibres (g)	2,7	2
Carbohydrates (g)	20	16,9
Copper (mg)	0,12	0,08
Potassium (mg)	210	150

Source: Aprifel

Grapes (black or white) are rich in minerals and trace elements in particular a significant amount of copper and potassium. The table below indicates mineral and trace element composition for white and black grapes.

Table 16: Mineral and trace element composition of grapes

Component	White Chasselas grapes (Average content per 100 g of raw product)	Black Muscat grapes (Average content per 100 g of raw product)
Calcium (mg)	16	13
Chloride (mg)	< 20	< 20
Copper (mg)	0,08	0,12
Iron (mg)	0,14	0,22
Iodine (µg)	< 20	< 20
Magnesium (mg)	7,5	7,3

Manganese (mg)	0,07	0,09
Phosphorus (mg)	21	20
Potassium (mg)	150	210
Selenium (µg)	< 20	< 20
Sodium (mg)	< 5	< 5
Zinc (mg)	0,07	0,06

Source: Aprifel

Grapes are also rich in vitamins, in particular vitamin A and vitamins of group B. The table below gives an estimate of vitamin content for white and black grapes.

Table 17: Vitamin composition of grapes

Component	White Chasselas grapes (Average content per 100 g of raw product)	Black Muscat grapes (Average content per 100 g of raw product)
Provitamin A Beta-carotene (µg)	27,4	67,7
Vitamin A equivalent (µg)	4,57	11,28
Vitamin B1 (mg)	0,031	0,057
Vitamin B2 (mg)	0,056	< 0,01
Vitamin B3 (mg)	< 0,10	< 0,10
Vitamin B5 (mg)	0,1	0,09
Vitamin B6 (mg)	0,054	0,034
Vitamin B9 (µg)	8,34	11
Vitamin C (mg)	4,14	3,11
Vitamin E (mg)	0,35	0,99
Vitamin K1 (µg)	2,18	5,7

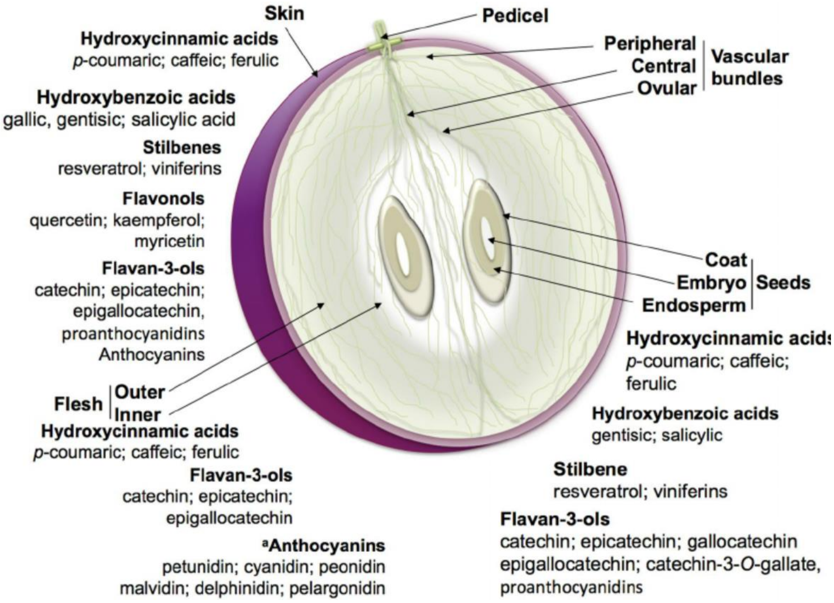
Source: Aprifel

Grapes are rich in polyphenols, which play a crucial role in grape quality, particularly due to their contribution to taste and colour. Flavanols and flavan-3-ols are involved in the astringency and bitterness of grapes (Drewnowski & Gomez-Carneros, 2000). The golden yellow colour of white grapes is attributed to the presence of flavonoids, yellow pigments, and, more importantly, the absence of anthocyanins (Ferreira *et al.*, 2016).

The structure of a ripe grape berry consists of three types: skin, flesh and seed. The chemical composition of each of these tissue types differ, which strongly influences final grape and grape product quality. For example, hydroxycinnamic acids like *p*-coumaric, caffeic or ferulic were found in skin, flesh and seeds. Anthocyanins, cyaniding or peonidin were only found in skin.

The structure of a ripe grape berry and pattern phenolics biosynthesis distribution between several organs and tissues is described in the scheme below.

Figure 24: Schematic structure of a ripe grape berry and pattern phenolics biosynthesis distribution between several organs and tissues

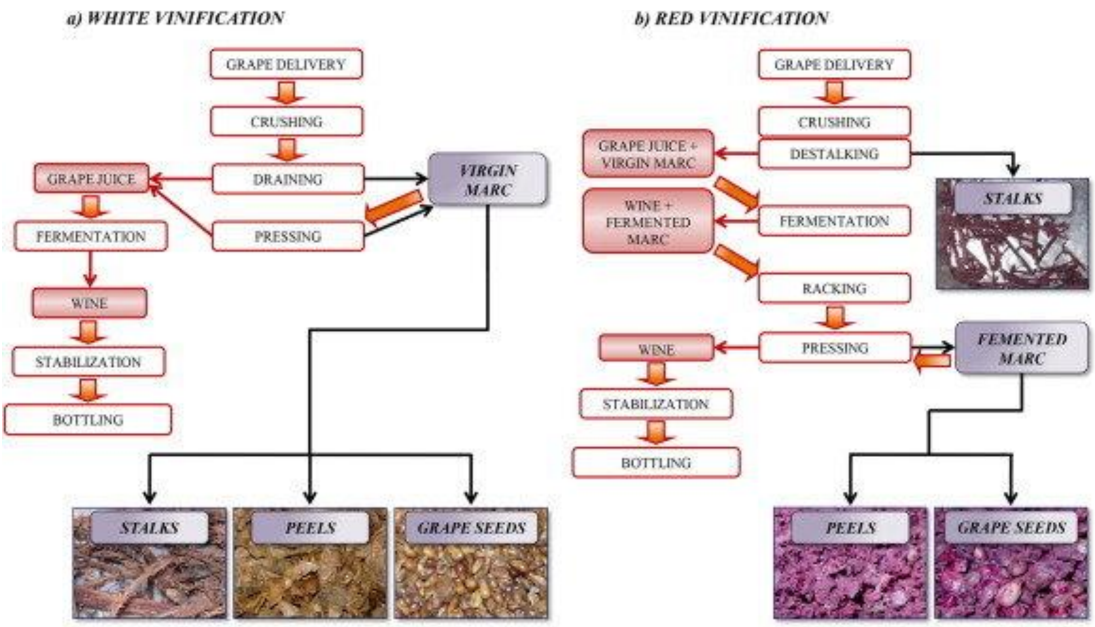


Source: Teixeira *et al.*, 2013

2.2.2.3. Processed grapes: winemaking by-products

The chart below illustrates red and white winemaking and their associated by-products. For white winemaking, the by-products include virgin pomace, stalks, peels, or grape seeds. Regarding red vinification, the by-products include stalks, fermented pomace, peels, or grape seeds. The B-Resilient partners decided to focus their attention on grape pomace, which represent one of the major by-products of winemaking (estimated to represent 10-13% of the initial weight of each grape) (data extracted from interviews with Italian and Spanish SMEs).

Figure 25: Red and white wine making process

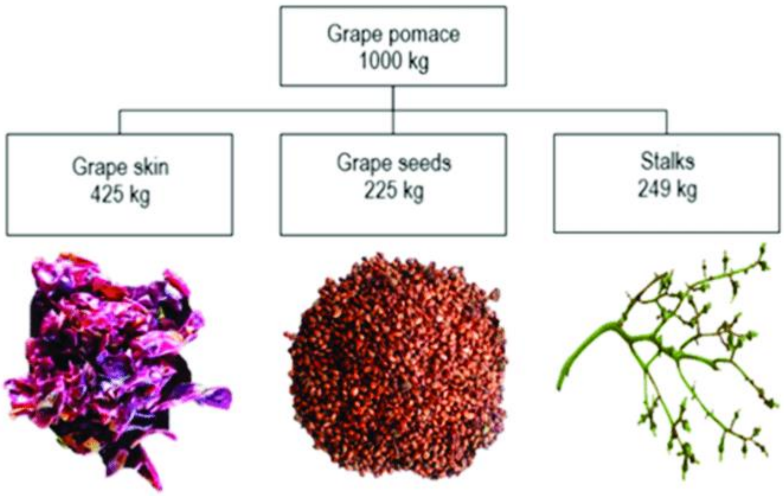


Source: Toscano *et al.*, 2013

Grape pomace

Grape pomace (or grape marc) consists of the solid remains of the grape after the juice is extracted. It includes skins, stalks and seeds, as illustrated in the figure below.

Figure 26: Composition of grape pomace (for 1.000 kg)



Source: Spinei & Oroian, 2021

Grape pomace is one of the most abundant solid by-products generated during winemaking (62% of the generated waste, according to Schieber et al, 2001). Many products, such as ethanol, tartrates, citric acid, grape seed oil, hydrocolloids, bioactive compounds and dietary fibre are recovered from grape pomace. The table below summarises one example of physico-chemical composition of grape pomace.

Table 18: Example of physico-chemical composition of grape pomace (Vitis Vinifera L.)

Compound	Dry Matter Content
Physico-chemical parameters	
Ash	4,65 ± 0,05 g/100 g
Moisture content	3,33 ± 0,04 g/100 g
Fiber	46,17 ± 0,80 g/100 g
Lipids	8,16 ± 0,01 g/100 g
Proteins	8,49 ± 0,02 g/100 g
Carbohydrates	29,20 g/100 g
Fructose	8,91 ± 0,08 g/100 g
Glucose	7,95 ± 0,07 g/100 g
Energy value	224 Kcal/100 g
Minerals substances	
Ca	9,90 g/kg
P	2,70 g/kg
Mg	0,80 g/kg
K	13,90 g/kg

Na	0,22 g/kg
S	1,50 g/kg
Mn	13,00 mg/kg
Zn	25,00 mg/kg
Cu	49,00 mg/kg
Fe	361,00 mg/kg
Se	0,20 mg/kg
Co	0,40 mg/kg
Bioactive compounds	
Vitamin E	5,00 mg/kg
Vitamin C	26,25 ± 0,01 mg AAE [a]/g
Soluble fiber	9,76 ± 0,03 g/100 g
Insoluble fiber	36,40 ± 0,84 g/100 g
Total anthocyanin content	131,00 ± 0,40 mg/100 g
Total phenolic content	60,10 ± 0,10 mg GAE [b]/g
Catehic tannins	13,10 ± 0,80 mg CE [c]/g
Hydrolysable tannins	3,70 ± 0,10 mg TAE [d]/g
Quercitin	128,70 ± 5,90 µg/g
Gallic acid	607,00 ± 9,00 µg/g
Catechin	1973,40 ± 17,60 µg/g
Procyanidin B2	1071,00 ± 17,70 µg/g

Source: Spinei & Oroian, 2021

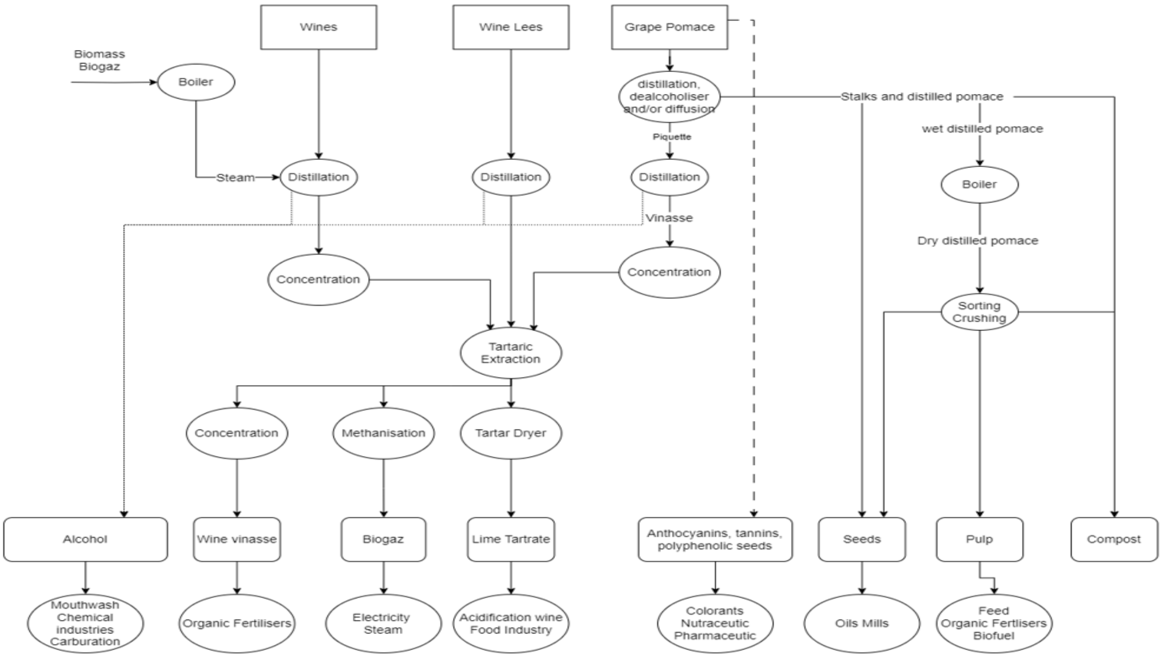
One Italian enterprise specialised in the processing of by-products stated that 100% of grape pomace is exploitable in the circular supply chain, with only 0,05% intended for energy production, making it the most valuable winemaking by-product. However, achieving such an excellent level of exploitation may be challenging for many companies due to various factors such as economic feasibility, technological limitations, and market demand.

As the molecular composition of the grape pomace is variable, one of the major challenges related to its valorisation is linked with the need to assess its chemical and biochemical composition, and ensure its stability, which is a crucial issue to unlock its potential for sustainable optimization. Collaboration between academia and industry is essential to drive innovation and address such issues, as it emerged from the interviews carried out in Greece.

2.2.3. Examples of valorisation of winemaking by-products

Winemaking generate several by-products. Based on literature review and the interviews with manufacturers, Figure 27 illustrates where by-products are generated in the transformation process.

Figure 27: Valorisation of winemaking by-products



Source : Institut Français du Vin, translated by Innov'Alliance

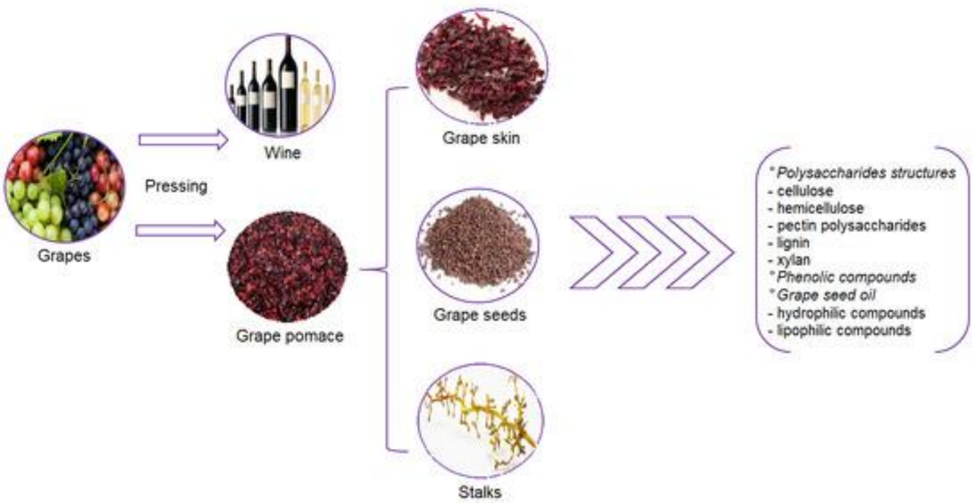
The literature reviews and the interviews conducted by the consortium partners involved in the grapes and winemaking VC, allowed to identify 6 major ways of valorisation:

- Food
- Pigment industry
- Feed
- Bioactive compounds
- Tartaric acid
- Energy
- Biomaterials
- Agriculture

2.2.3.1. Food

Grape pomace, as a result of the winemaking process, can be used for various applications, including human consumption.

Figure 28: Example of grape pomace valorisation in food ingredients



Source: Spinei & Oroian, 2021

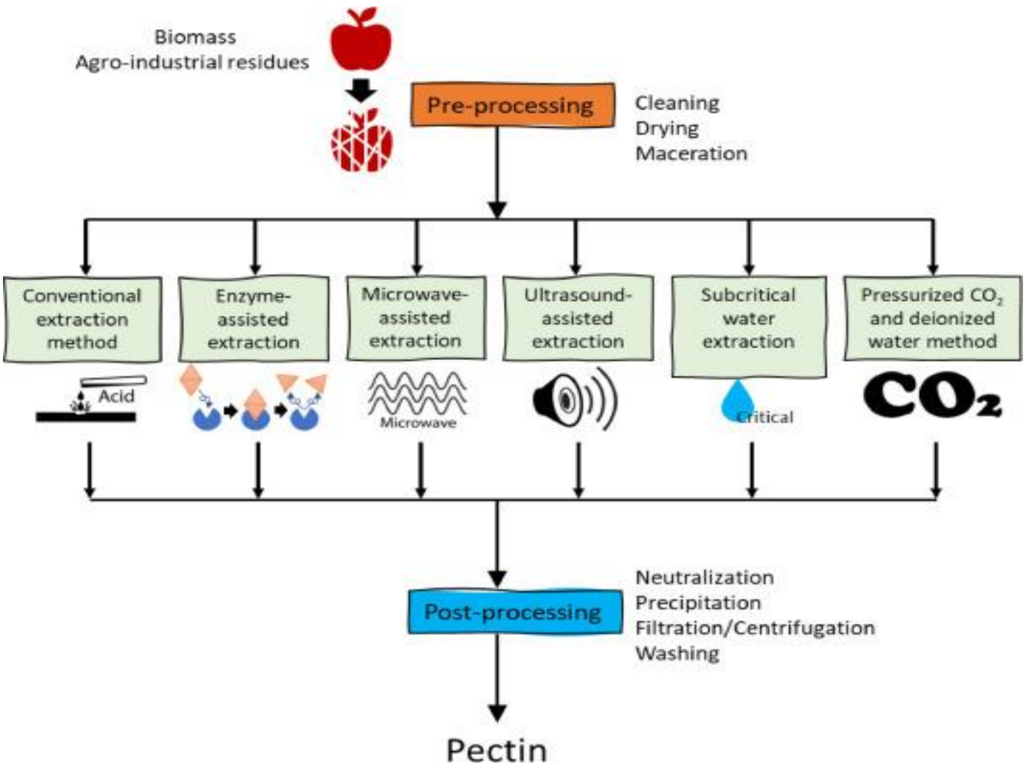
Two valuable compounds issued from grape pomace seems to be particularly used in the food industry: pectin and grapeseed oil.

Pectin

The review of the scientific literature illustrated that pectin as is key area of research to recover value from grape pomace. Pectin as a fermentable soluble dietary fibre has attracted considerable research and development interest worldwide, due to its diverse processing properties and health benefits (Zhang et al., 2021a). The total content of pectin in grape pomace is high and ranges from 3,21 to 7,27 % of dry grape pomace (Limareva *et al*., 2019).

Extraction of pectin is performed by several methods. The following figure summarises the main techniques of extraction.

Figure 29: Overview of extraction methods of pectin



Source: Roman-Benn *et al*., 2023

The type of extraction affects the yield, physico-chemical and functional properties of pectin.

For example, enzymatic extraction of pectin is environmentally safe and more efficient in terms of pectin yield. However, enzymes contribute to degradation of pectin and modify physico-chemical characteristics of pectin. The type of extraction has environmental and technological consequences which are summarized in the following table.

Table 19: Comparison of different pectin extraction methods

	Extraction temperature	Yield	Extraction Time	Energy Consumption	Technological input	Environmental concern
Conventional method	+++	++/+++	++	+++	+	+++
Enzyme-assisted extraction	+	++	+++	++	++	++

Microwave-assisted extraction	+/++	++/+++	+	++	+++	++
Ultrasound-assisted extraction	+/++	++/+++	+	++	+++	++
Subcritical water extraction	++++	++	+	+++	+++	++
Pressurised CO_2 and deionised water method	+++	+	++	+++	+++	+

Source: Roman-Benn *et al*., 2023

Pectin has a wide range of uses due its biodegradability and biocompatibility properties. In food industry, pectin has 5 main uses:

- Texture agent
- Gelling agent
- Emulsification capacity
- Food encapsulation
- Food coating/film

Pectin also has applications in biomedical and pharmaceutical industries.

Grapeseed oil

Grapeseed oil is a historical method of valorisation of grape pomace. Grapeseed oil is rich in phenolic compounds, fatty acids and vitamins, which makes it interesting not only in the food industry, but also in pharmaceutical and cosmetics. Grapeseed oil has beneficial properties for health, such as anti-inflammatory, cardioprotective, antimicrobial and anticancer properties. The physicochemical composition varies according to species and the extraction technique. The physicochemical composition is described in the following table.

Table 20: Physico-chemical composition of grapeseed oil

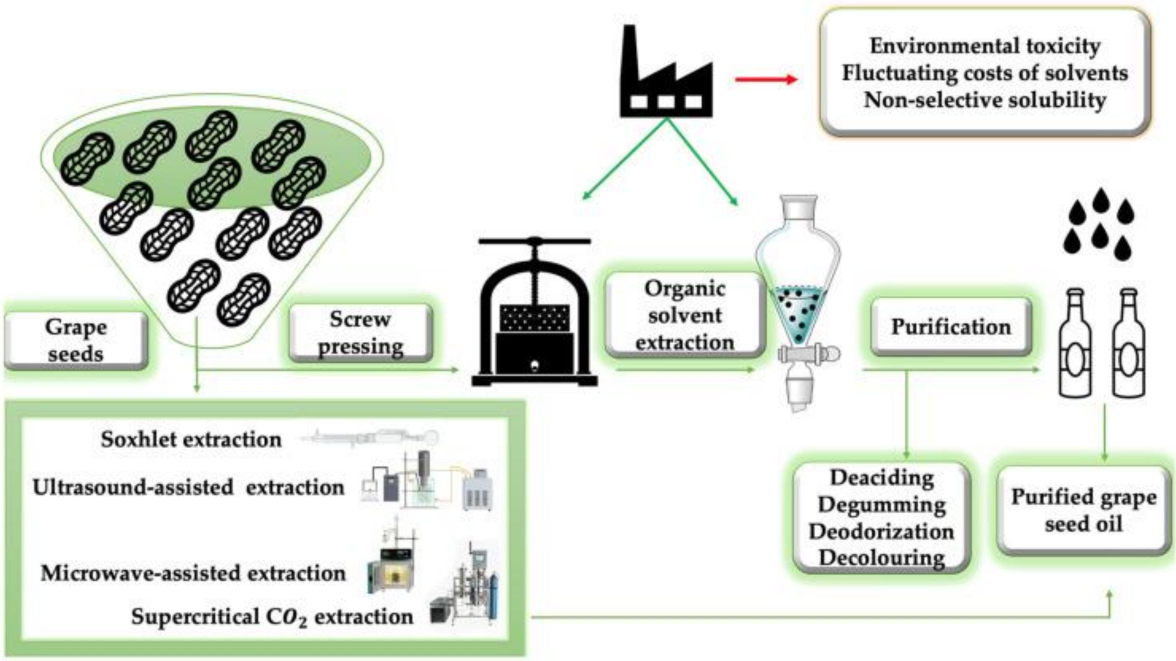
PHYTOSTEROLS	mg/kg/OIL
Cholesterol	nd–0,10
Cholestanol	Nd
Brassicasterol	0,6–0,9
2,4 methylencholesterol	nd–0,18
Campesterol	0,1–9,3
Campestanol	–
Stigmasterol	10,2–10,8
Δ-7 campesterol	0,16–0,27
Δ-5 2,3 stigmastadienol	–
Clerosterol	0,90–0,94
β-sitosterol	66,6–67,4
Sitostanol	3,92–4,70
Δ-5 avenasterol	1,98–2,09

Δ-5 2,4 stigmastadienol	0,41–0,47
Δ-7 estigmastenol	1,99–2,30
Δ-7 avenasterol	0,98–1,10

Source: Garavaglia *et al*., 2016

The production of grape seed oil from grape pomace is described in the diagram below.

Figure 30: *Extraction methods for obtaining grape seed oil*



Source: Gitea *et al*., 2023

In the food industry, grape seed oil is perfect for cooking due to its high smoke point and can be used as a raw dressing or as an ingredient in various recipes. With a fruity touch, this oil solidifies at lower temperatures, making it an excellent choice for marinating fish, meats, and creating dressings. It is also a valuable component in cosmetic products due to its high linoleic acid content, providing smoothness and texture to the skin. Rich in Vitamin E, Omega-6, and Omega-3, grape seed oil supplies essential nutrients that the human body cannot produce, necessitating inclusion in the diet.

Limitations to the valorisation of grape seed oil:

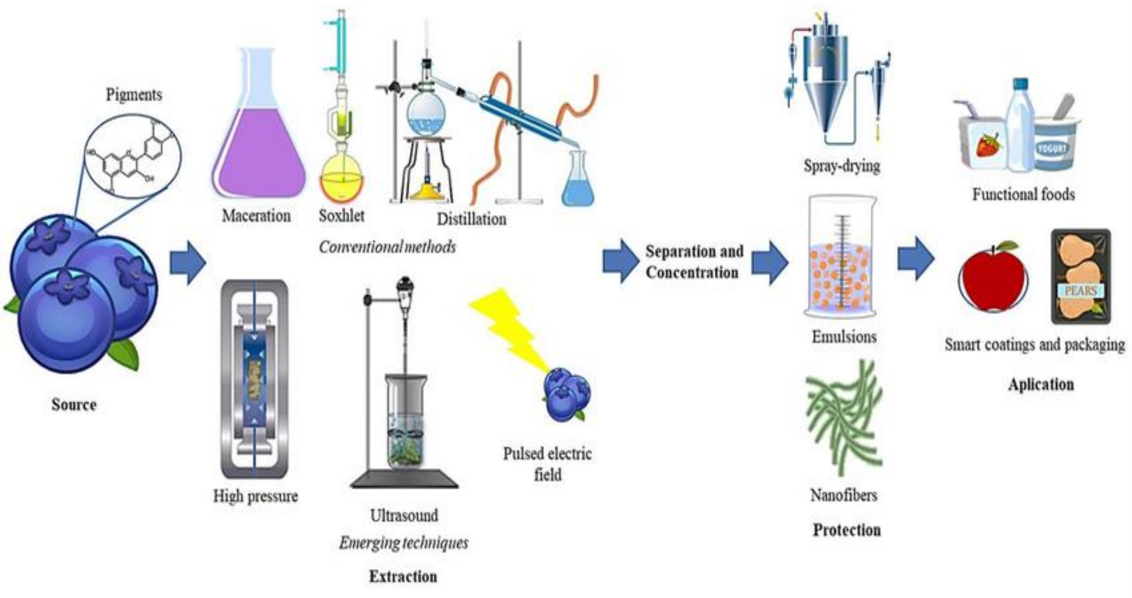
- Extraction technologies are varied and have very different impacts on physicochemical and organoleptic characteristics. In addition, the scalability of technologies is a problem raised by the manufacturers interviewed.
- Other natural pectins, notably apple pectin, are preferred by manufacturers. Apples are richer in pectin than grapes. Similarly, there are more and more competitors to grapeseed oil: olives, sunflowers, etc.
- Pectin can be synthesised, which limits the use of this by-product.

2.2.3.2. Pigment industry

Grapes are rich in anthocyanins. Anthocyanins are responsible for the red and blue colours of grapes. Chemically, they belong to the flavonoid family, a subclass of polyphenols, which are benzene compounds containing hydroxyl groups (Bueno *et al*., 2012). Anthocyanins play a variety of roles in the plant: they attract pollinators and animals that hide their seeds, repel herbivores and also act as a photoprotector.

In wine, the concentration and type of anthocyanins depend on many factors, such as the grape variety, ripeness, climate, terroir or the wine itself. grape variety, ripeness, climate, terroir or type of vinification type of vinification (Burns *et al*., 2002, Soares de Andrade *et al*., 2013). Cyanidins, delphinidin and peonidin are the main anthocyanins in grapes. However, malvidin, petunidin and pelargonidin can also be found in grapes. Anthocyanins are found in the pomace. As the pomace is unstable, colour producers have 24 hours to collect, extract and stabilise the compounds.

Figure 31: General process for the obtention of pigments from plant sources and their application in the food industry



Source: Favre *et al*., 2019

Grape anthocyanins, or grape skin extracts, range in colour from violet-red to brick red. They are used in a variety of food applications, particularly for products with an acidic pH. Grape extracts are therefore naturally found in *(non-exhaustive list)*:

- Alcoholic beverages,
- Non-alcoholic drinks and functional drinks
- Ice creams, yoghurts and other dairy products
- Fruit preparations (coulis, toppings, sorbets, etc.)
- Confectionery (as well as natural tartaric acid)

The interviews carried out in Greece with an RTO highlighted a new ongoing project focussing on the extraction of anthocyanins and compounds like resveratrol from grape pomace, to be used as supplements with positive health claims. The work in progress aims to assess their effects on gut microbiome and cognitive performance

Limitations to the valorisation of anthocyanins:

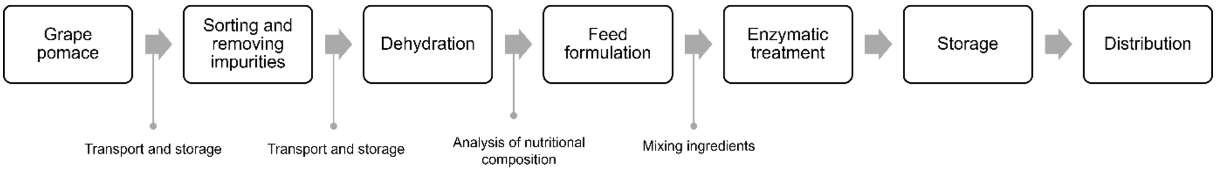
- Anthocyanins can be synthesised in laboratories. Thus, if the lab production is more cost-effective than extracting them from pomace, industries are less motivated to invest in technologies for extracting natural pigments from grape by-products.
- The chemical structure of anthocyanins, which are responsible for grape colouring, varies depending on the grape variety. This variability can make selective extraction difficult. In addition, different methods may be needed according to the grape variety.

- Anthocyanins are unstable and very sensitive to oxidation, which can alter the colour and integrity of the pigments. To solve this problem, several solutions have been adopted: proximity to the sources of the deposits, transport in the dark, etc.
- Extracting natural anthocyanins may need the use of solvents. Handling them can present health and environmental risks.
- Extracting pigments from grapes requires significant investment (both in extraction technologies and in the treatment process), which limits the profitability of this activity.

2.2.3.3. Feed

An additional application of grape pomace can be found in animal feed, through it must be process before used (see figure below).

Figure 32: Process of obtaining feed from grape pomace



Source: Innov'Alliance

Transport and storage are important stages in the process. During these stages, numerous bacteria and transformations in the pomace can limit its quality. The sugars in the pomace quickly transform into alcohol. To solve this problem, processors usually dry the pomace.

Adding grapes into animal feed can offer a number of benefits. However, it is important to note that this needs to be done in a balanced way and taking into account the specific nutritional requirements of each animal species. Some of the potential benefits of grape pomace application in animal feed:

- Source of nutrients: grapes contain nutrients as vitamins (especially vitamin C), minerals, dietary fibre, and antioxidants, which can contribute to the overall health of animals.
- Energy supply: grapes, and more particularly seeds, can contain lipids which provide a source of energy. However, the addition of grapes must be balanced to avoid excessive calorie intake.
- Improved digestion: The fibre present in grapes can help to improve the digestive health of animals by promoting intestinal transit.
- Antioxidants: Grape pomace is rich in polyphenols, particularly flavonoids: catechins, epicatechins, proanthocyanins, stilbenes, rasveratrol, etc. The antioxidants in grapes can help protect cells from oxidative damage and promote general health.
- Appetence: Some animals can enjoy the sweet taste of grapes, which can make food more appetising and encourage consumption.
- Anti-inflammatory properties: Certain compounds present in grapes have anti-inflammatory properties, which can be beneficial for animals' joint and general health.

Grapes can also have specific effects on certain species. In lambs, the addition of grape marc to the finishing ration reduces the absorption of carbohydrates and nitrogen secreted by rumen microbes (Flores *et al.*, 2020). Using grape marc as a feed supplement for dairy cows increases their milk production and quality, and considerably reduces their methane emissions (Moate *et al.*, 2014).

Limitations to valorisation of grape pomace for feed:

- The investment in equipment and facilities for processing grape pomace into animal feed represent a substantial initial capital expenditure, which impacts largely on the economic feasibility of this type of project. Costs are high and margins are minimal for manufacturers, limiting the interest of producing feed from grape pomace.
- Feed is not a common form of grape pomace recovery. It was rarely mentioned during interviews with manufacturers, mainly because it is considered to have little added value.
- As the grapes are treated with phytosanitary products, the latter pass to the grape marc. Excessive levels of phytosanitary residues can have an impact on the animal's health and development.
- Grape seeds are not digested by animals, and can be dangerous for certain species (e.g. dogs, for whom grapes can cause serious kidney damage). Moreover, grapes are naturally high in sugar, and excessive consumption can contribute to health problems such as obesity or diabetes in some animals.

2.2.3.4. Bioactive compounds and their other uses

Rich in vitamins and polyphenols, notably concentrated in the skin and seeds, grapes are renowned for their antioxidant properties. There are interesting applications in nutraceuticals and pharmacy (other than food, already described in a previous section), as illustrated during the interviews with several manufacturers. The phenolic compounds in different parts of the grape and its products are summarized in table 12.

Table 21: Phenolic compounds in grape components

Resource	Phenolic compounds
Seed	gallic acid, (+)-catechin, epicatechin, dimeric procyanidin, proanthocyanidins
Skin	Proanthocyanidins, ellagic acid, myricetin, quercetin, kaempferol, trans-resveratrol
Leaf	myricetin, ellagic acid, kaempferol, quercetin, gallic acid
Stem	rutin, quercetin 3-O-glucuronide, trans-resveratrol, astilbin
Raisin	hydroxycinnamic acid, hydroxymethylfurfural
Red wine	malvidin-3-glucoside, peonidin-3-glucoside, cyanidin-3-glucoside, petunidin-3-glucoside, catechin, quercetin, resveratrol, hydroxycinnamic acid

Source: Xia *et al*., 2010

The concentration of polyphenols can vary according to different parameters: species, terroir, weather conditions, etc., though all the polyphenols listed in the table above are present in grapes.

The bioactivities of phenolic compounds are summarized in the table below.

Table 22: Phenolic compounds in grape pomace

Phenolic compound	Bioactivity
Resveratrol	Free radical scavenging
	Antiproliferation
	Enhancing plasma NO level
	Regulating lipid metabolism
	Protection against membrane oxidation

Quercetin	Antibacterial
	Enhancing plasma NO level
Catechin	Anticancer
	Free radical scavenging
	Antibacterial
	Anti-inflammation
	Protection against membrane oxidation
Flavone	Antiproliferation
Flavonol	Free radical scavenging
Procyanidin	Anticancer
	Free radical scavenging
	Anti-inflammation
	Antioxidant
Anthocyanin	Vasorelaxation
	Free radical scavenging
	Antibacterial
	Antioxidant
	Inducing aptosis
Flavonol	Free radical scavenging
Procyanidin	Anticancer
	Free radical scavenging

Source: Xia *et al*., 2010

Anthocyanins, flavanols, flavonols and resveratrol are the most important grape polyphenols. They possess many biological properties, such as antioxidants, cardioprotective, anticancer, anti-inflammation, antiaging and antimicrobial properties (Shrikhande, 2000).

Phenolic compounds are used in the pharmaceutical field, notably to combat certain cancers. The following table summarizes the anticancer activities of phenolic compounds present in grapes.

Table 23: Anticancer activities of phenolic compounds from grapes

Phenols	Subjects	Effects
Proanthocyanidins	Mouse mammary	Inhibited breast cancer metastasis
Anthocyanin	Rat liver clone 9 cells	Activated antioxidant response element upstream of genes
	Colon cancer cell lines	Induced 2-4 times increase in DNA fragmentation
	Vascular tumour biology	Repaired and protected genomic DNA integrity and retard blood vessel growth in some tumours

Procyanidin, catechin or gallic acid	Mice spleen cells	Inhibited DNA damage induced by hydrogen peroxide
Catechin	Human breast cancer cell line	Decreased cell viability and proliferation
Procyanidins		Decreased cell viability and proliferation
Flavone	Human colon carcinoma	Reduced cell proliferation, induced differentiation and aptoptosis
Flavonoid		More effectively induced apoptosis than antitumor agent camptothecin
Resveratrol	Prostate cancer cell lines	Induced apoptosis and antiproliferation effects
	Human mammary epithelial cells	Inhibited cyclooxygenase-2 Transcription

Source: Xia *et al*., 2010

Limitations of valorisation of phenolic compounds in grapes:

- The high extraction costs associated with isolating polyphenols and phenolic acids from grape pomace can pose a significant barrier to valorisation. Extraction processes often require specialized equipment, solvents, and skilled labour, contributing to the overall cost. Additionally, the efficiency of extraction methods can vary depending on factors such as pomace composition, processing techniques, and desired product purity.
- The prices of synthetic or non-upcycled molecules are often lower than those extracted from grape pomace, which reduces the economic attractiveness of valorisation efforts for industrials. Industrial decision-makers may therefore opt for the more cost-effective option, potentially favouring synthetic alternatives over natural extracts derived from grape pomace.

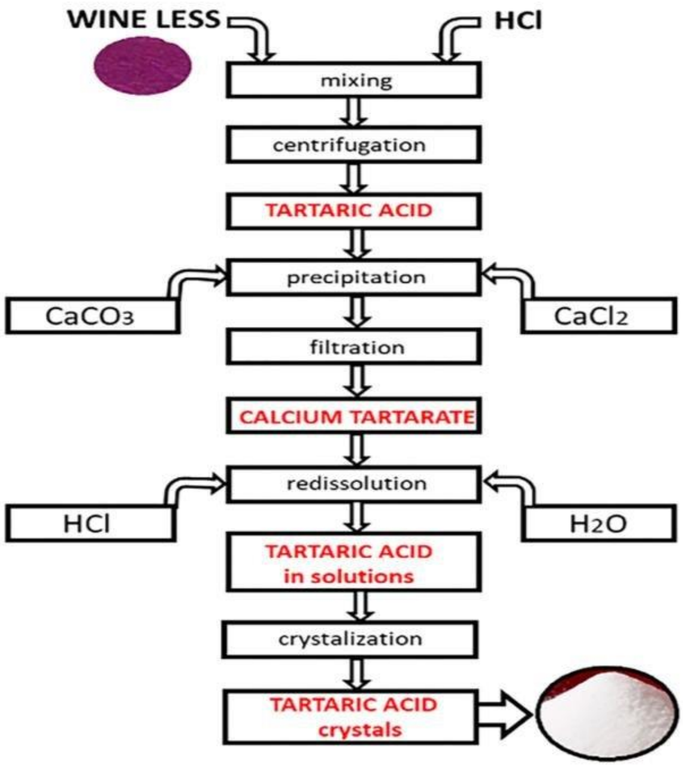
Tartaric acid

Tartaric acid is a natural organic element extracted from grapes, found in pomace and musts. It is one of the most widely distributed plant acids, with a number of uses in food, but also different industrial sectors (cosmetics, nutraceuticals or pharmaceuticals). The compound has several useful properties: it can be used as acidifier, antioxidant, stabiliser and pH corrector.

In winemaking, it acts as a natural acidity corrector, enhancing taste and brightening colour. In the food sector, it serves multiple purposes. It functions as a leavening agent in confectionery and desserts, and as an acidifier and natural preservative for jams, juices, and preserves. It is also used in table water for effervescence.

Tartaric acid concentration varies during grape ripening and is more related to climatic conditions than varietal character. The process to extract tartaric acid is described in the following figure.

Figure 33: Extraction process of tartaric acid



Source: Rajković *et al*., 2010

Calcium tartrate, containing 50% tartaric acid, is sent to chemical industries to produce pure tartaric acid. This pure acid has various applications:

- In construction, it acts as a retarder for gypsum setting.
- In the food industry, it functions as a leavening agent, acidifier, antioxidant, flavour enhancer, and stabilizing agent (E-334).
- In the wine industry, it corrects acidity in wine (Ros, 2023).

While the food industry is the major consumer of tartaric acid, applications can be found also in cosmetics. Indeed, tartaric acid is a type of alpha-hydroxy acid (AHA) with is used in skincare products as:

- An exfoliant: AHA like tartaric acid has skin benefits and is used as chemical exfoliant. It causes the dead skin cells on the outermost surface of skin, also known as the stratum corneum, to come “unglued” and slough off. Tartaric acid helps to reveal the newer, fresher skin cells beneath. AHAs, like tartaric acid, help acne in drying whiteheads and blackheads and reduce acne.
- A pH stabiliser: Tartaric acid allows for better absorption of other products and nutrients. Absorption can be a problem for some ingredients like vitamin C in its purest form or L-ascorbic acid. Moreover, tartaric acid stabilises pH of cosmetical formulation.
- An antioxidant: Tartaric acid has antioxidant properties. Antioxidants are invaluable to the skin as they fight off free radicals. Free radicals are unstable atoms that are missing one of their electrons. In order to complete themselves, free radicals can attack the healthy cells of skin and seal an electron, doing deep damage to the cells. Antioxidants such as tartaric acid scavenge and neutralize free radicals by providing them with their missing electrons.
- Humectant properties: Tartaric acid acts also as a humectant, binding moisture to skin.

Limitations to the valorisation of tartaric acid:

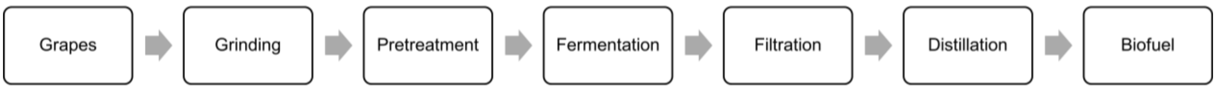
- The stabilisation of grape pomace is a major issue. As it is rich in sugars, it rapidly transforms into alcohol. In France, industrialists are often located close to grape pomace sources, limiting the problems related to biomass instability.
- The cosmetics, nutraceuticals and pharmaceuticals markets are niche ones, accounting for little recovery of grape pomace in terms of quantity (tonnage).
- The supply of grapes is a major difficulty for the manufacturers interviewed. Quantities are low, which limits manufacturers' profitability.
- Some polyphenols or AHAs present in grapes can be synthesised in laboratories (e.g. resveratrol); when the lab production process is preferred by manufacturers, this limits the quantity of grape pomace recovered.
- Scaling extraction technologies from research purposes to industrial production is a problem and demands massive investments. The markets for these bioactive compounds are small, which limits the profitability of the investment.

2.2.3.5. Energy

Energy is an important way of valorisation of winemaking by-products, as illustrated during the interviews with manufacturers. Grapes are rich in sugar, that can be transformed into bioethanol, and used therefore as biofuel.

Grape pomace is a promising potential source of methane (El Achkar al., 2016). The process to produce biofuel is described in the following figure.

Figure 34: Grape biofuel manufacturing process scheme



Source: El Achkar *et al*., 2016

During the production of wine, grape pomace is separated from the grape juice prior to the fermentation of white wines, or after a few days of skin contact in red wines (Prescott *et al*., 1993). Chemical analyses of grape pomace revealed the presence of significant amounts of fermentable sugars that are retained in the pomace after pressing the grapes. (Korkie *et al*., 2002).

The main challenge in the use of grape pomace for methane production is the structure and the composition (Monlau *et al*., 2012b). The solid matter of grape pomace is mainly composed of cellulose, hemicellulose, and lignin. The quite low anaerobic biodegradability of the grape pomace is likely due to the high amount of lignin and cellulose in its dry matter. In fact, lignin is the most resistant to microbial degradation and oxidation (Bayard *et al.,* 2015), whereas cellulose is usually degradable under anaerobic conditions in its pure form (Carlsson *et al*., 2012). Grape pomace pretreatment before anaerobic digestion seems to be necessary to alter the structural properties of lignin and cellulose, reducing the complexity of lignocellulosic fractions.

The methane production key values for grape marc are summarised in the following table.

Table 24: Methane production from grape pomace

Parameter	Value
Dry matter	26,1 %
Organic matter	75%
Methane potential	200 m3 CH_4/T MO 49 m3 CH_4/T MB
CH_4 Percentage	79 %
Ph	4

Source: Margaron SAS, n.d.

The production of energy from grapes pomace depends on a number of factors, including the organic compounds present, the state of ripening, etc. However, the use of grape pomace for methane production seems not very common amongst manufacturers (unlike in the case of apple pomace, for instance). Indeed, this is a relatively rare and underdeveloped way of valorisation, mainly because grape pomace allows for several different applications with higher value-added (cosmetics, agri-food, etc.).

It is interesting to mention that one of the interviews conducted in Emilia Romagna highlighted the project "Legami di Vite", which aims at developing a circular economy through the aggregation and valorisation of by-products and supply chain winemaking sector. Amongst its activities, the project targets the production of natural tartaric acid and advanced biofuels from the valorisation of winemaking by-products.

Limitations to the valorisation of grape pomace for biofuel:

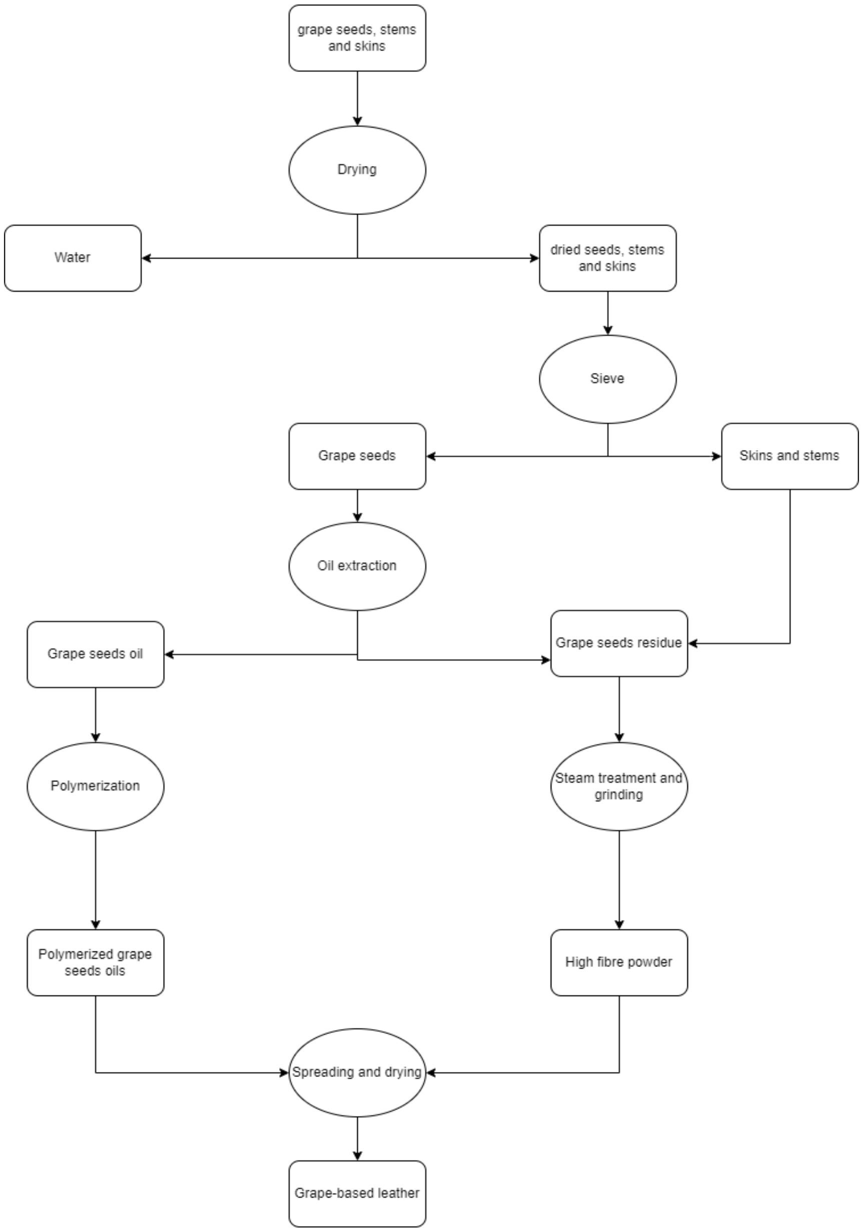
- The cost of converting grape marc into biofuel is high. The literature indicates that this is a major obstacle to the development of this recovery method. In addition, switching to biofuel requires modifications to engines, which demands, in turn, major investment for users.
- Biofuels increase engine consumption by around 20%. As a result, users have to fill their tanks more regularly. Finally, the efficiency of biofuels differs according to the season.
- The seasonal nature of grape marc requires collection logistics and storage infrastructures that allow the marc to be transported to the anaerobic digestion plant on a daily basis. The necessary infrastructure (tarmac roads, investment in a methane production unit, etc.) is costly, which limits the profitability of such an investment.
- Because of its seasonal nature and physico-chemical characteristics (average dry matter content of 37,2%), grape pomace should be anaerobically digested as a minority co-substrate as a minority co-substrate, and be gradually introduced into the mixture.
- Grape seeds are not destroyed during the digestion process of micro-organisms during the methane production, and end up as residual products of the process.

2.2.3.6. Biomaterials

Biomaterials, as an additional way of recovery grape pomace, emerged both from the scientific literature review and interviews with industrialists. This field covers a wide range of materials, such as leather, textile fibres, food packaging, bioplastics, insulation in the construction industry, etc. As with other vegetable leathers, there is no clearly accepted definition. Some consider that applying a layer of grapes enables the material to be considered as vegetable leather, while others believe that grape-based vegetable leather must contain a maximum number of grapes. Either way, incorporating grape by-products allows to propose customised effects and reduces the amount of polymer used.

An example of grape-based leather production is described in **Figure *35***.

Figure 35: Grape-based leather manufacturing process



Source: Vegea, n.d.

Several projects, such as Vegea Textile in Italy, work on applications of grape pomace as biomaterial.

Grape leather has a number of interesting properties including resemblance to animal leather, mechanical properties similar to animal leather, water resistance, etc. However, the exact properties of grape leather can vary depending on the specific production methods used by manufacturers. This type of recovery, promising in terms of value-added, is developing particularly in the luxury goods sector.

Limitations to the valorisation of grape leather as a biomaterial:

- There is no consensus on the definition of plant-based packaging. For some respondents to the interviews carried out by the project partners, particularly in France, the simple fact that a film of grape wax is applied to the packaging can make it plant-based packaging. For others, to be considered plant-based packaging, the packaging must contain a high percentage of co-products.

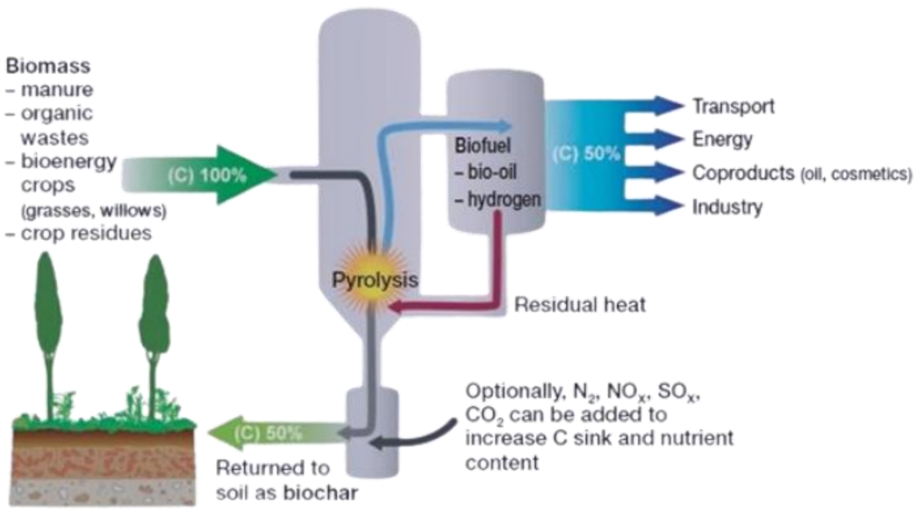
- Pesticide residues are a major problem in the field. In fact, regulations impose strict rules on residues on manufacturers (bacterial contamination, pesticide residue, etc.) particularly for packaging in contact with food. Non-food contact packaging has relaxed rules in this area.
- The use of grapes in biomaterials is hampered by problems of access to raw materials. Indeed, grape co-products are prioritised in areas with higher added value (cosmetics, agri-food, nutraceuticals, etc.). Raw materials for biomaterials are in short supply.

2.2.3.7. Agriculture

Agriculture is an important way of recovering winemaking by-products. Whether in the form of compost or biochar, grape pomace has beneficial properties for soil health, which nevertheless depend on the quality of biochar.

Biochar is a residue of pyrolysis process and is often used to pre-dry biomass feedstock or is sold as charcoal briquettes. Pyrolysis is one of many technologies to produce energy from biomass (Bridgwater, 2003). Biochar has a number of properties that are valuable in agriculture, including a good water retention capacity and soil stabilisation and alkalinisation. Biochar yields depend on the pyrolysis temperature, heating rate and residence time, and it decreases as the pyrolysis temperature increases (Gheorghe *et al.*, 2009).

Figure 36: Concept of pyrolysis process with biochar sequestration



Source: Lehmann, 2007

Grape biochar differs from charcoal in its physico-chemical properties of porosity, CEC, conductivity and pH, and can have a lifespan of several decades, or even hundreds of years, once incorporated into the soil. However, grape biochar is neither a fertilizer or soil improver in the traditional sense, but it acts as a soil conditioner and soil amendment with specific properties that can enhance soil health and productivity in various ways. One of the key functions of biochar, including grape biochar, is to improve water and nutrient retention in the soil.

Numerous projects are emerging on this topic, such as the Vinichar project in France, implemented by the Chambers of Agriculture of the Aude and Hérault departments, and the French Vine and Wine Institute.

Limitations to the valorisation of grape pomace for biochar:

- Access to raw materials for manufacturing biochar from grape pomace can be challenging due to seasonal availability, the geographical concentration and the variability in quality.

Even in regions where grape pomace is readily available, there can be costs associated with collecting, transporting, and storing the raw material. For farmers and wineries, managing grape pomace as a waste product may already incur expenses for disposal or recycling. Additional costs may be incurred if they choose to sell or supply grape pomace to biochar manufacturers, especially if transportation distances are significant.

2.3. Apple

2.3.1. Overview of the apple market

Apples (scientific name: *Malus Domestica*) are mostly associated with table fruits or juice. The apple market seems to be economically saturated. This section provides an overview of the economic and market dimension of apple growing and transformation.

2.3.1.1. Apple production

Apples have the reputation of a healthy food, from the core to the peel. Commercially, there is a distinction between table apples (which are consumed fresh, for raw eating) and cider apples, which are processed. More than 80 % of the fresh apples are destined for fresh consumption.

Table 25: EU apple production by country – Forecast 2023/2024 (in 1000 tons)

Country	2022	2023	% change 2023/2022	European market share in 2023 (in %)
Austria	151	111	-26,25	0,97
Belgium	239	203	-14,92	1,78
Croatia	57	65	14,50	0,57
Czech Rep	138	103	-25,69	0,90
Denmark	24	15	-37,50	0,13
France	1391	1501	7,91	13,15
Germany	1072	952	-11,19	8,34
Greece	321	212	-33,79	1,86
Hungary	280	550	96,43	4,82
Italy	2113	2104	-0,42	18,44
Latvia	10	5	-50,41	0,04
Lithuania	51	35	-31,37	0,31
Netherlands	235	207	-11,73	1,81
Poland	4495	3995	-11,12	35,01
Portugal	291	313	7,32	2,74
Romania	405	406	0,36	3,56
Slovakia	32	27	-16,67	0,24
Slovenia	50	47	-6,76	0,41
Spain	412	536	30,11	4,70
Sweden	30	24	-20,00	0,21
Total	11797	11411	-3,27	100

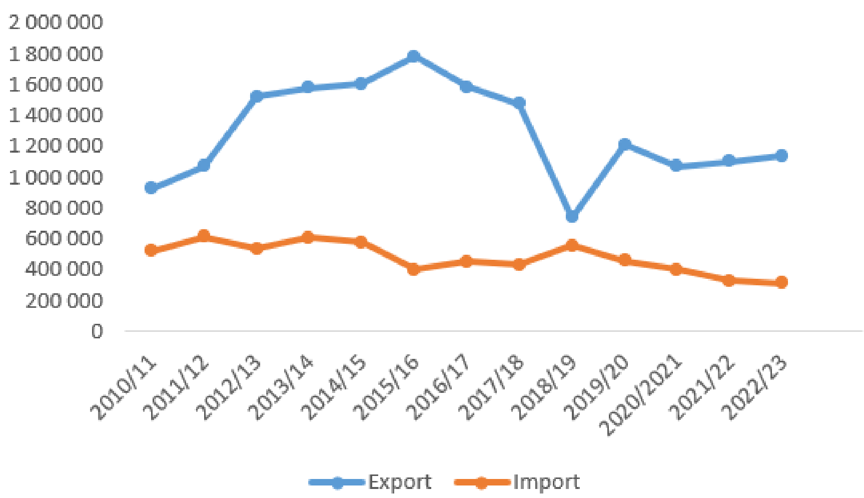
Source: WAPA, 2023

Apple cultivation is concentrated in three major European countries: Poland, Italy and France. A study conducted during the AlpBioEco Interreg Alpine Space project showed that the largest contiguous apple cultivation territory in terms of area is in the Alps, and more specifically in the Italian region of Trentino Alto Adige, which is also one of the most intensive cultivation regions

(AlpBioEco, 2019). For many years, the South Tyrol department was Europe's leading apple-growing region.

According to the FAO, Poland is the largest apple producer in Europe, with almost 4 million tonnes produced in 2023, representing 35% of the European production. Italy is the second main producer with 2,05 million tonnes; France is third with 1,39 million tonnes. Nevertheless, the apple harvest is expected to shrink by 3,3% between 2022 and 2023. Climatic hazards and a drop in cultivated area are the main factors behind this decline. Two of the three largest apple producers (France and Italy) were affected by drought during the past 3 years. However, apple production is in surplus, enabling extra-EU trade.

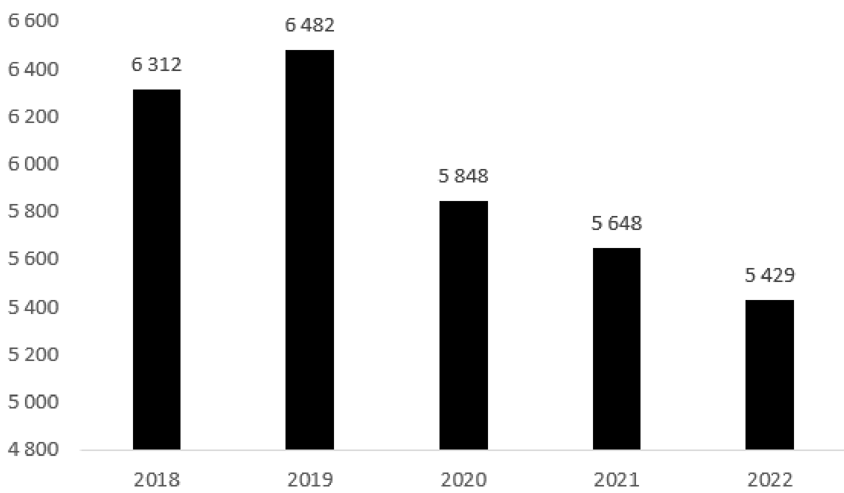
Figure 37: EU trade balance for apples (in tons)



Source: EuroStat, 2023

Europe remains historically in surplus when it comes to apple trade. Forecasts for 2024 indicate a stable balance in favour of Europe. Intra-EU trade of apples is important. For example, France imports almost one apple in 6 from Poland. Some countries, like Latvia and Lithuania, largely depend on apple imports, both within and outside the EU.

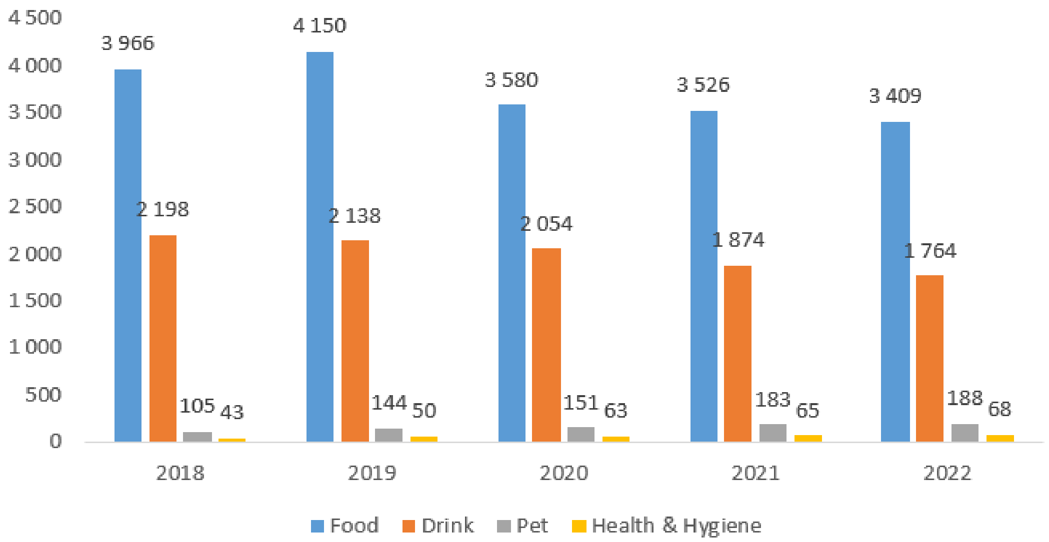
Figure 38: Evolution of European apple-based products launched by year in Food, Drink, Feed and Health and Hygiene on the market between 2018 and 2022



Source: data extracted from Mintel, 2023

In the European market, nearly 29 800 of apple-based products have been launched in Food, Drink, Feed and Health and Hygiene categories between 2018 and 2022. During the same period, apple-based product launches in the same category declined by nearly 17 %, though apple production in the European market was 11 million tonnes. Nevertheless, apple products were launched also in other categories: in the pharmaceutical industry, in the fragrance industry, etc.

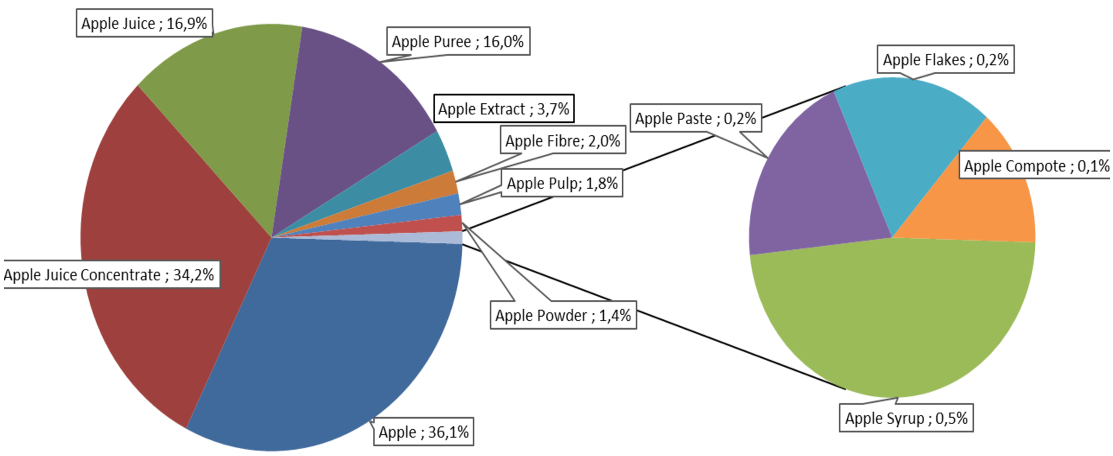
Figure 39: Distribution by super-category and by year between 2018 and 2022



Source: data extracted from Mintel, 2023

Considering the distribution per super-category, between 2018 and 2022, apple-based products were mainly launched in the food and drink (Figure 4). They represent more than 98 % of the total product launches on the European market.

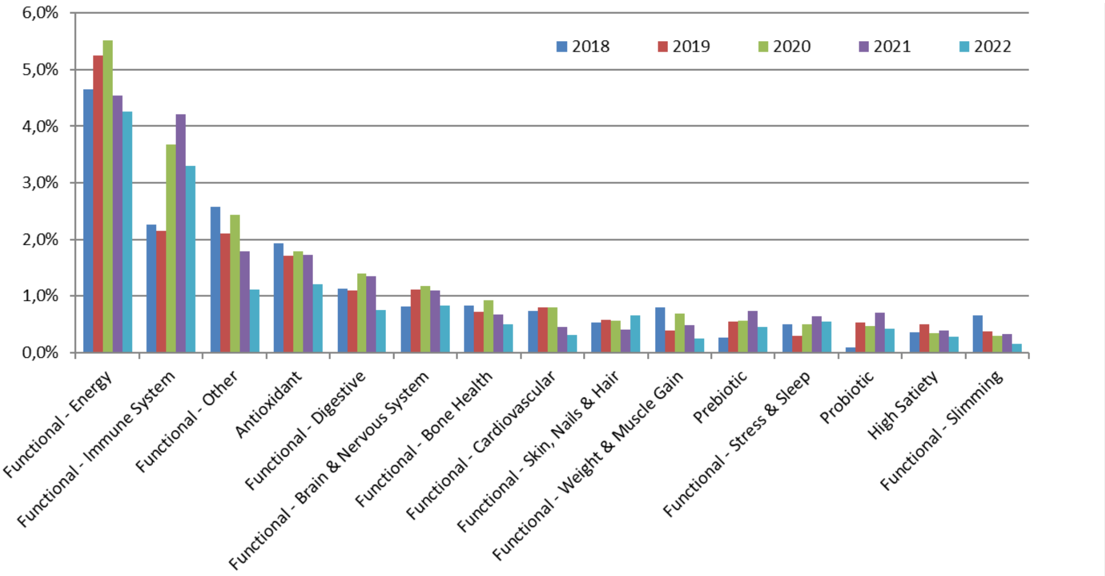
Figure 40: Ingredients preparation for apple-based products: category food, drink and pet food (European market)



Source: data extracted by Mintel, 2023

Apples are mainly processed as concentrate (34,2% of product launches), juice (16,9%) or puree (16%) (see figure above) Nevertheless, apple pieces remain the most represented product on the market.

Figure 41: Evolution of claims for apple-based products: category food, drink and pet food (European market)



Source: data extracted by Mintel, 2023

During 2018-2022, the new apple-based product launches mainly concerned "energy" and "immune system" claims, and new claims such as "beauty benefits" or "eye health" also appeared. Concerning claims for apple-based products, the two most important on the market are "energy" and "immune system"-related claims. Claims regarding "immune system" have significantly increased between 2018 and 2021.

Apple production in target regions

Amongst the regions represented by the B-Resilient partnership, the partners decided to focus the market analysis of the apple value chain on 5 regions where either the production and transformation of this fruit are important for the regional economy or there is a specific attention for apple by-products valorisation: Sud-Provence-Alpes-Côte d'Azur, Pays de la Loire, Brittany and Normandy in France and Wallonia, in Belgium.

i. Sud-Provence-Alpes-Côte d'Azur

Table 26: Apple production in Sud-Provence-Alpes-Côte d'Azur

Area	31.400 sq km
Population (persons)	5,1 million (2023)
Apple production	308,6 tonnes (2023)
Production area	9.300 hectares (2023)
% National production	Almost 20% of French production in 2023
Ecosystem	Mainly small exploitations, though the region host a large national and international company which is a major market player both in harvesting and in processing

Source: data collected from INSEE, FranceAgriMer, interviews

Sud-Provence-Alpes-Cotes d'Azur is France's leading producer of table apples. It is the largest producer of Golden (119,100 tonnes in 2023), second in Granny Smith (31,300 tonnes) and Gala (54,300 tonnes). Production takes place mainly in the Alpes de Hautes-Provence and Hautes-Alpes departments, where the climate is ideal for apple production (over 300 days of sunshine a year and wide temperature variations), at altitudes between 450 and 900m. Over the past few years, the region's harvest has fallen due to the vagaries of the weather, which have reduced its production.

The region is also home to several apple processors, notably for making apple compote, as well as other industries that exploit the fruit's ingredients (such as nutraceuticals, cosmetics, etc.).

ii. Pays de la Loire

Table 27: Apple production in Pays de la Loire

Area	32.082 sq km
Population (persons)	3,9 million (2023)
Apple production	38.000 tonnes (2023)
Production area	5.200 hectares
% National production	Almost 17% of French production
Ecosystem	Around 25 producers

Source: data collected from INSEE, Agreste, interviews

The Pays de la Loire is France's fourth-largest producer of table apples and third-largest producer of cider apples. It is also the third-largest producer of Granny Smith and Gala apples. Pome fruits (apples and pears) represent 65% of the regional orchard, while cider apples 15%. Two departments account for most of the region's apple production: Maine-et-Loire and Sarthe. Here, apples account for 85% of the region's total fruit-growing area. The climate in Pays de la Loire is ideal for apple production, thanks to the region's mild climate and rich soil.

iii. Brittany

Table 28: Apple production in Brittany

Area	27.208 sq km
Population (persons)	3,37 million (2023)
Apple production	44.000 tonnes
Production area	Around 3.300 hectares in 2020.
% National production	Data non available
Ecosystem	Around 100 producers and 2 cooperatives

Source: data collected from INSEE, Agreste, interviews

Brittany is one of the most important producers of cider apples. Britanny has a climate that is particularly adapted to growing apples (mild and humid). The region produces close to 45 % of French cider. Brittany is an important transformer of apples. Apple transformation in Brittany breaks down as follow: 65% of apple production is transformed in cider, 18% in juice and vinegar and 17% in brandy. In recent years, Brittany production is declining due to the drought.

iv. Normandie

Table 29: Apple production in Normandy

Area	3.627 sq km
Population (persons)	3,317 million (2023)
Apple production	111.000 tonnes
Production area	Data non available
% National production	Data non available
Ecosystem	Around 200 producers

Source: data collected from INSEE, Agreste, interviews

Normandy has an oceanic climate, favourable to apple growth, and the region is the biggest cider producer of France. Indeed, almost 60% of French cider is produced in Normandy. Apple production in Normandy is concentrated on a dozen cider apple species (Clos Renaux, Bisquet, Marie Menard, Avrolles, etc.). Normandy also produces large quantities of apple juice and apple vinegar.

v. Wallonia

Table 30: Apple production in Wallonia

Area	30.688 sq km
Population (persons)	11,7 million (2023)
Apple production (national level)	203 tonnes (2023)
Production area	5.348 hectares (2023)
% National production	10% of Belgian production
Ecosystem	Mainly small apple farms

Source: data collected from StatBel, Direction générale de l'Agriculture, des Ressources naturelles et de l'Environnement du Service public de Wallonie, interviews

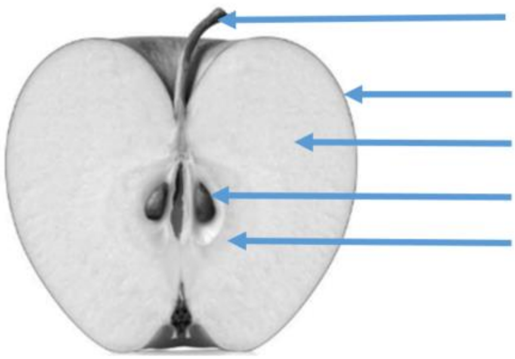
The Walloon region is mainly made up of small apple farms, while bigger producers are located in the Flanders region, where most of the national apple production is concentrated (90%). Despite hosting only 10% of the national production, today in the Walloon region, a new value chain of old varieties apple trees is developing.

Apples in Belgium are processed in 4 main products: cider, apple compote, juice and syrup. In recent years, the country has experienced a loss of the orchard surface area (127 hectares lost between 2021 and 2022), which is explained by a transfer of culture towards pears. Indeed, today Belgium is the biggest European producer of pears. Most of the apple valorisation is carried out in the feed and energy sector (bio-methanisation).

2.3.2. Botanical and anatomical data

Apple is the fruit of the common apple tree *Malus domestica* of the Rosaceae family (*Pomoideae* subfamily) (Hellier *et al*., 1993). From a botanical point of view, the apple is a berry, that is, a fleshy fruit without a hard core. Apple is a round fruit, with a stem and a leaf on the upper side. A smooth and colourful skin that protects the flesh surrounds this fruit. The apple is composed of different parts described in the scheme below.

Figure 42: Basic anatomy of the apple



Three structures stand out in the fruit at the tissue level: peel (skin), mesocarp (flesh) and endocarp (cortical area containing seeds, also called the core). The mesocarp holds most of the fruit and it is the tissue most consumed.

2.3.2.1. Physiology and quality

There are four main stages of fruit growth in apples. The first is a stage of cell differentiation and tissue diversification. The second stage is flowering with the cessation of tissue growth. Then, there is a stage of accumulation of reserve substances (starch and organic acids). Lastly, there is the ripening of the fruit that makes apples edible. Apple fruit ripening consists of a set of biochemical and physiological changes conferring to the fruit its organoleptic characteristics (aroma, colour, juiciness…). Beyond maturity, senescence of the fruit begin with cell degradation and death.

Apple is a climacteric fruit characterized by an autonomy of maturation after harvesting with an autocatalytic synthesis of ethylene. Fruit harvesting accelerates the process of fruit maturity (Johnston *et al*., 2002). This phenomenon results in the softening of the fruit and production of ethylene which can alter the fruit's organoleptic properties and quality.

Multon *et al*. (1994) define three quality categories:

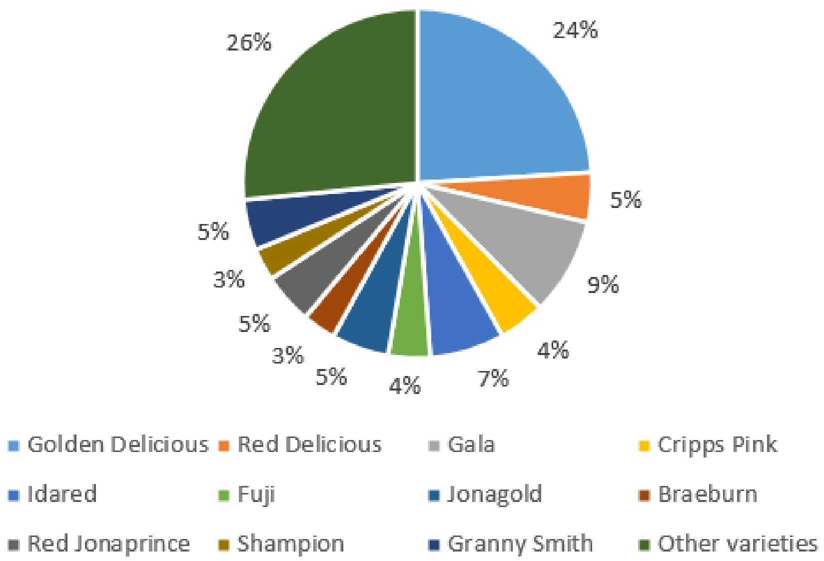
- Technological qualities: for example, suitability for transformation
- Food quality: hygienic, nutritional, and sensory qualities
- Quality of use and service: suitability for conservation, economic aspect

To preserve quality and marketability of apple after harvest for several months, there are three main levers for action:

- Picking the fruit before the beginning of its maturation
- Storing fruit under controlled atmosphere to limit ethylene production and respiration
- Keeping the temperature between 0 and 3°C.

The diversity of apple cultivars characterizes the nutritional composition, modulate quality and suitability for be processing. There are more than 7500 known cultivars of apples, but some have a large market share in Europe. The most common apple groups are Golden Delicious, Idared, Jonagold and Gala, which account for almost 45% of the production area of apples for dessert in Europe.

Figure 43: Apple stock in Europe in March 2021



Source: Data extracted from World Apple and Pear Association (WAPA), 2021

2.3.2.2. Fresh apple composition

Fresh apple fruit has a varied and balanced composition. Mature apples are mainly composed of water (85%). The other main components are carbohydrates (12-14%), organic acid (0,3-1%), proteins (0,3%) (Al Daccache *et al.*, 2020; Renard *et al.*, 2001). Apples are particularly rich in fibers. Apples are also composed of lipids, minerals, phenolic compounds and vitamins (Tsao *et al.*, 2003).

Table 31: Average composition of a fresh apple (per 100g)

Compound	(g)	Minerals	(mg)	Vitamins	(mg)	Energy intake	
Carbohydrates	12,6	Potassium	145,0	Vitamin C	5,0	Kilocalories	54,0
Proteins	0,3	Phosphorus	9,0	Provitamin A	$7{,}0 \times 10^{-2}$	Kilojoules	226,0
Lipids	0,3	Calcium	4,0	Vitamin B1	$3{,}0 \times 10^{-2}$		
Organic acids	0,6	Magnesium	4,0	Vitamin B2	$2{,}0 \times 10^{-2}$		
Fibres	2,1	Sodium	3,0	Vitamin B3	0,3		
Water	84,3	Iron	0,2	Vitamin B5	0,1		
		Copper	$4{,}0 \times 10^{-2}$	Vitamin B6	$5{,}0 \times 10^{-2}$		
		Zinc	$9{,}0 \times 10^{-2}$	Vitamin B9	$1{,}2 \times 10^{-2}$		
		Manganese	$3{,}0 \times 10^{-2}$	Vitamin E	0,5		

Source: Colin-Henrion, 2008

The following table describes the average nutritional composition for a Golden apple, including phenolic acids and flavonoids.

Table 32: Average nutritional composition of a Golden apple (skinless raw product, per 100g)

Compound	Content
Water	85,5 g
Fibers	2,5 g
Carbs	11,7 g
Phenolic acids	14,27 mg
Flavonoids	16,83 mg

Source: Aprifel, n.d.

2.3.2.3. Processed Apple

The processed apple sector is important because it contributes to the increase in apple consumption (Amiot-Carlin *et al.*, 2007). For example, in France in 2004, the average consumption per capita was: 63 kg of fresh fruit, 7 kg of processed fruit and 23 litres of fruit juice apple products, including juice, apple sauce, or fermented products such as cider.

Apple Juice

The juice-making process generally remains the same regardless of the fruit. The first step before processing is selection of fruits and their harvest. For fruit juice production, there are key steps such as: washing, pressing (usually mechanical), sieving, centrifugation, pasteurisation, and bottle packaging. The diagram below describes apple juice concentrate processing.

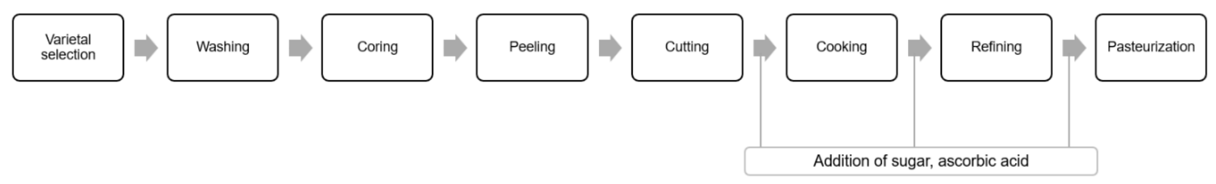
Figure 44: Flow chart of apple juice concentrate production

Source: Welke *et al.*, 2009

Apple sauce

The diagram below describes the key steps in the apple sauce manufacturing process. The order of these steps may differ from one industrial process to another. An important step is cooking, the duration and temperature of which will influence the quality of the final product.

Figure 45: Major steps in apple sauce production process

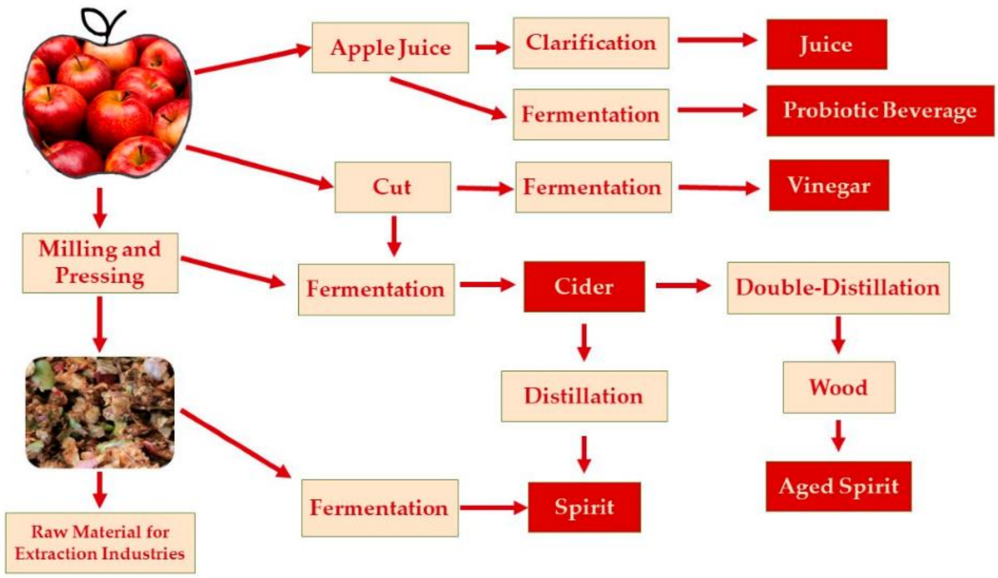


Source: Colin-Henrion, 2008

Fermented apple products

There are different fermentation processes, which lead to different fermented apple products. For example, these apple products are probiotic beverage, vinegar, cider or spirits. The diagram below describes different processes for different apple products.

Figure 46: Fermented apple products and processes for their obtention



Source: Guiné *et al*., 2021

2.3.3. Apple by-products

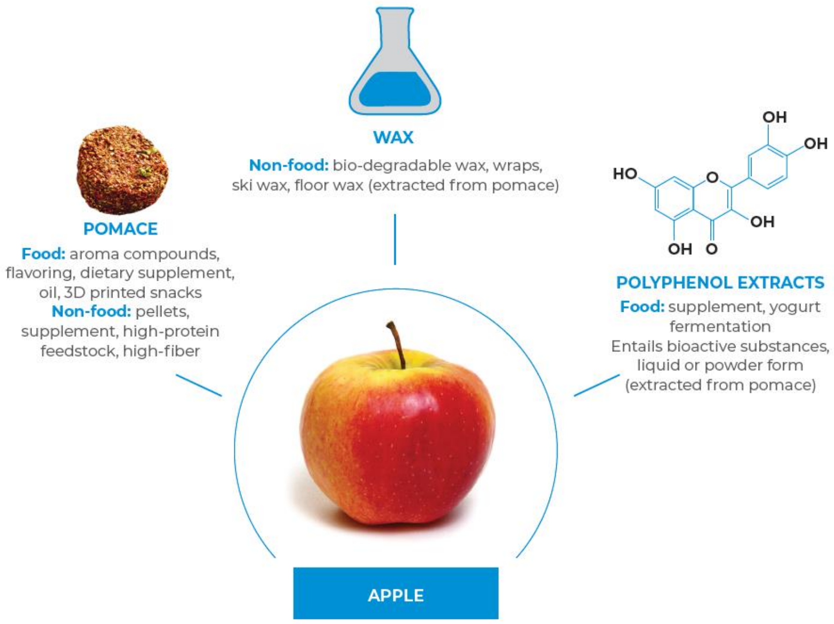
The first by-products are generated in the field: apple not picked or not in use, pruning wood, flowers, etc. It is difficult to quantify these by-products. Also, it is complicated to valorise them through certain issues: difficulty in quantifying them, setting up specific collection, transport costs, stability and heterogeneous composition, etc.

In the packaging station, there is only 5% apple loss. In fact, most apples not suitable for the market are reused for the transformation: apple juice or apple compote. Apples remaining unfit for consumption can be reused for different applications. The by-products composition depends on the nature of the co-products, the variety of apple and apple processing:

- Field culture conditions and variety: will affect pulp content, particle size and rheological characteristics (flow, elasticity, plasticity, viscosity). The level of sugar and acidity can also be affected
- State of maturity of the fruit and storage: will have an impact on the particle size therefore rheological parameters. In particular, during storage, pectin can degrade, and sensory properties can be altered.
- Process:
  - Cooking: temperature/residence-time pair softens tissues to facilitate refining and inactivate certain enzymes. However, too much cooking degrades the pectin and will lead to a decrease in the size of the particles thus varying effects on the rheological properties
  - Refining: the size of the sieves will determine the size of the final particles and the pulp content

The basic research is an important skill to provide a technical overview of already investigated fields regarding to reuse of apple waste materials and by-products. It is a basic structure for discovering potential and novel innovations. This section describes fundamental results regarding raw materials characterisation, feasibility analysis for apple characterisation.

Figure 47: Main apple by-products



Source: AlpBioEco, 2019

2.3.3.1. Apple pomace

Apple pomace is the most important co-product in the apple production process. It is made up of residues from the production process: peel, seed, stem, juice, etc. Pomace represents about 25% of the apple mass (Zlatanovic *et al*., 2019a). However, interviews with industrialists indicated a very different mass depending on industrial processes. The mass can vary between 15 and 40%, depending on the actors interviewed. The percentage of physical residue depends on factors such as the production process and ripeness of the apples. It remains little used by manufacturers. The main recovery methods identified will be described in the following section.

Characteristics and composition of apple pomace

Apple pomace is the solid residue left after grinding and pressing apples for the production of cider, juice or apple sauce (Givens *et al*., 1987; Kafilzadeh *et al*., 2008). Withdrawn, fallen or damaged apples (broken or damaged during picking, unsuitable for packaging) are abundant during the apple season.

Pomace contains residues of skin, pulp, stem, core, seeds and juice (Sudha *et al*., 2007; Crashaw, 2004). Kolodziejczyk *et al*., (2007) analysed apple pomace using a sampling method. The pomace is made up of 54% pulp, 34% peel, 7% seeds, 4% seed kernels and 2% stems. The companies questioned (processors, solution providers or producers) stated similar values. It has a density of between 400 and 1000 kg/m^3 (Kennedy *et al*., 1999). Density and moisture content depend on the manufacturing process and the ripeness of the apples.

Due to its high humidity and high fermentable sugar content like glucose, fructose and sucrose, apple pomace is unstable and degrade very quickly (Jung *et al*., 2015). It is often ensiled or dehydrated for longer storage (Shalini *et al*., 2010; Crashaw, 2004).

Table 33: Approximative composition of apple pomace

Constituents	Composition (dry weight basis)	Constituents	Composition (dry weight basis)
Moisture (%)	3.90–10.80	**Alcohol-soluble fraction of carbohydrate**	
Protein (%)	2.94–5.67	Saccharose (%)	3.80–5.80
Total carbohydrate (%)	48.0–62.0	Glucose (%)	19.50–19.70
Fibre (%)	4.70–51.10	Fructose (%)	48.30
Insoluble fibre	36.50	Xylose, mannose and galactose (%)	1.20–4.40
Soluble fibre	14.60	L-malic acid (%)	2.60–3.20
Fat (ether extract, %)	1.20–3.90	Arabinose and rhamnose (%)	7.90–6.0
Pectin (%)	3.50–14.32	Glucooligosaccharides (%)	3.40–3.80
Ash (%)	0.50–6.10	Xylooligosaccharides (%)	3.0–3.70
Minerals		Arabinooligosaccharides (%)	0.20–0.40
Phosphorus (%)	0.07–0.076	Uronic acid (%)	2.70–3.40
Potassium (%)	0.43–0.95	**Alcohol-insoluble fraction of carbohydrate**	
Calcium (%)	0.06–0.10	Glucan (%)	41.90–42.90
Sodium (%)	0.20	Starch (%)	14.40–17.10
Magnesium (%)	0.02–0.36	Cellulose (%)	7.20–43.60
Copper (mg/kg)	1.10	Polysaccharides of xylose, mannose and galactose (%)	13.0–13.90
Zinc (mg/kg)	15.00	Polysaccharide of arabinose and rhamnose (%)	8.10–9.0
Manganese (mg/kg)	3.96–9.00	Acid detergent lignin (%)	15.20–20.40
Iron (mg/kg)	31.80–38.30	Uronic acid (%)	15.3

Sources: Chen *et al.*, 1988; Hang and Walter, 1989; Kennedy, 1994; Joshi and Sandhu, 1994; Masoodi and Chauhan, 1998; Bhushan, 2002; Constenla *et al.*, 2002; Schieber *et al.*, 2003; Marcon *et al.*, 2005; Virk and Sogi, 2004; Nawirska and Kwaúniewska, 2005; Sudha *et al.*, 2007; Gullón *et al.*, 2007)

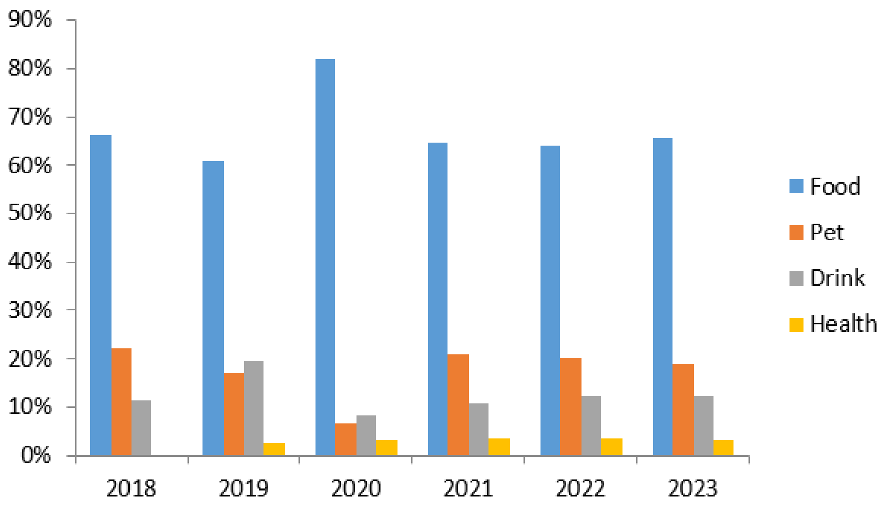
Source: Bhushan *et al.*, 2008

The composition of apples themselves is variable and depends on variety, ripeness, harvest season, etc. (Grigoran, 2012). Apple pomace is generally low in protein (3-11% of dry mass) and rich in fibre and sugars. Crude cellulose varies from 18 to 50% of dry mass. Sugar content also varies, with apple pomace being rich in fructose (14 to 35% of dry mass). Sucrose and glucose contents are lower, but also variable: 1-11% (Guillon *et al.*, 2007) and 6-13% of dry mass (Kennedy *et al.*, 1999; Kolodziejczyk *et al.*, 2007).

Apple pomace use on market

More than 2,000 apple pomace-based products have been marketed in Europe towards final consumers.

Figure 48: Breakdown of apple pomace-based product launches in the EU between 2018-2023



Source: data extracted from Mintel, 2023

NB: The molecules derived from apple pomace (quercetin, apple polyphenol, etc.) have not been included. Similarly, the data does not include intra-company trade, which may be carried out for feed.

These products are mainly based on apple pomace fibres. The other components of apple pomace are used in a wide variety of ways. Being rich in fibres, apple pomace contains a large quantity of pectin. Pectin is a natural gelling agent, largely used in the food industry for food preparation (to thicken or gel preparations), e.g., in marmalade or in jellies.

Examples of apple pomace valorisation

The examples of value-adding and constraints presented below are taken from interviews conducted by the project partners in the regions covered by this study, as well as from a review of scientific publications. Five ways of valorisation of apple pomace have been identified:

- Feed
- Energy
- Food
- Extraction of bioactive compounds (mainly antioxidants)
- Packaging

All partners and industrialists reported that the main valorisation of apple pomace are in the feed and energy sectors.

From the interviews conducted, it emerges that the economic viability of processing and transforming by-products is the major difficulty faced by industrials: the investments to be made to turn apple pomace into useful products/resources are often too high with respect to the economic added value generated, making the project financially unfeasible. The technology seems to be less a constraint and is often mastered, though there are still technical issues concerning the quality of the apple pomace (making it challenging to create standardized or high-value products) and the biomass stability.

All valorisation processes require having a transformation tool near the place where apple by-products are generated and have a quantity of apple by-products large enough to amortise the investment of the processing tools.

For example, the extraction of bioactive compounds today seems to offer an interesting perspective of valorisation. In particular, the extraction of polyphenols allows for producing a substitute of synthetic polyphenols (Vidot *et al*., 2019). However, there are still obstacles that limits this process: the stability and quality of target compounds, their water and sugar content, etc.

i. Feed

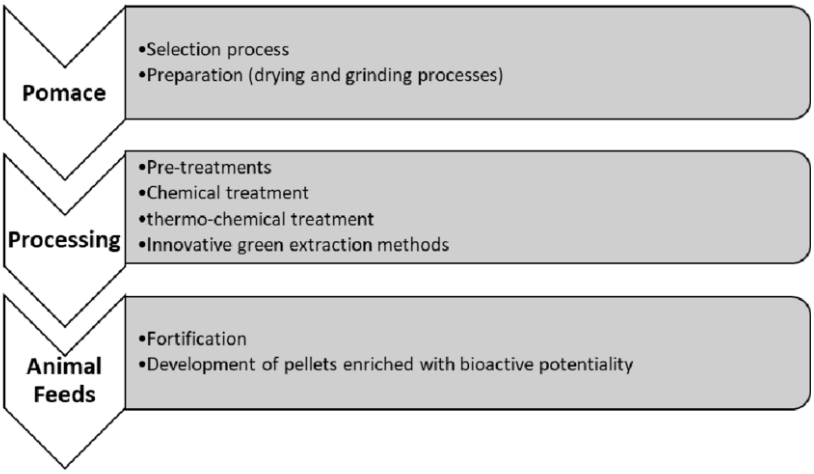
Animal feed is an important way of valuing apple pomace. Interviews conducted with French and Belgian companies indicate that historically, this is the primary way of valorisation, and the one that allows the valorisation of the largest quantity of apple pomace.

Because of its composition (high in fibre, low in protein and reduced in sugar content), apple pomace is particularly well suited as an animal feed supplement, especially for ruminants (Anrique *et al*., 2003; Azizi *et al*., 2014). It has a relatively high energy value, making it an important feed supplement. On the other hand, due to its composition (absence of digestible nitrogenous matter, rich in cellulose matter, organic acid and pectic substance), the use of apple pomace in the animal diet is limited, depending on the species. Above a certain dose, apple pomace can cause loss of appetite and digestive problem due to its high pectin content (Roy & Desnoux, 2013).

Apple pomace continues to be researched as a treatment for diseases such as non-alcoholic fatty liver disease for animals (Skinner, 2019).

This recovery method also has the advantage for manufacturers of being cheap and able to absorb large quantities of by-products. Indeed, it does not require large investments for apple pomace producers, but only transport and storage costs which are relatively low. Processing costs are borne not by the apple pomace producers but by animal feed producer.

Figure 49: Steps for the valorisation of apple pomace for feed

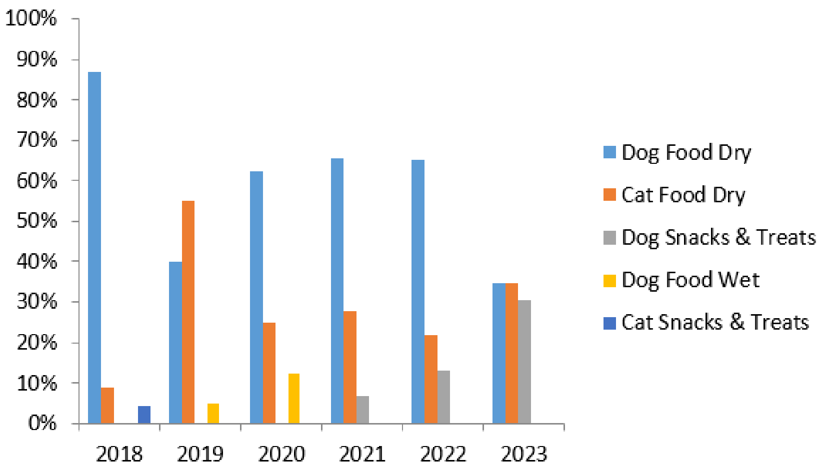


Source: Malenica *et al.*, 2022

Fresh apple pomace deteriorates rapidly, making it a relatively unstable by-product. Indeed, at room temperature, water and sugars allow microbial growth within apple pomace. Moreover, the immediately fermentable sugars contained in the pomace cause it to undergo rapid and intense alcoholic fermentation. For manufactures in feed processing, the problem of stabilizing the pomace was quickly resolved. Manufacturers dry the pomace to evaporate all the water. However, despite the drying of the apple pomace, pesticide residues remain present, limiting the valorisation due to animal health concerns. This issue emerged during the interviews with Belgian and French apple producers and processors.

Fibres from apple pomace are also used in pet food, as they improve digestibility from animals. Around 500 products containing apple pomace fibres have been identified by the Mintel database. The breakdown is shown in the following figure.

Figure 50: Breakdown of EU launches of pet food products made with apple pomace (2018-2023)



Source: data extracted from Mintel, 2023

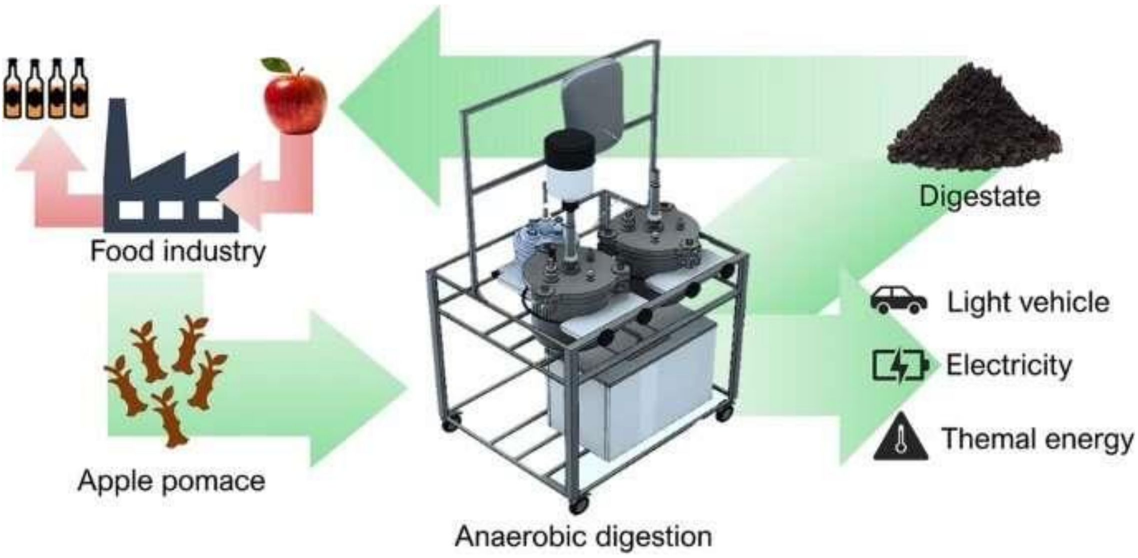
Interviews with manufacturers revealed a number of limits to the use of apple pomace in feed. The literature also reports similar problems. The limitations mentioned are as follows:

- Ethanol is the main fermentation product of apple silage, being 17% of the dry matter. Due to concerns on animal health, specialists recommend limiting the amount of apple pomace in animal feed or feeding it to livestock to a short period of time (source: IDELE). In silage made from crushed apples, the ethanol level fluctuates between 22 and 29% of dry matter, due to the alcoholic fermentation by yeasts.
- Pesticide and plant protection product residues. Apples and apple pomace contain peelings: the latter retain a substantial quantity of residues of crop protection and phytosanitary products. These products, particularly pesticides, can be stored in the fatty tissues of animals and in milk. Some of the companies interviewed mentioned this issue as a major constraint of the apple pomace recovery in animal feed.

ii. Energy

A large proportion of apple pomace is used to produce bioenergy (biogas or methane/ methanogenesis). The biogas production scheme is illustrated in the following figure.

Figure 51: Process for valorisation of apple pomace for bioenergy



Source: Ampese *et al*., 2022

Apple pomace contains simple sugars that can be fermented to produce various alcohols such as ethanol (Hang *et al*., 1981; Vendruscolo *et al*., 2008). Ethanol is considered a renewable and sustainable biofuel, and is usually blended with petrol. Apple-based ethanol is produced by anaerobic fermentation, which converts around 80% of the mass of apple pomace (Sudha, 2021).

High moisture and sugar levels in apple pomace also make it a suitable feedstock for anaerobic digestion to produce methane (CH_4) gas (Jewell & Cummings, 1984; Kalia *et al*., 1992). Whilst this methane can be captured and sold as a commodity, for smaller processors it is often used on-site to reduce another energy cost.

The production of energy from apple pomace depends on a number of factors, including the organic compounds present, the state of ripening, etc. The methanogenic capacity of apple pomace will average between 50 and 55 nm^3 of CH_4 per tonne of raw material. Studies are still underway to improve the yield of apple pomace converted into ethanol (Demiray, 2021). However, apple methanogenic potential is low compared to the other fruits or vegetables.

Biobutanol is another biofuel that can be produced from apple pomace. However, biobutanol production processes are complex, and yields are low compared to petrochemical-based processes (Gallastegui *et al*., 2018).

The low levels of investment needed to convert apple pomace into methane makes it profitable in the short term and makes it possible to valorise large quantities of apple pomace. In France, this way of valorisation is largely supported by the public sector with financial incentives. In addition, such investments can be made jointly by several companies, lowering the individual effort.

In addition, the production of bioenergy enables the industrials to limit their energy costs, particularly those using gas, allowing also for additional revenue from selling energy. This way of valorisation was mentioned during the regional interviews carried out in France and Belgium, particularly for methane production, which is developing both countries.

Limitations to the valorisation of apple pomace for bioenergy:

- Apples are a seasonal crop. The majority of harvesting and pressing campaigns take place between September and November each year. Thus, apple and relative apple pomace provide only for a temporary supply of substrate to energy producers. This issue was raised during interviews conducted in France.
- Apples do not have one of the highest methanogenic potentials. In fact, with a methanogenic potential of 59 m^3 CH_4 per tonne of raw material, it is one of the lowest potentials. By comparison, brewers' grains have a better potential (70 m^3 for brewers' grain).

iii. Food

Apples play a significant role in the food industry, contributing to a wide array of products due to their versatility, taste, and nutritional value. While energy and animal feed are the most common way to transform the waste or unused parts into valuable products, the valorisation of apple by-products in the food industry is also interesting. Indeed, apple pomace can be recycled for human consumption. Several areas of research and development are underway. Three look particularly promising: pectin, apple flour and fermented functional ingredients.

Pectin

Apple pomace is a potential source of dietary fibres consisting approximately of 45-60 % of wet weight including 5,5-11,7% pectin (Bhushan & Gupta, 2013). Apple fibre can have several functional properties including enhancing water and oil retention, to improve emulsion or oxidative stabilities, improve the viscosity, texture, sensory characteristics and shelf-life of the food product (Elleuch *et al*., 2011). Fibres from cooked apple pomace can be used as textural ingredients due to enhanced physicochemical properties such as water-holding capacity or as functional foods (Rabetafika *et al*., 2014). Besides properties interesting in food technology, increasing the fibre content in foods can also improve their healthiness (Wu *et al*., 2014). Pomace can be dried and used as a crude ingredient or undergo further processing to improve its physical and textural properties. The extraction of fibre generally involves a leaching step to remove soluble sugars. The fibre can undergo additional processing to decolourise; however, unbleached pomace fibre can also be utilised as a food ingredient. A study has shown that apple pomace fibre can be used to reduce fat content from 30 to 20% in uncured chicken sausages, providing healthier alternative to fat (Choi *et al*., 2016).

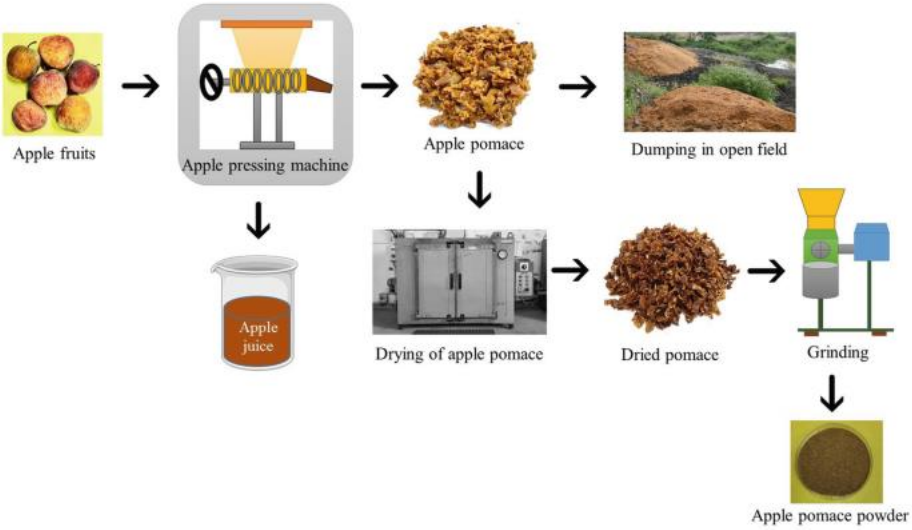
Pectin is a family of complex variable polysaccharides extracted from the primary cell walls of higher plants and traditionally used in jam, jelly and confectionary making (Canteri-Schemini *et al*., 2005). Using apple pomace for pectin extraction is considered the most practical and economical solution to utilise this by product (Bhushan *et al*., 2008; Miceli-Garcia, 2014).

This valorisation is common to all the regions where interviews were conducted.

Apple flour

Apple flour is an alternative to traditional wheat flour. The wasted apple pomace from juicing is drained and ground into a thin layer to be dried out and dehydrated. Once the pomace is efficiently dried, it enters the multi-step milling process that produced a fine flour ready for packaging and manufacturing. Apple flour is a nutrient-dense ingredient that offers a range of health benefits. It is high in dietary fibre, which helps promote healthy digestion and can help regulate blood sugar levels. It is also a good source of vitamins and minerals, including vitamin C, potassium, and calcium. Moreover, apple flour is lower in calories and carbohydrates than regular wheat flour, which may support weight loss. However, apple flour has a subtly sweet and fruity flavour contrary to conventional flour. As apple flour is gluten-free, it is particularly suitable for specific human diets, especially those of people with gluten intolerance. It is notably used in pastries to replace wheat flour.

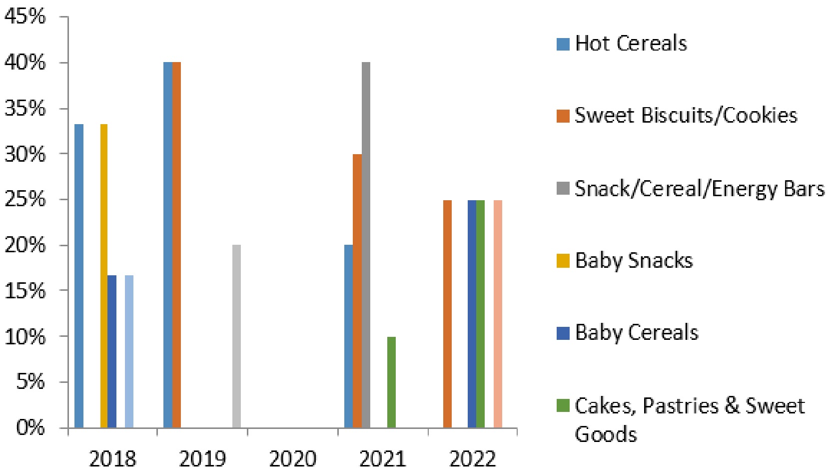
Figure 52: Apple flour production process



Source: Rana *et al*., 2022

Considering the actual use of apple flour by product category, 25 products have been launched on the European market according to Mintel. The distribution by category is illustrated in the following figure.

Figure 53: Breakdown of EU launches of food products containing apple flour (2018-2023)



Source: Data extracted from Mintel, 2023

The valorisation of apple pomace into apple flour has been mentioned during the interviews conducted both in France and Belgium. Several innovation projects are currently ongoing in this sector. However, some limitations to the apple pomace valorisation into apple flour were raised during the interviews conducted by the project partners, namely:

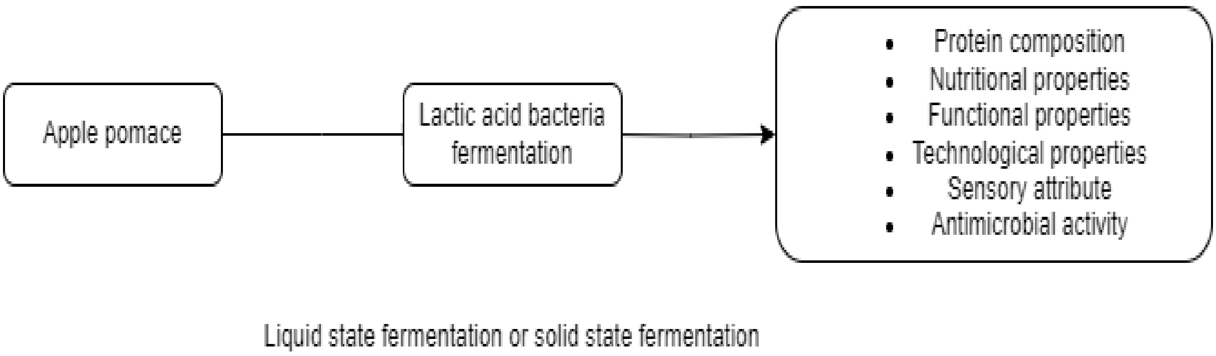
- Consumer demand for apple flour remains too weak for industrial investments. Indeed, consumers prefer other types of flours, such as wholewheat flour. Low demand does not stimulate the industrial investments for transformers.
- Manufacturers and producers who make use of by-products, such as apple flour, are neither compelled to do so, nor valued for the use of an ingredient issued from a virtuous circular production process. There are no fiscal or economic incentives for manufacturers to use apple flour.
- The stabilisation of the biomass for making apple flour is an issue raised by Belgian manufacturers. Interviews in France did not highlight a similar problem.

Fermented functional ingredients

Another way of valorising apple pomace for food purposes is to transform it into enriched ingredients, using lactic fermentation techniques. Apple pomace has been utilised as a substrate for the fermentation and production of a number of chemicals including organic acids (acetic acid, citric acid, lactic acid), alcohol, protein enriched feeds and enzymes (including cellulase, hemicellulase, ligninolytic, amylase, chitinase, chitosonase and pectinase) (Dhillon *et al*., 2013; Kosseva, 2013; Miceli-Garcia, 2014).

Fermentation techniques depend on a number of factors: the destination of the ingredient, the quality of the pomace, the quality of the fruit, etc. One of the main problems encountered by companies adopting this technique is pomace stabilization. This valorisation is common to all the regions where interviews were conducted. Fermentation is one of the oldest food-processing methods, consisting of modifying food through the use of microorganisms (bacteria, molds, and yeasts). Microorganisms use a part of the substrate to grow and reproduce and enrich it with the products of their metabolism. Enzymes from microorganisms, particularly amylases, proteases, and lipases, hydrolyze polysaccharides, proteins and lipids produce compounds that prevent food spoilage and consequently modify the nutritional, technological, and sensory attributes of foods.

Figure 54: Main potential outputs from apple pomace fermentation



Source: illustration elaborated on the base of the results from interviews with industrials

Fermentation techniques and processes depend on their purpose. However, the process is similar depending on the techniques used. The quality of the fermentation depends on different parameters: the sugar level, the quality of the apple, the maturity of the apples, etc. Indeed, the apple pomace deteriorates quickly, in particular because of its sugar content. Fermentation is a process adopted in several sectors: cosmetics, nutraceuticals, pharmaceuticals, food processing, etc.

Limitations to the valorisation of apple pomace for fermented functional ingredients:

- The stabilization of apple pomace is a major issue. As apple pomace contains carbohydrates, it rapidly transforms into alcohol, particularly during transport. This problem has been raised by the interviews carried out in Wallonia. In France, startups offering solutions are often located close to apple pomace sources, limiting the problems of biomass instability. Some have invested in dryers, enabling pomace to be dried directly after the process, while others are focusing on fermentation to stabilize apple pomace.

- Markets are small and do not allow industrials to sell enough apple pomace. The French manufacturers interviewed were unanimous on this point.
- In France, setting up an apple pomace recycling industry in the food sector encounters major problems: access to raw materials, logistics issues, stabilization of the biomass, strict regulation, etc. Furthermore, manufacturers have no incentive to use it.

2.3.3.2. Bioactive compounds

Rich in polyphenols and vitamins, apples are renowned for their antioxidant properties and for their bioactive compounds, in particular phlorizin and polyphenols. Polyphenols are present in the apple skin, seeds, etc. Consequently, such elements are also rich in fresh apple pomace. Interviews with French companies and a research laboratory illustrated that these molecules can be used in cosmetics, nutraceuticals, and pharmaceuticals. Research in this area is ongoing.

Apples have detoxifying properties and contains nutrients that stimulate cell regeneration and regulate sebum. For example, apples contain both quercetins, a powerful anti-inflammatory capable of protecting cells from everyday aggressions (pollution and stress in particular), and polyphenols, which are major antioxidants that protect skin from ageing and stimulate hydration. This type of antioxidant is particularly used in cosmetics and dietary supplements.

The list of polyphenols is presented in the following table.

Table 34: Polyphenol content of fresh apples

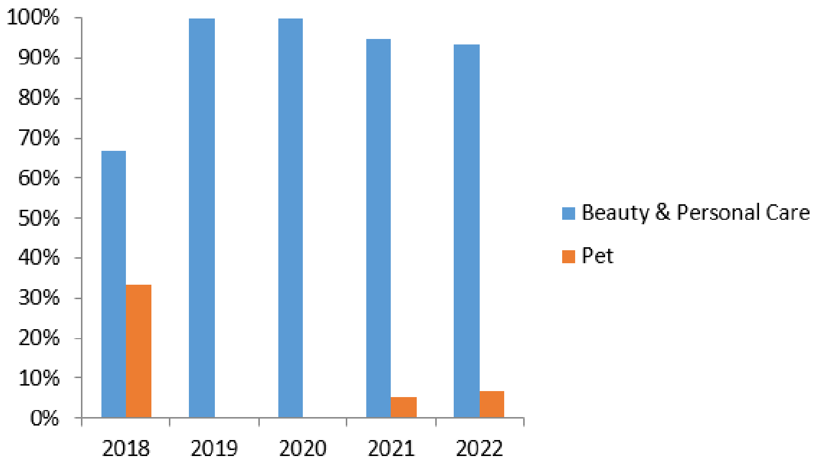
Class	Subclass	Polyphenol	Content in mg/100 fresh matter
Flavonoids	Anthocyanins	Cyanidine-3-O-galactoside	0,81
		Cyanidine-3-O-arabinoside	0,06
		Cyanidine-3-O-xyloside	0,06
	Dihydrochalcons	Phloridzin	2,75
		Phlortine-2'-O-xylosyl-glucoside	2,60
		3-Hydroxyphlorin-2'-O-glucoside	0,11
	Flavanols	(+)-Catechin	1,24
		(-)-Epicatechin	8,33
		Procyanidin B2	14,56
		Quercetin	0,13
		Quercetin-3-O-galactoside	2,36
		Quercetin-3-O-glucoside	0,64
		Quercetin-3-O-xyloside	0,78
		Quercetin-3-O-rhamnoside	1,33
		Quercetin-3-O-rutinoside	0,23
		Quercetin-3-O-arabinoside	1,40
Phenolic Acids	Hydroxybenzoic acids	Gentisic acid	0,22
		Syringic acid	0,90

	Hydroxycinnamic acids	p-Coumaric acid	0,29
		5-p-coumaroylquinic acid	1,05
		4-p-coumaroylquinic acid	2,25
		Caffeic acid	0,42
		Ferulic acid	0,06
		4-Caffeoylquinic acid	0,54
		4-Caffeoylquinic acid	13,25

Source: Auclair, 2008

Quercetin is recognized for its potential health-promoting properties and is an area of ongoing scientific interest in nutrition and wellness. Around 60 products containing quercetin has been launched between 2018 and 2022, mainly in the cosmetic sector. However, the French manufacturers interviewed unanimously stated that the molecules used are not necessarily bio-sourced or extracted from apple pomace.

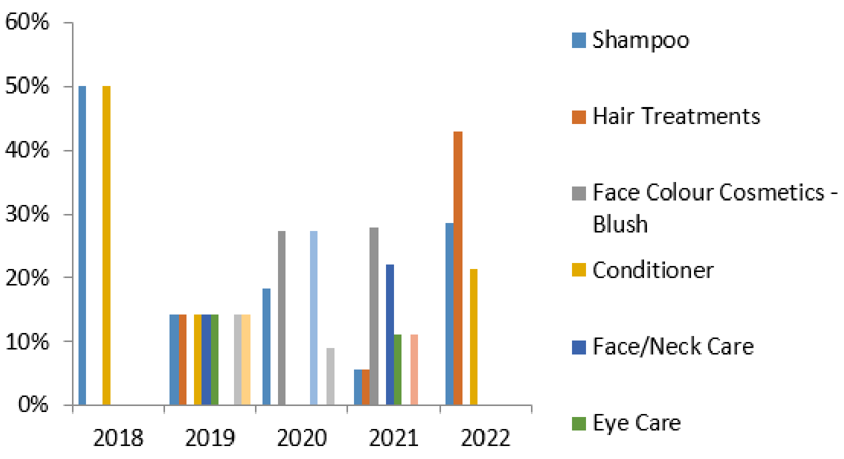
Figure 55: EU product launches for products containing quercetin (2018-2022)



Source: Data extracted from Mintel, 2023

NB: Mintel database does not allow to cannot distinguish between synthetic or bio-sourced quercetin.

Figure 56: Use of quercetin by cosmetics sub-category



Source: Data extracted from Mintel, 2023

NB: Mintel database does not allow to cannot distinguish between synthetic or bio-sourced quercetin.

One of the French laboratories interviewed also mentioned the valorisation of apple pomace in the pharmaceutical sector. Indeed, apples can be used in this field for their organoleptic properties, but also for the molecules contained in their seeds, skin and other parts. French companies have also indicated that apple pomace can be sold to pectin mills, which extract pectin from apples. For example, scientific publications indicate that apple polyphenols help limit the growth of cancer cells in the human body and also provide protection against viral infections.

Limitations to the valorisation of bioactive compounds of apples:

- The economic profitability of extracting bioactive compounds from apple pomace is limited. The volumes used in nutraceuticals and cosmetics are very low.
- The extraction process is costly for manufacturers and requires investments whose ROI is considered to be too long. The extraction yields for molecules of interest need to be improved.

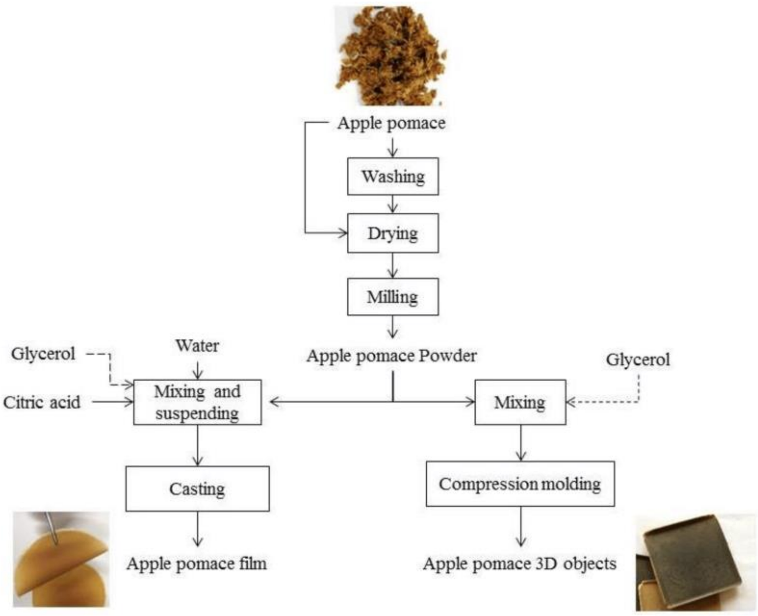
2.3.3.3. Packaging

Scientific literature (Liu *et al*., 2021; Gustafsson *et al*., 2019) and interviews with industrialists have indicated that packaging is promising in the sector of apple pomace valorisation. Several forms of packaging have been identified: apple leather (from pomace), apple paper, etc.

Nevertheless, there is no official consensus on packaging based on upcycled co-products. Indeed, some manufacturers consider that applying a layer of apple wax or an apple-based film is sufficient to call the product "apple packaging". Others, on the other hand, consider that to be called "packaging" from a co-product, the manufacturing process must be more complex and start from the co-product. As part of the B Resilient project, the choice was made to focus on the second definition.

The manufacturing process is described in the diagram pictured in the following figure.

Figure 57: Flowchart of the methods used for production of bio-based films and 3D objects from apple pomace



Source: Gustafsson *et al*., 2019

Although the apple has interesting characteristics for packaging, particularly for its fibres, the current state of the art does not make it possible to obtain a 100% apple-based film. Projects carried out in various sectors (aeronautics, automobiles, etc.) aimed at incorporating apple fibres into bioplastic indicate that the apple is "only" a substitute for petrochemical products.

Limitations to the valorisation of apple by-products for packaging:

- There is no consensus on the definition of plant-based packaging. For some respondents to the interviews carried out by the project partners, particularly in France, the simple fact that a film of apple wax is applied to the packaging can make it plant-based packaging. For others, to be considered plant-based packaging, the packaging must contain a high percentage of co-products.
- Converting apple pomace into packaging requires costly processing investments, for limited outlets. This issue was raised by one of the French companies surveyed.
- Pesticide residues are a major problem in the field. In fact, regulations impose strict rules on residues on manufacturers (bacterial contamination, pesticide residue, etc.) particularly for packaging in contact with food. Non-food contact packaging has relaxed rules in this area. However, the elasticity of the apple-based material is favoured when it is not washed, and therefore still has a quantity higher than the standard of pesticide. The film prepared from non-washed apple pomace was at least three times more flexible than the one prepared from washed apple pomace and glycerol This problem is particularly present in France and was noted by expert interviews.
- Although lignin is present in the apple pomace, the plasticizing effect of lignin might not be very significant in the formation of apple pomace fibreboards.

2.4. Dairy

2.4.1. Overview of dairy and cheese whey markets

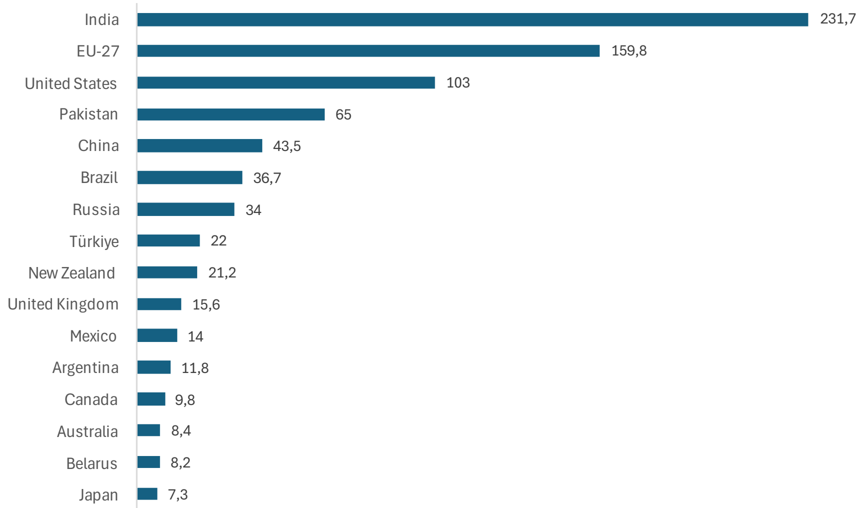
Consumed for 12.000 years, milk is the universal food par excellence. Over the centuries, discoveries and industrial processes have improved its preservation and transport, guaranteeing its quality. Milk remains at the heart of European diet and European culture.

2.4.1.1. Key Facts about milk production

This section is to provide a short overview of the European dairy production, pointing out the main producing countries, as well as the main trends in terms of dairy trade between Europe and the rest of the world.

World milk production is estimated at around 948 million tonnes (FAO, 2023). The breakdown by country is as follows:

Figure 58: Worldwide production of dairy in 2023 – in millions of metric tons



Source: FAO, 2023

Europe is the one of world's leading milk-producing regions. Almost 25% of the world's milk is produced in Europe. It is estimated that milk production will increase by almost 2% between 2022 and 2023. However, since 2015, the number of animals producing milk has been falling steadily, from 21,4 million to 19,4 million in 2023.

European milk production breaks down as follows:

Table 35: Breakdown of European milk production by animal origin in 2022

Animal origin	Share of European milk production (%)
Cow's milk	96,4
Ewe's milk	1,88
Goat's milk	1,56
Buffaloes' milk	0,19

Source: Eurostat, 2023

Most of the European milk production comes from milking cows. Other milks (ewe's milk, goat's milk, buffalo’s milk) account for a little over 3,5% of European milk production.

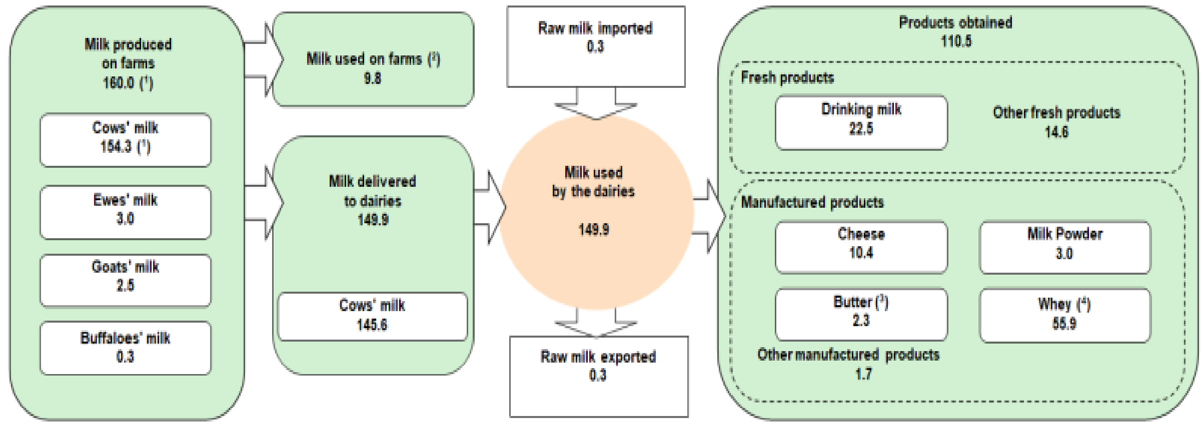
Table 36: Breakdown of cow’s milk production by country in 2023, sorted by % of European production

Country	Production (in thousand tons)	% of European production
Germany	32.424	22,40%
France	23.427	16,19%
Netherlands	13.894	9,60%
Poland	13.021	9,00%
Italy	12.918	8,92%
Ireland	8.710	6,02%
Spain	7.330	5,06%
Denmark	5.685	3,93%
Belgium	4.661	3,22%
Austria	3.243	2,24%
Czechia	3.223	2,23%
Sweden	2.819	1,95%
Finland	2.196	1,52%
Portugal	1.891	1,31%
Hungary	1.652	1,14%
Lithuania	1.352	0,93%
Romania	1.205	0,83%
Estonia	860	0,59%
Latvia	829	0,57%
Slovakia	807	0,56%
Bulgaria	690	0,48%
Greece	629	0,43%
Slovenia	559	0,39%
Croatia	377	0,26%
Cyprus	304	0,21%
Malta	37	0,03%

Source: Eurostat, 2023a

Milk production in Europe is highly concentrated. Two countries – Germany and France – account for almost 39% of European milk production. The five largest milk-producing countries (Germany, France, the Netherlands, Poland and Italy) account for 2/3 of European milk production (Eurostat, 2023a).

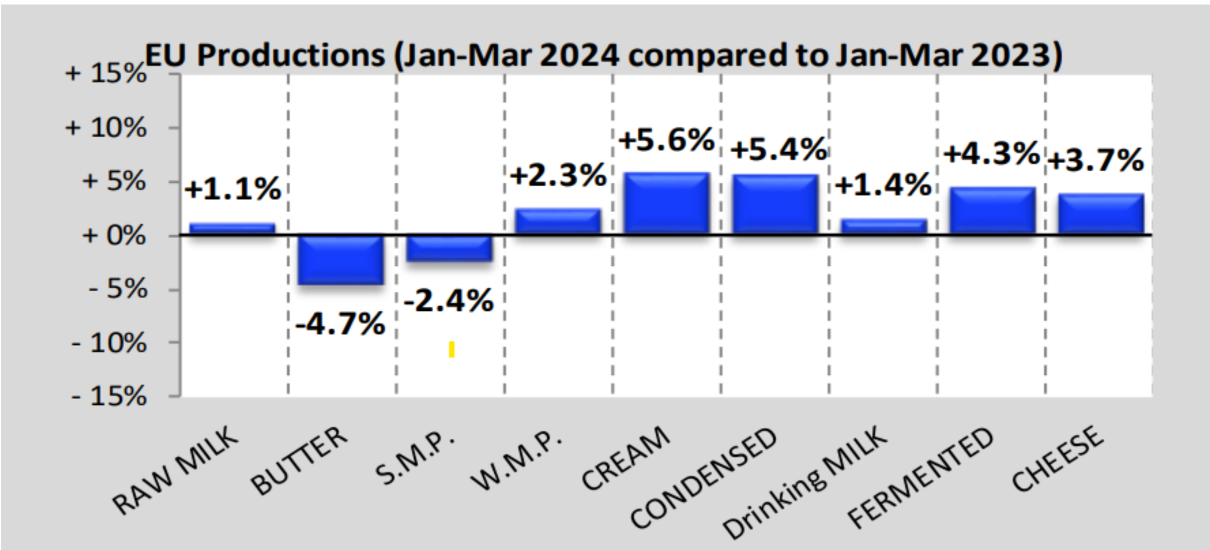
Figure 59: European production and use of milk (million tonnes, 2022)



Source: Eurostat, 2023b

Milk delivered to dairies accounts for almost 94% of milk consumption. Cow's milk accounts for 97% of milk delivered to dairies. Dairies process milk into 110,5 million tonnes of products, and manufactured products account for the majority of products obtained (approximately 2/3 of production). Whey is the main product processed and accounts for almost half of the volume processed (Eurostat, 2023b).

Figure 60: EU cow's milk collection and products obtained for Jan-Mar 2023 vs Jan-Mar 2024

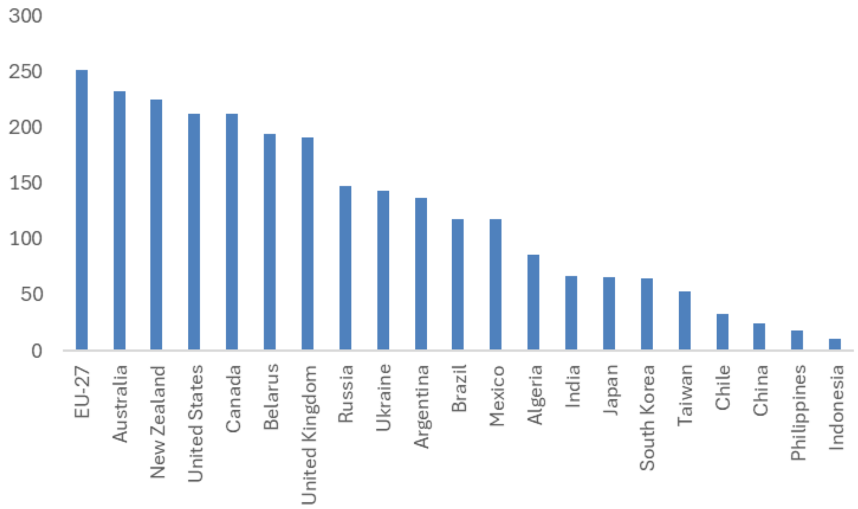


N.B.: SMP = skimmed milk powder; WMP = milk and cream powders, excluding skimmed milk powders

Source: Eurostat, 2023a

European production of processed milk-based products (see figure above) varies widely from one product to another. For example, butter production contracted by 4,7% in the first quarter of 2024. Cream, on the other hand, is expanding by 5,6%, and cheese production up 3,7% (Eurostat, 2023a).

Figure 61: Per capita consumption of milk products (milk, skimmed milk powder, whole milk powder, cheese), in milk equivalent, across selected countries (2023)



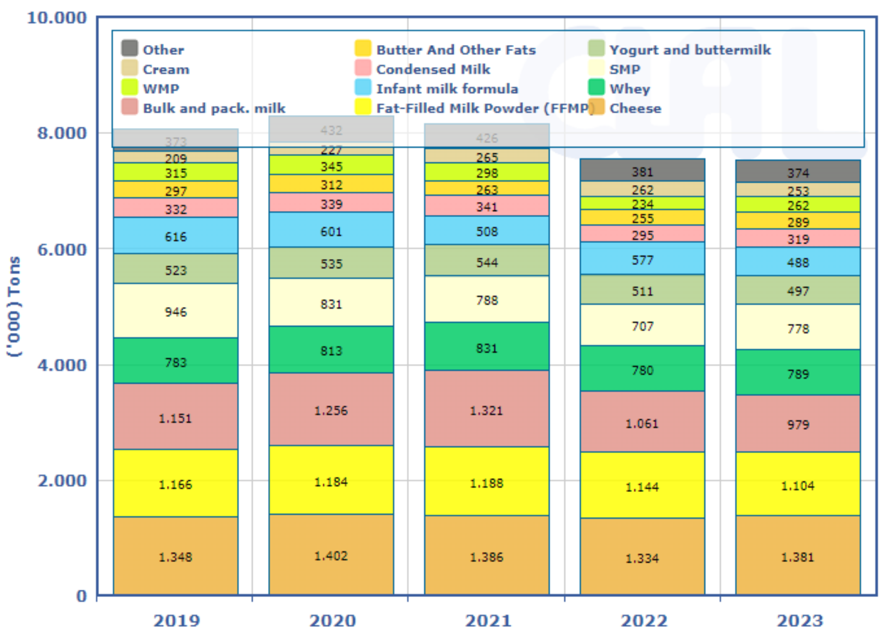
Source: Clal.it, 2024

The EU-27 is the world's most important consumer of milk in all its forms, relative to its population. On average, a European consumes more than 251 kg of milk in all forms (cheese, milk, Skimmed Milk Powder - SMP or Whole Milk Powder - WMP). As well as being one of the world's biggest milk producer regions (second to Asia), it is also the biggest consumer (on average). Milk is mainly consumed in the form of fresh milk and cheese. Europeans are the biggest consumers of cheese in the world, with over 20 kilograms consumed per year per capita (Clal.it, 2024).

2.4.1.2. European market for dairy cheese

Dairy cheese trade

Figure 62: Dairy Export Total for EU-27 countries, 2019-2023



Source: Clal.it, 2023

European exports of milk and milk-based products have been falling since 2020. Cheese and fat-filled milk powder account for almost 1/4 of European exports (Clal.it, 2023).

European Exports by dairy products

Europe has historically been a milk exporting area. The main export zone in Europe is the European market itself. Intra-EU trade accounts for almost 40% of total trade.

Exports to non-EU countries vary. The tables below show the main export countries by dairy product: butter, cheese, SMP and WMP. The UK, however, remains the main trading partner in Europe. Nevertheless, trade with the UK is declining (COMEXT, 2024).

Table 37: EU Exports of butter - main destinations (2023)

Country	Quantity (in tonnes)	2023/2022
United Kingdom	47.144	-19 %
USA	45.104	+12 %
China	14.041	+25%
South Korea	11.739	+10 %
Saudi Arabia	16.184	+80 %
Switzerland	4531	-42 %
U.A. Emirates	5.773	+2%
Taiwan	5.002	-1%
Singapore	5.027	+2%
Indonesia	4.096	-3%
Morocco	7.306	+116 %
Other	84.024	+46 %
Total	249.968	+14%

Source: COMEXT, 2024

The export volume of butter in European Union has been increasing since 2021. The European Commission estimates that the increase between 2021 and 2023 is 11%. Data published by the European Commission show a slight decline in European exports compared to January-February, with exports slightly declining (-1%). The 10 main butter exporting countries account for 2/3 of European exports (COMEXT, 2024).

Table 38: EU Exports of cheese - main destinations (2023)

Country	Quantity (in tonnes)	2023/2022
United Kingdom	426.987	+1%
USA	126.490	-2%
Japan	101.876	-8%
Switzerland	71.238	+1%
South Korea	53.937	-9%
Saudi Arabia	40.952	-8%
Ukraine	34.390	+3%

China	33.679	+16%
Canada	26.627	+1%
Australia	27.040	+4%
Libya	22.996	+4%
Other	413.519	+15%
Total	1.379.731	+14%

Source: COMEXT, 2024

Cheese exports rose between 2017 and 2023, from 1.275.000 tonnes to 1,380,000 tonnes (+8%). Europe is highly dependent on cheese exports. Indeed, the top 10 export markets account for 70% of all cheese exports (by volume). The British market remains the main export market for European cheese, accounting for 31% of exports. Nevertheless, the Chinese market is the most dynamic in terms of growth, with an increase of 16% (COMEXT, 2024).

Table 39: EU Exports of skimmed milk powder - main destinations (2023)

Country	Quantity (in tonnes)	2023/2022
Algeria	144.468	+29%
China	68.246	-17%
Indonesia	26.874	-37%
Egypt	51.884	+27%
Nigeria	19.911	-41%
Philippines	27.068	-19%
Yemen	34.779	+12%
Malaysia	32.495	+26%
Saudi Arabia	40.678	+58%
Morocco	31.096	+11%
Vietnam	28.154	+38%
Other	271.775	+17%
Total	777.426	+10 %

Source: COMEXT, 2024

SMP exports have been on a downward trend since 2017, falling from 794.000 tonnes to 777.000 tonnes in 2023. However, for the first time since 2017, the sector has seen exports grow between 2022 and 2023 (+10%). The 10 main SMP exporting countries account for 2/3 of European exports (COMEXT, 2024).

Table 40: EU Exports of whole milk powder - main destinations (2023)

Country	Quantity (in tonnes)	2023/2022
Oman	44.427	-13%
China	14.155	-34%
United Kingdom	17.260	+8%
Kuwait	10.508	-24%

Dominican Republic	9.057	+16%
Algeria	25.835	+279%
Saudia Arabia	6.731	+2 %
Senegal	6.397	+3%
Singapore	6.559	+22%
Bangladesh	2.255	-52%
Ivory Coast	3.405	-12%
Other	115.105	+27%
Total	261.692	+12%

Source: COMEXT, 2024

WMP's 10 largest export markets account for 56% of European exports in this field. European WMP exports are not very dependent on one or more markets. Nevertheless, WMP exports have been on a downward trend since 2017, falling from 404.000 tonnes to 262.000 tonnes in 2023 (COMEXT, 2024).

EU Imports of Dairy Products – Main origins

Table 41: EU Imports of butter - main origins (2023)

Country	Quantity (in tonnes)	2023/2022
United Kingdom	5.219	+22%
Norway	58	Data non available
Belarus	1	0%
Ukraine	3	0%
Switzerland	1	0%
Other	2.014	+ 1338%
Total	7.292	+65%

Source: COMEXT, 2024

Table 42: EU Imports of cheeses - main origins (2023)

Country	Quantity (in tonnes)	2023/2022
United Kingdom	18.236	-3%
Switzerland	7.927	-5%
Ukraine	82	Data non available
Serbia	248	0%
Norway	324	+78%
Turkey	218	0%
Bosnia-Herz.	134	+23%
Iceland	47	+12%
USA	73	+30%
Other	30	-123%

Total	27.319	-3%

Source: COMEXT, 2024

The United Kingdom remains Europe's main trading partner for dairy products. It accounts for over 70% of European imports of butter and 67 =% of European imports of cheese. More generally, trade is mainly with non-EU European countries (Switzerland, Norway, etc.). Trade with these countries increased between 2022 and 2023 (COMEXT, 2024).

Cheese production in the B-Resilient partner regions

i. Flanders

Table 43: Cheese production in Flanders

Area	13.522 sq km
Population	11,7 million persons (January 2024)
Cheese production	Regional data breakdown non available
% of national production	Data non available

Source: Statbel, 2024; interviews

The dairy industry in Belgium produced about 100.000 tons of natural cheese (cheese with whey as a by-product) in 2020 (Statbel, 2024). Based on a production coefficient of 8,5 L of cheese whey per kg of cheese, the cheese whey production in Belgium is 850.000 m³. The cheese production per month fluctuates between 6-10% of the total production.

In 2023, Belgian dairy farms produced no less than 80.900 tonnes of mozzarella, or an increased production of 12.300 tonnes (+18%). Consumer cream also increased to a level of 268 million litres, an increase of 11,4 million litres (+4%) of cream compared to 2022.

In large dairy companies, (non-)pasteurised milk is processed into (non-)pasteurised cheese and cheese whey with a dry matter (DM) content of 4-6%. This whey is often concentrated by reverse osmosis to obtain whey with a higher DM (often 16-30%). This whey can be processed into whey protein for food and feed applications or used directly as animal feed. In a small dairy company with relatively low volumes of whey, the whey is often not concentrated and transported by a farmer for use as animal feed.

The composition of whey shows a large variability, depending on the type of cheese produced, type of enzyme (rennet, bacterial) for casein coagulation, conservation (e.g., lysosyme, nitrate), concentration of yellow colorant (carotene). The storage conditions vary depending on the company: larger companies usually store the concentrated whey in a silotank at 8 °C until transport. However, in smaller companies, whey is stored at ambient temperature in a tank for several days, leading to spontaneous fermentation to pH < 3.6 (Statbel, 2024; interviews).

ii. Galicia

Table 44: Cheese production in Galicia

Area	29.574 sq km
Population	2,7 million persons
Cheese production	Regional data breakdown non available
% of national production	Data non available

Source: MAPA, 2022; interviews

According to data reported by the Spanish Ministry of Agriculture, Fisheries and Food, the total production of raw cow's milk in 2022 was 7.383.349 tonnes at the national level, with Galicia being the main producer of this type of milk with a production of 2.976.713 tonnes. This national production represented a growth of 2,81% compared to 2018 and 5,95% compared to 2016. In relation to the production of Galician cow's milk, an increase in production has also been observed, with 7,74% compared to 2018 production and 12,31% compared to 2016.

In addition, Galicia is also the leading autonomous community in organic raw milk production, with 49% of production with respect to the nearly 24.000 tonnes produced in 2022.

According to the statistical data collected by the Ministry of Agriculture, Fisheries and Food, the total production in tonnes of cheese (538.210 tonnes) is distributed as follows by type of cheese: 263.200 tonnes of cheese from pure cow's milk, 74.900 tonnes from pure sheep's milk, 52.300 tonnes from pure goat's milk and 147.800 tonnes from blends.

Additionally, the cheeses are classified according to categories, being soft paste (75.700 tonnes produced), semi-soft paste (46.300 tonnes), semi-hard paste (112.300 tonnes), hard paste (145.200 tonnes), extra-hard paste (900 tonnes), fresh cheese (157.700 tonnes).

Together with these data, total milk production has also been reported, amounting to 2.455.500 tonnes. Within this amount of whey produced, 849.100 tons correspond to whey in liquid form, 218.700 tons to whey in concentrate form and 28,8 tons to whey powder and whey blocks.

As far as the region of Galicia is concerned, according to the Galician Institute of Statistics, the number of dairy companies has risen to 162 in 2021 with a net turnover of 1.396.820 € (MAPA, 2022; interviews).

iii. La Rioja

Table 45: Cheese production in La Rioja

Area	5.045 sq km
Population	323.377 persons (2023)
Cheese production	Regional data breakdown non available
% of national production	Data non available

Source: interviews

Milk production has increased over the last two decades in La Rioja. In 2003, 21.4 million litres of milk were produced, while by 2021 this figure had risen to 29,3 million litres. The growth in this figure is mainly driven by cow's milk production, which has risen from 20 million litres in 2003 to more than 27 in 2021. Goat's and sheep's milk have also seen significant percentage growth over the last two decades, but in smaller quantities: 1,361 million litres of sheep's milk and 0,859 for goat's milk, both in 2021. Rioja cheese production is particularly well known for its PDO, Queso Camerano, a goat's milk cheese emblematic of the Community. In 2021, an estimated 87 tonnes of this cheese were exported to the USA (interviews).

iv. Central Macedonia

Table 46: Cheese production in Central Macedonia

Area	18.811 sq km
Population	1.782.630 persons (2023 estimation)
Cheese production	Data non available
% of national production	50% of national production

Source: interviews

Central Macedonia is the most important producer of milk in Greece. It produces 50% of total milk in Greece and 30% of the total feta produced. However, the Greek production of cow's milk is not able to fully meet the needs of consumer demand in Greece. This is mainly due to the structure of the sector, as the latter consists of many small farms which cannot exploit economies of scale and reduce production costs. The Greek dairy sector is facing a significant decline in production and a reduction in the number of the holdings and a total failure to attract young farmers. In Central Macedonia there are:

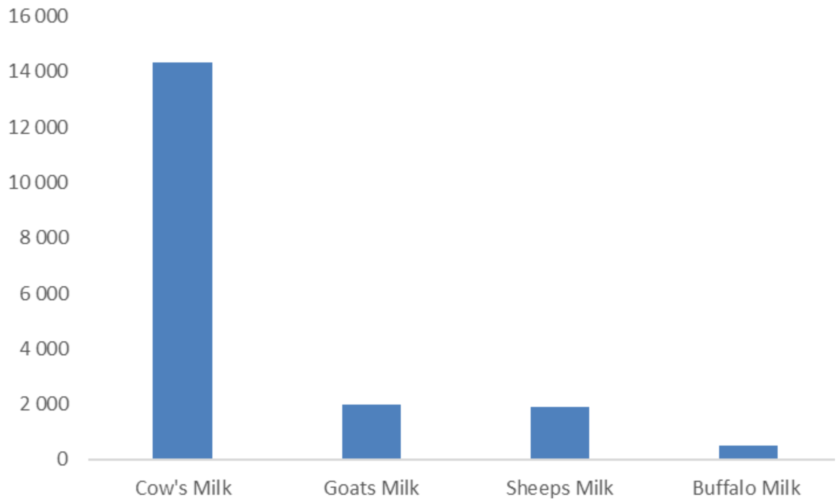
- more than 1/4 of the country's farms,
- more than 40% of productive animals raised,
- approximately half of the country's cow's milk produced

In Central Macedonia there are 34% of the country's farms, which breed 42,8% of dairy cows' fresh local milk. The region houses 14% of the milk processing companies in Greece, with a share of 24% in the total turnover of the sector (approximately €587 million) and 25% in its employees (interviews)

2.4.1.3. Cheese whey-based products launched in Europe

The following section breaks down the launches of cheese and cheese whey-based products in Europe.

Figure 63: Breakdown of cheese launches between 2018 and 2023 by milk type

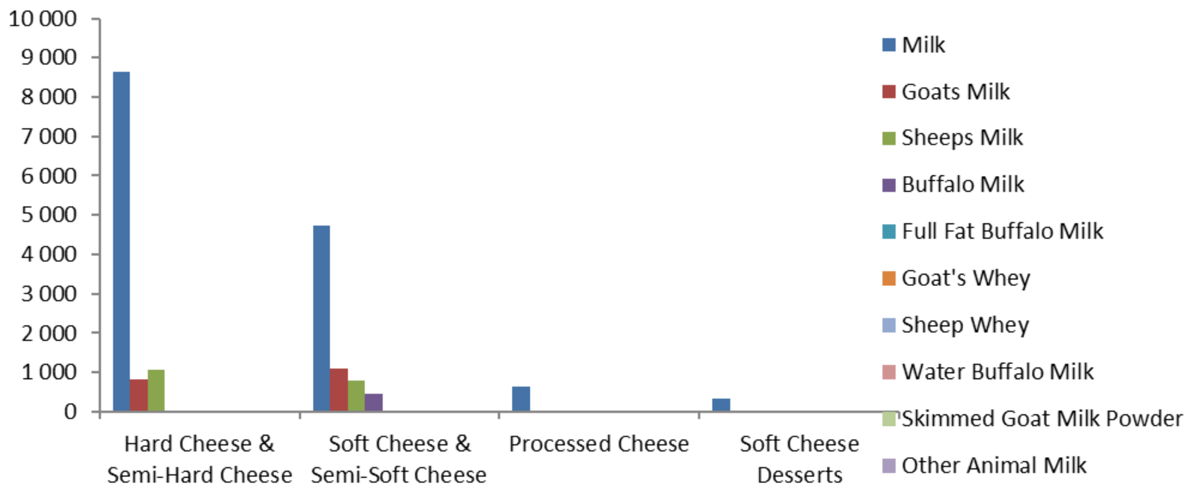


Source: Mintel, 2024

Cow's milk production is the most important. Indeed, the number of launches containing cow's milk remains in the majority, with over 70% of milk-based products launched containing cow's milk.

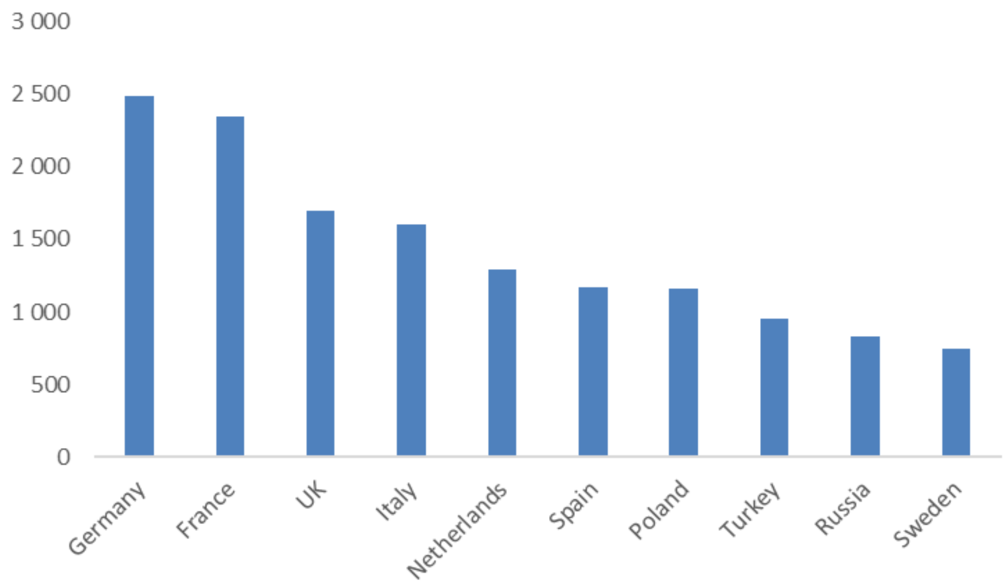
The following figure breaks down the launches of cheese products by type, and by origin of milk (with processed cheese consisting of natural cheese with additives such as salt, emulsifiers, stabilisers, flavour enhances and food colourings; the soft cheese desserts category includes all dairy-based desserts made with soft cheeses such as "fromage frais" or "fromage blanc").

Figure 64: Breakdown of cheese launches by origin of milk



Source: Mintel, 2024

Figure 65: Breakdown of cheese launches by country in Europe



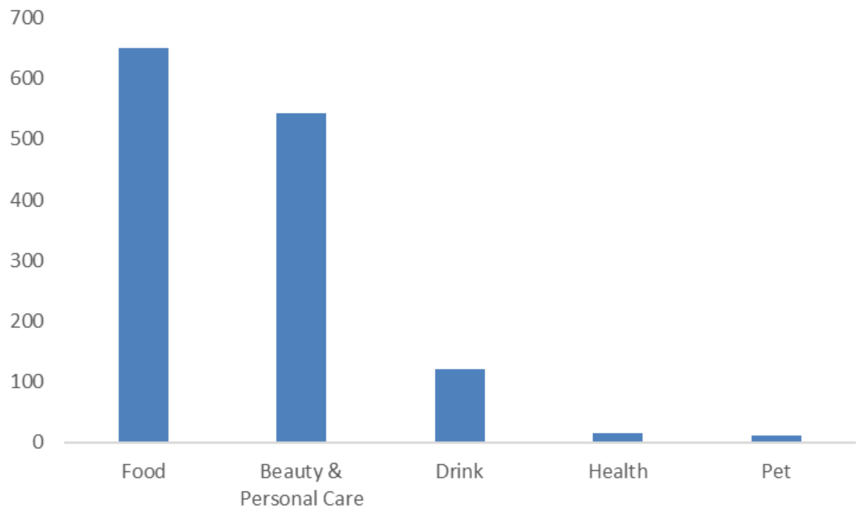
Source: Mintel, 2024

Product launches related to cheese whey

When milk is processed into cheese, butter or yoghurt, by-products such as whey are created. Whey is a by-product containing proteins, lactose, lipids, vitamins and minerals. Each type of whey is different in terms of its functional or organoleptic properties, depending on the upstream technology used. There are different types, such as demineralised whey and sweet whey.

The European whey market is projected to reach approximately $3,92 billion by the end 2024. The major factors that propel the growth of the European whey protein market are rising demand for dairy ingredients, consumer awareness towards healthy diet, growing functional beverage market.

Figure 66: Breakdown of whey products by category between 2019 and 2023

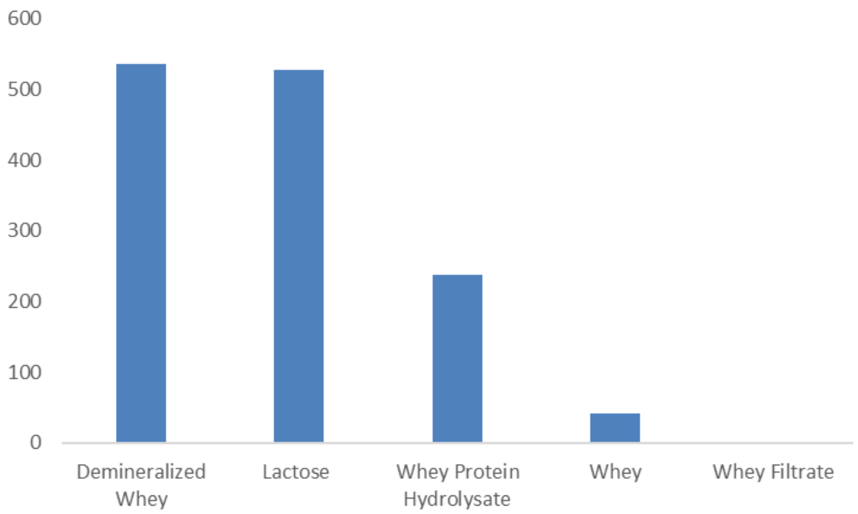


Source: Mintel, 2024

A total of 1340 products containing whey have been launched between 2019 and 2023. Launches in the food sector remain the majority and have been stable between 2019 and 2023. Cosmetics is the second most active category. Nevertheless, the number of launches containing dairy products is declining, but with milk beverage launches remaining stable. However, the dynamism of launches is relatively low compared with the growing number of plant-based alternatives.

Among the most active product categories are baby foods and soaps, whose number of launches declined between 2019 and 2023.

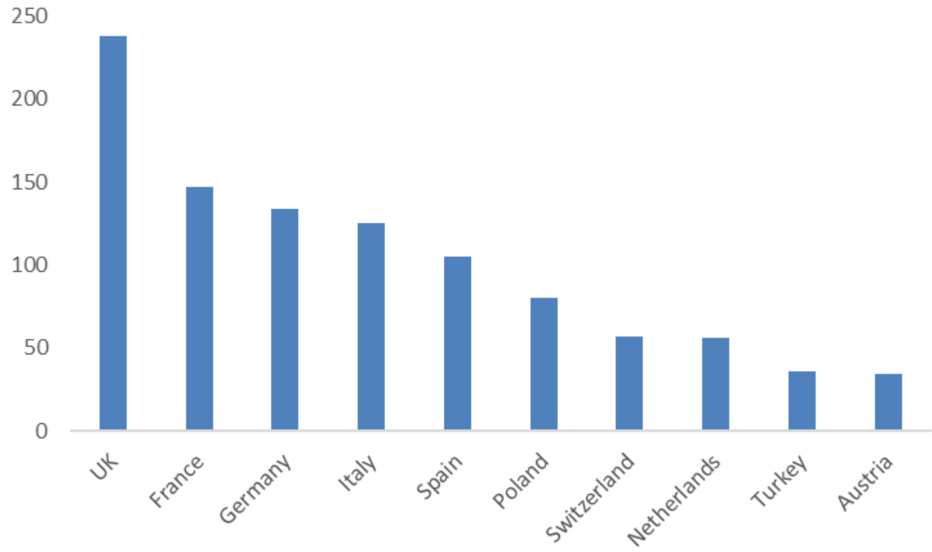
Figure 67: Breakdown of launches by ingredient between 2019 and 2023



Source: Mintel, June 2024

Two ingredients account for over 70% of all milk-derived whey product launches: demineralized whey, mainly launched in the food sector, and lactose, which dominates cosmetics launches.

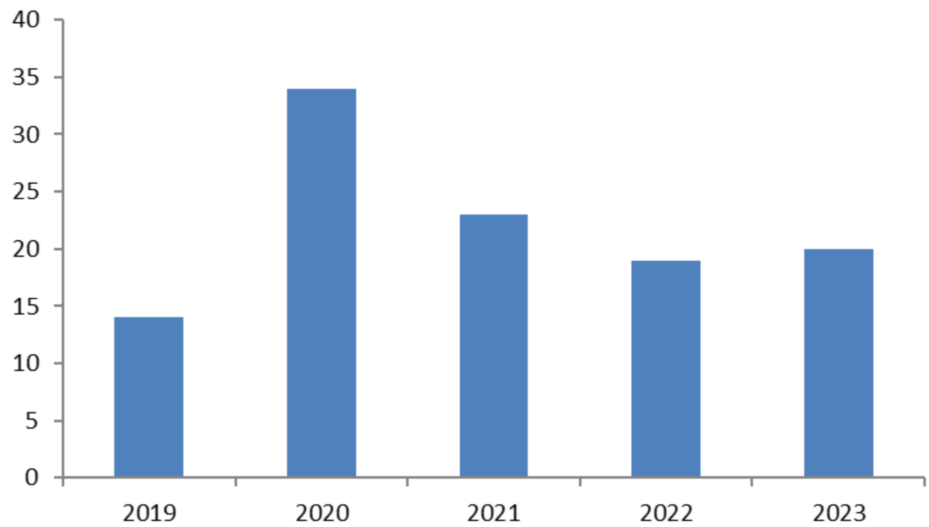
Figure 68: Breakdown of whey-based product launches by country (2023)



Source: Mintel, June 2024

Launches are mainly significant in Western European markets. The UK is the main market for milk-based product launches. The UK is also Europe's biggest milk consumer, with 1,2 litres per person per week, or over 60 litres per person per year. By way of comparison, France, the second most active market in terms of product launches, consumes just 41 litres of milk per year.

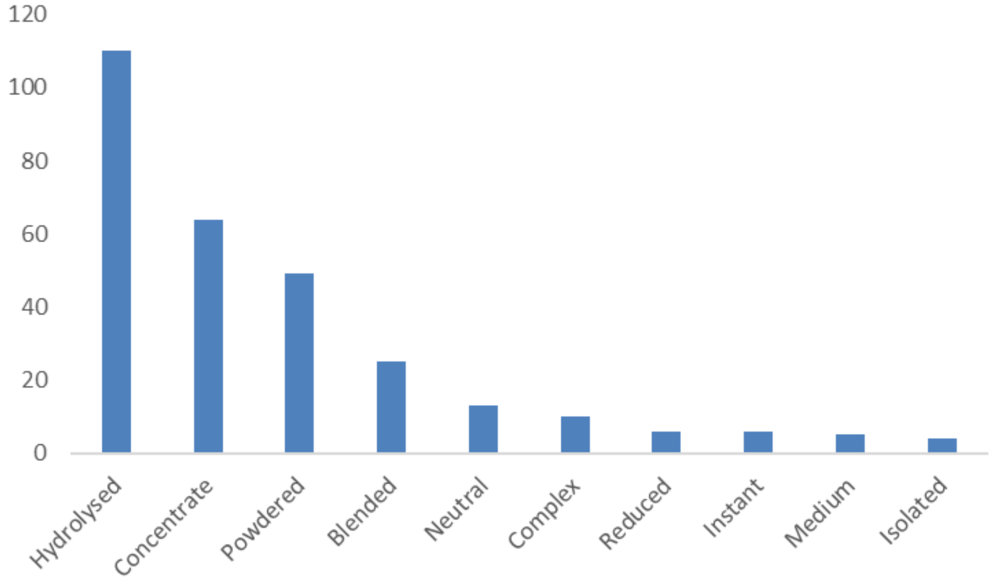
Figure 69: Sports nutrition products launched - breakdown of product launches by year



Source: Mintel, June 2024

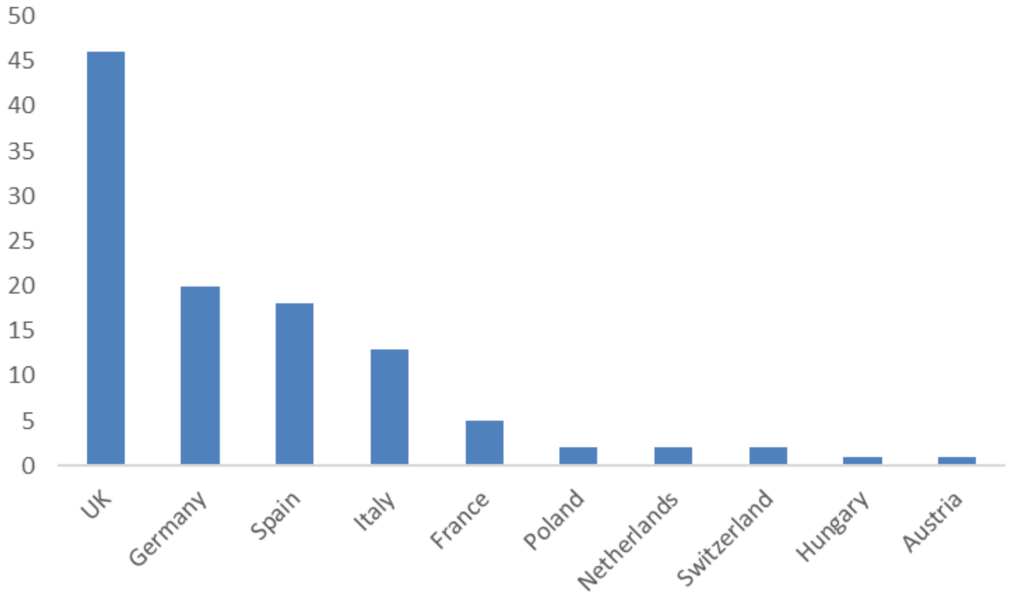
110 sports nutrition products containing whey and whey powder were identified through the Mintel database. The number of launches increased over the period but remained low. Launches are exclusively in the nutritional & meal replacement drinks category. Other sports nutrition categories (snacks, cereal bars, etc.) are not marketed in powder form.

Figure 70: Breakdown of sports nutrition powdered whey products by ingredient preparation type (products may be comprised of several ingredient preparations)



Source: Mintel, June 2024

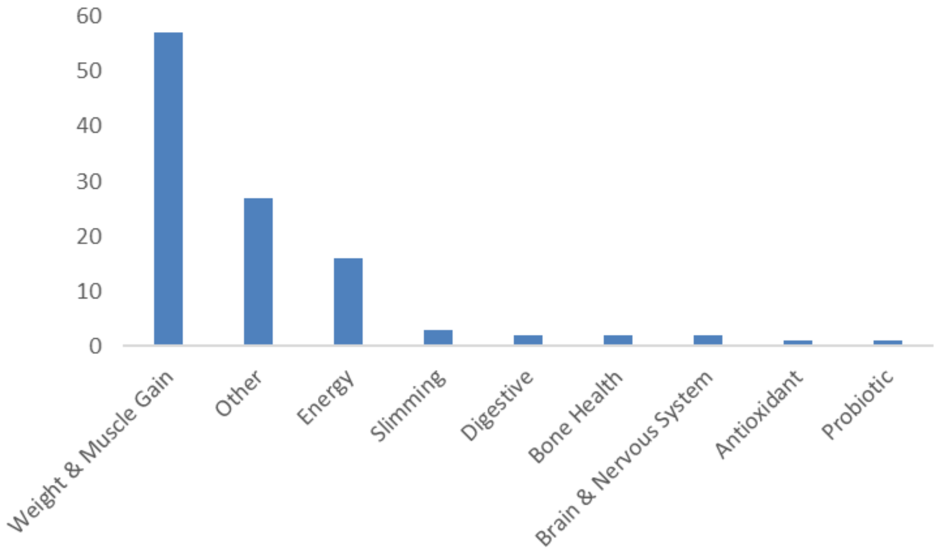
Figure 71: Breakdown of sports nutrition whey powder product launches by market



Source: Mintel, June 2024

The UK market is the most active in terms of whey powder product launches. The British sports nutrition market is one of the largest in Europe, with sales of over 3 billion euros. Consumers, motivated by the awareness of causality between nutrition and its impact on physical health, seek products that align with this relationship. According to Euromonitor, the UK will account for nearly 45% of sales in 2022.

Figure 72: Top functional claims attributed to whey powder sports nutrition products



Source: Mintel, June 2024

Consumers use whey powder products for a number of reasons – mostly aligning with this notion of relationship between sports/health nutrition and physical health. Marketing claims indicate that weight and muscle gain is the main claim attributed to whey powder sports nutrition products.

2.4.2. Cheese (whey) production, composition and biochemical properties

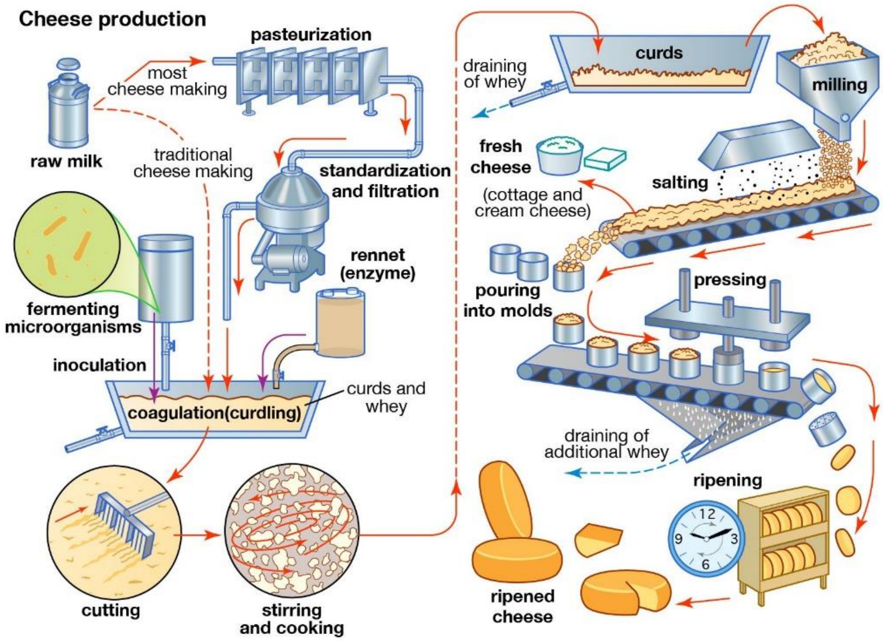
2.4.2.1. Cheese (whey) production

During the cheese-making process, milk goes through a series of processes prior to the obtention of the final product, with some intermediary processes already obtaining a cheese product.

The raw milk goes through pasteurisation, followed by a process of standardisation and filtration, before a coagulant (typically rennet) is added to start the curdling process. The curdled milk is cut, stirred and cooked before the whey is drained. The curdles then go through a milling and salting process. At this stage, cottage and cream cheeses can be obtained. The salted curdles can also go through a pressing and ripening process before obtaining harder cheeses (Bandler, 2023).

Cheese whey drained during the cheese-making process represents 85-95% of the total volume of initial milk used, with every 1 kg of cheese being produced resulting in about 9 kg of whey (Kosikowski, 1979).

Figure 73: The cheese-making process (for cottage, cream and ripened cheeses)



Source: Encyclopaedia Britannica, Inc., 2014

2.4.2.2. Cheese whey composition and biochemical properties

The composition of (cheese) whey is highly dependent on the kind of whey (sweet or acid), as well as the animal milk source, the animal's feed, the processing method used for the cheese obtention, and the time of year/stage of lactation (Tsakali *et al.*, 2010). Cheese whey retains on average 55% of all milk nutrients (Kosikowski, 1979).

The following tables outline the typical composition of whey(s), including basic nutritional components, as well as vitamins and minerals.

Table 47: Composition of whey (depending on type), % of total volume

Component	Fluid sweet whey	Fluid acid whey	Condensed acid whey	Dried sweet whey	Dried acid whey
Total solids	6,35	6,50	64,00	96,50	96,00
Moisture	93,70	93,50	33,50	3,50	4,00
Fat	0,50	0,04	0,60	0,80	0,60
Total protein	0,80	0,75	7,60	13,10	12,50
Lactose	4,85	4,90	34,90	75,00	67,40
Ash	0,50	0,80	8,20	7,30	11,80
Lactic acid	0,05	0,40	12,00	0,20	4,20

Source: Kosikowski, 1979

Table 48: Mineral and vitamin composition of fluid whey (sweet and acid) per 100g

Name	Amount		Unit
	Whey, sweet	Whey, acid	
Calcium, Ca	47	103	mg
Iron, Fe	0,06	0,08	mg
Magnesium, Mg	8	10	mg
Phosphorus, P	46	78	mg
Potassium, K	161	143	mg
Sodium, Na	54	48	mg
Zinc, Zn	0,13	0,43	mg
Copper, Cu	0,004	0,003	mg
Manganese, Mn	0,001	0,002	mg
Selenium	1,9	1,8	µg
Vitamin C	0,1	0,1	mg
Thiamin	0,036	0,042	mg
Riboflavin	0,158	0,140	mg
Niacin	0,074	0,079	mg
Pantothenic acid	0,383	0,381	mg
Vitamin B-6	0,031	0,042	mg
Folate	1	2	µg
Choline	16	16	mg
Vitamin B-12	0,28	0,18	µg
Vitamin A	3	2	µg

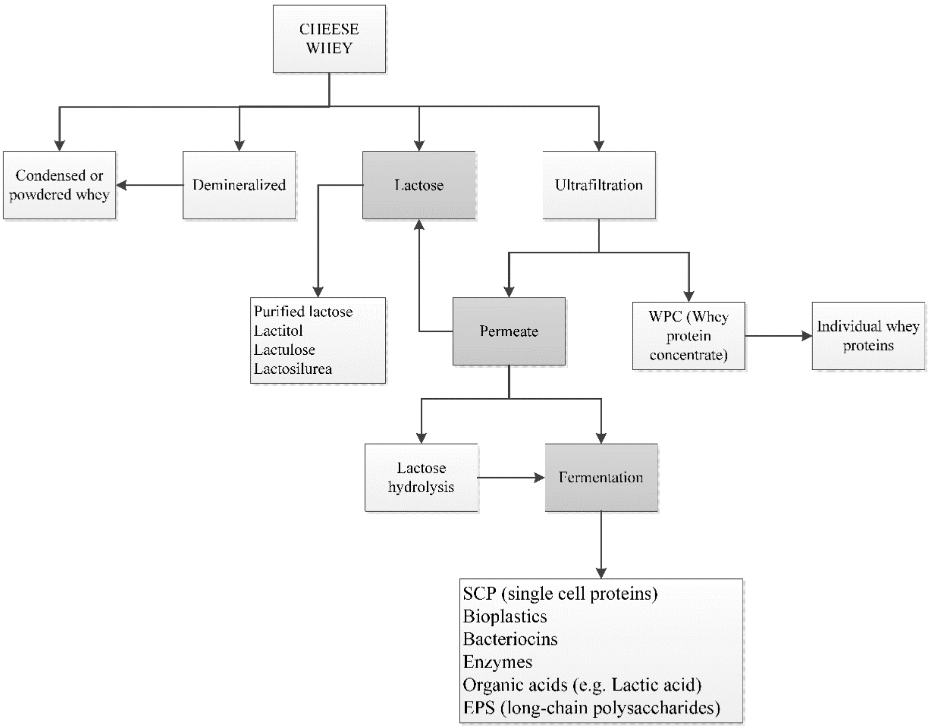
Source: USDA, 2019a; USDA, 2019b

2.4.3. Examples of valorisation of cheese whey

The main components of whey, whatever the form (sweet or acid, fluid or dry), make it an interesting source for "functional proteins and peptides, lipids, vitamins, minerals, and lactose", and so an interesting component to be revalorised in a variety of different sectors (Ryan, 2016).

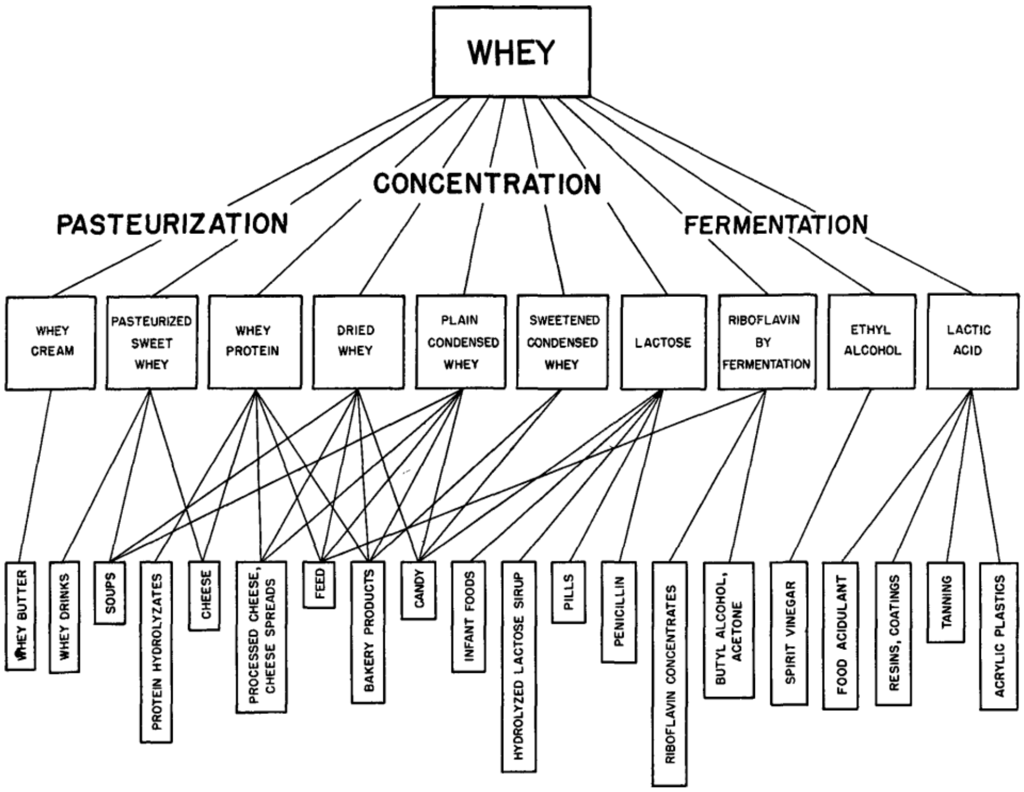
The following figure outlines current possibilities in the valorisation of cheese whey, depending on the stage of transformation of the cheese whey.

Figure 74: Scheme of current possibilities of cheese whey valorisation



Source: Mollea *et al*., 2013

Figure 75: Flow sheet of products from whey



Source: Webb & Whittier, 1948

Several projects are emerging around the valorisation of cheese whey. Three such projects have been identified in Spain. The first, Resupeq, focuses on the valorisation of cheese whey from small cheese makers into whey-based drinks, other dairy products, and snacks and other products (Asincar, 2020). Another initiative, Wheypack, focuses on valorisation of cheese whey into bioplastics (polyhydroxybutyrate, *i.e.*, PHB) through fermentation by micro-organisms (Wheypack, 2024). BIOPOL focuses on the transformation of cheese whey into highly degradable bioplastics aimed for cosmetics applications (Bioga Business Technology Cluster of Life Sciences, 2021).

EU project AgriChemWhey aimed to develop a blueprint for an economically sustainable integrated biorefinery model, replicable across the EU. The project sought to create this biorefinery model to convert diary side streams (including cheese whey) into bio-based chemicals (Circular Bio-based Europe, 2024).

From the major sector uses outlined above, supported by ongoing research/projects and as identified through the series of interviews, four sectors of valorisation of cheese whey were selected in this analysis to provide more in-depth descriptions of possible valorisation. Animal nutrition and agronomic applications were grouped together, emerging as the first sector of valorisation, followed by energy, then food and nutritional supplements (also grouped), and a final category grouping biochemical and bioplastic applications (industrial production).

2.4.3.1. Feed & Agriculture

Feed

Whey can be utilised in various forms as an animal feed additive, with different effects. Condensed and dried forms of whey are most useful as an additive in pig and chicken feed, notably in cases of proximity to cheese makers. Lactose in the cheese whey can prevent coccidiosis in chickens, and the riboflavin can improve chick growth, egg hatchability and prevent curled toe paralysis (Webb & Whittier, 1948). Cattle fed a diet of whey and grain were found to have greater gains relative to an only grain-fed control (Anderson *et al*., 1974).

Information gathered in interviews from cheese makers across Europe (notably in Galicia and Flanders) supports these findings. Indeed, Spanish cheese makers *Calidad Pascual* reported their cheese whey being revalorised as animal feed. Flemish cheese company *De Zuivelarij* revalorises part of the cheese whey obtained from halloumi cheese production into ricotta cheese, but the market for ricotta is not significant enough, and so half of the whey obtained from the halloumi production goes to other uses, notably feed (99% of their disposed cheese whey). Similarly to *De Zuivelarij*, *Kaasmaakerij Karditsel* valorises most of their cheese whey into feed for pigs. A third interviewed Flemish company also reported valorising their cheese whey through animal feed.

Agriculture

There are some possible benefits in the use of cheese whey as a soil amendment, with potential increase in (corn) germination, reduction in soil pH, increase in soil organic matter, macronutrients relative to a control (Aboukila, 2019). However, these finding are more anecdotal relative to the majority of findings. Indeed, the disposal of cheese whey onto land can lead to damage to soil and growth of plant life, notably due to the high salinity of cheese whey (Kosikowski, 1979).

2.4.3.2. Energy

According to the interviewed *Aula de Produtos Lácteos e Tecnoloxías Alimentarias* (of the University of Santiago de Compostela), one of the major research axes in the valorisation of cheese whey is the utilization of whey for biofuels, or as a base for biogas. This is echoed by the *Centre for Research and Technlogy – Hellas* (in Greece), who highlight that cheese whey has a high potential in its valorisation for the production of biofuels (*e.g.*, bioethanol). The centre also identifies fermentation of cheese whey as a significant pathway in its valorisation. Indeed, with stricter regulations on carbon emissions, fermentation is expected to replace anaerobic digestion as a key process in dairy biorefineries.

There exists significant opportunity for the use of cheese whey in bioenergy and biochemical production, with recommendation from one research review for a biorefinery concept (Asunis *et al.*, 2020). This echoes the EU project AgriChemWhey's objective to create an integrated biorefinery concept (Circular Bio-based Europe, 2024). Indeed, the model for an integrated biorefinery increases the possible range of value-added products made from cheese, while allowing for sustainable management of waste and other residual streams from production.

Anerobic digestion is one of the processes that may be used to valorise the energetic potential of cheese whey, however, high organic load in the whey can result in an inhibited methanogenic activity. Cheese whey has strong potential, due to its efficiency, for both the production of hydrogen and methane, in two-stage processes (Venetsaneas *et al.*, 2009). Two-stage processes may result in higher CH_4 production, but these require greater capital and have higher operational costs. Dark fermentation is an alternative process by which energy can be derived. Indeed, the high carbohydrate content of cheese whey means high potential for conversion to biohydrogen. Lactate and ethanol fermentation are two possible processes for the obtention of energy from cheese whey, but these processes are currently typically undergone with sugarcane, corn starch or other lignocellulosic raw materials, and as such, cheese whey makes for a less interesting initial biomass (Asunis *et al.*, 2020). Current ethanol production with whey permeate is not as economically competitive as the more traditional lignocellulosic bioethanols (Ryan, 2016).

A few of the interviewed companies related valorising their whey into some form of energy. Indeed, *Queizuar S.L.*, in Spain, has a biodigestor to transform residual lactose (from cheese whey) and obtain energy. Lactose derived from *Milcobel*'s cheese whey is sold mainly for feed, but also to the chemical industry where the lactose can be fermented to result in biogas production. *Kaasmaakerij Karditsel*'s remaining cheese whey not valorised for feed is used for biofermentation to produce biogas.

2.4.3.3. Food & Nutritional supplements

One significant sector in which cheese whey is valorised is in the food (and nutritional supplements) industry. Indeed, the major (nutritional) components of cheese whey, as well as the functional characteristics derived from these components, offer a large range of potential benefits for its use in the food industry. According to the Aula de Produtos Lácteos e Tecnoloxías Alimentarias (of the University of Santiago de Compostela), one of the major research axes in the valorisation of cheese whey is the valorisation of whey for nutritional purposes (infant, senior and sports nutrition), due to their functionalities as thickeners, emulsifiers, and capacity for microparticulation.

The following tables list possible uses for cheese whey in the food (and nutrition) industries, according to their functional characteristics, and different whey types.

Table 49: Whey foods

A. Foods supplemented with sweet whey or its derivatives	
Ice cream Ice cream coatings Bread Sweet rolls Crackers Cookies Cakes Icings Snack foods Gravy mixes Seasoning mixes Orange juice Meat products	Candy coatings Fudge, caramels, chocolate Margarine Syrups Infant foods Toppings Meat sauces Soups Soft drinks Cheese foods Dulce de leche Puddings Compound coatings
B. Foods supplemented with acid whey or its derivatives	
Fruit beverages Fermented milks Cheeses Cheese powders Salad dressings Cheese dips and spreads	Bread Crackers Sherberts Sausage binders Process cheese foods
C. Fermented foods from whey or its fractions	
Vinegar Lactic acid Wine Cordials	Ethyl alcohol Single cell protein Dough or dough yoghurt Cultured milk products

Source: Kosikowski, 1979

Table 50: Main industrial uses of whey constituents and their functional characteristics in food manufacturing

Food category	Functionality
Dairy items	Fat substitutes Emulsifying/water binding Protein enrichment Fat replacement
Beverages	Colloidal state Stability Flow resistance Creaminess Nutritional supplementation
Sport supplements	Nutritional supplementation
Dessert products	Whipping properties Milk powder alternatives Emulsifying agent Body/texture Foaming
Infant formula	Nutritional balance
Dietetic foods	Nutritional balance
Convenience meals Prepared food	Flavour enhancer Emulsifier Stabiliser Viscosity controller Freeze thaw stability Egg yolk replacement Water binding capacity Acid solubility
Bakery items	Flavour Stabilization Foaming and egg substitution
Confectionery items	Emulsifying agent Aerating properties Egg substitute Fat binding Foam stabiliser

Source: Soumati *et al*., 2023

Beyond the functional qualities of different components in cheese whey, its actual components have strong nutritional value. Cheese whey products make for an important source of antioxidants and polyphenols (Sik *et al*., 2023). The high amounts of amino acids in (cheese-)whey proteins, with high protein quality scores means cheese whey has high potential benefits for use in muscle protein synthesis – as such, it makes for an interesting sports nutritional supplement (Ha & Zemel, 2003). Whey protein varieties, when combined with a physical training programme, can result in increased muscle hypertrophy, peak torque, muscle strength, physical performance, muscle response, and reduced body fat. ß-lactoglobulin, the most abundant protein in whey, is composed of “26% of branched-chain amino acids”, among nine essential amino acids “essential for muscle protein synthesis” (Fassina *et al*., 2019).

The use of whey in the food industry is already significant. Several Galician companies are already working on the valorisation of (cheese) whey into market food products. *GALACTEUM* transforms cheese whey into powder for a range of products (ice cream, dairy products, bakery and confectionery, sport and nutrition, biscuits and snacks, cooking, infant nutrition). According to the company, cheese whey provides dairy solids, flavour, increased solubility, *Maillard* reaction for golden colour and product sweetness, functional formulation, and optimises sauces (Galacteum, 2020). *Prolactea* transforms cheese whey into a powder for additive use in yoghurts, fermentation dairy drinks, desserts, etc (Prolactea, 2024). The Estrella Galicia Beer Factory in Galicia produces a ‘Milk Stout’ arising from the valorisation of both brewery spent grains, and lactose from cheese whey (Hijos de Rivera, 2022).

Flemish cheese company *De Zuivelarij* revalorises part of the cheese whey obtained from halloumi cheese production into ricotta cheese, but the market for ricotta is not significant enough, and so half of the whey obtained from the halloumi production goes to other uses. *De Zuiverlarij* is also experimenting with other food products for valorisation of cheese whey, including ricotta cheesecake, polenta fries, and beer. *Milcobel* valorises cheese whey in two ways: the fat and minerals derived from cheese whey are re-utilised in cheese production, and proteins and lactose derived from cheese whey are sold (the proteins are then used for dietary products, nutritional products and infant food, lactose is mainly used for feed).

The project Resupeq focuses on the valorisation of cheese whey from small cheese makers into whey-based drinks, other dairy products, and snacks and other products (Asincar, 2020).

2.4.3.4. Industrial use (biochemicals and bioplastics)

According to the Centre for Research and Technlogy – Hellas (in Greece), cheese whey also has a high potential in its valorisation for the production of bio-based chemicals, such as acetic acid or polyhydroxyalkanoates (PHAs). The volatile fatty acids of cheese whey also have various industrial applications and can also be considered precursors to the production of bioplastics. This market is expected to grow in response to policies reducing the use of conventional plastics.

The lactose in whey permeate can be converted to PHAs, as well as polylactic acid. Bioplastics produced from these chemicals can be used “in the packaging, spraying materials, device materials, electronic products, agricultural products, automation products, chemical media and solvent industries”. Lactic acid, derived from cheese whey, has high potential for industrial use. Indeed, it can be used in the production of polylactic acid-based polymers (PLA) but can also be converted into “several chemicals of industrial importance”, with applications in the “food, pharmaceutical, textile, leather and chemical industries” (Zandona *et al*., 2021).

The following table identifies potential biopolymers that can be produced from different types of whey.

Table 51: Biopolymers synthesised from different cheese whey substrates, and the necessary fermenting microorganism

Substrate	Microorganism	Biopolymer
Cheese whey	Lactobacillus sp. Rhodovulum sulfidophilum DSM-1374	Poly(3-hydroxybutyrate)
Ricotta cheese exhausted whey	ß-Galactosidase treatment and *Haloferax mediterranei* DSM1411	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) with hydroxyvalerate (HV)
Fermented cheese whey	Mixed photosynthetic consortium of bacteria and algae	PHA with a hydroxyvalerate (HV)
Sweet whey powder	Mixed microbial culture (mostly *Thauera* and the *Lampropedia* genera)	PHA

Source: Zandona et al., 2021

Once again, interviews with different European companies demonstrate the real-world applications of research. One of the Spanish companies interviewed has a patent to produce bioactive peptides from protein sourced from cheese whey. Lactose derived from *Milcobel*'s cheese whey is sold mainly for feed, but also to the chemical industry where lactose can be converted into lactate to produce polylactic acid.

2.4.4. Limitations and Recommendations

As outlined in the previous sections, there are many possible methods to valorise whey from the cheese-making industry. However, these valorisations are not without their limitations. According to the Centre for Research and Technology – Hellas (in Greece), there is a need to develop cost-effective, highly efficient and environmentally-friendly processes to contribute to the *sustainable* valorisation of cheese whey; life-cycle assessments (LCA) and life-cycle costing (LCC) studies should be conducted, with a focus on the energy-saving potential of the valorisation of cheese whey.

There is an opportunity in the development of biorefinery plants with the necessary equipment for the valorisation of cheese whey from small-volume cheesemakers; a specialised technician would be required for this sort of enterprise. In Galicia, the main barriers to valorising cheese whey are economic and logistical. Indeed, volumes of small cheesemakers are small, and a complete recovery requires facilities, complex collection, and the infrastructure for logistics, as well as the capacity to process and sell the cheese whey. This region has very high volumes of whey from small cheesemakers but companies that collect the serum have a high cost and are few. Additionally, volumes are highly variable and difficult to standardise. According to *Calidad Pascual*, the cost of recovering and valorisation currently exceeds the potential recovered value.

These limitations are also found in Flanders. According to *De Zuivelarij*, major obstacles to the valorisation of cheese whey include transport costs, product stabilisation, the need for a constant supply, the current lack of a market (in Flanders) for ricotta. *Kaasmaakerij Karditsel* identified storage as a significant obstacle to the valorisation of cheese whey. *Milcobel* also finds barriers in transportation costs, and the small size of the current lactose market. They highlight that the most interesting form of valorisation of cheese whey (for them) is its transformation into nutritional components. However, this is the most difficult option as the composition of these nutritional components must be constant and of the highest quality, and must be void of any contaminants and microbiological activity. Nevertheless, considering the multitude of possible uses in the food industry, owing to the nutritional as well as functional components of cheese whey, this sector shows the most promise for the valorisation of cheese whey.

2.5. Wheat bran

2.5.1. Overview of the wheat bran market

Wheat bran is the main co-product resulting from the grinding of wheat grains for the production of flour. Indeed, the wheat milling industry generates various co-products besides the primary products, including wheat bran, wheat germ, and middling. These by-products are abundant but often underutilised.

Today, the wheat bran market seems to face challenges related to saturation, especially in certain segments or regions. However, the growing emphasis on sustainable and natural ingredients might provide opportunities for the wheat bran market to evolve, especially if consumer demand continues to drive interest in fibre-rich, natural products.

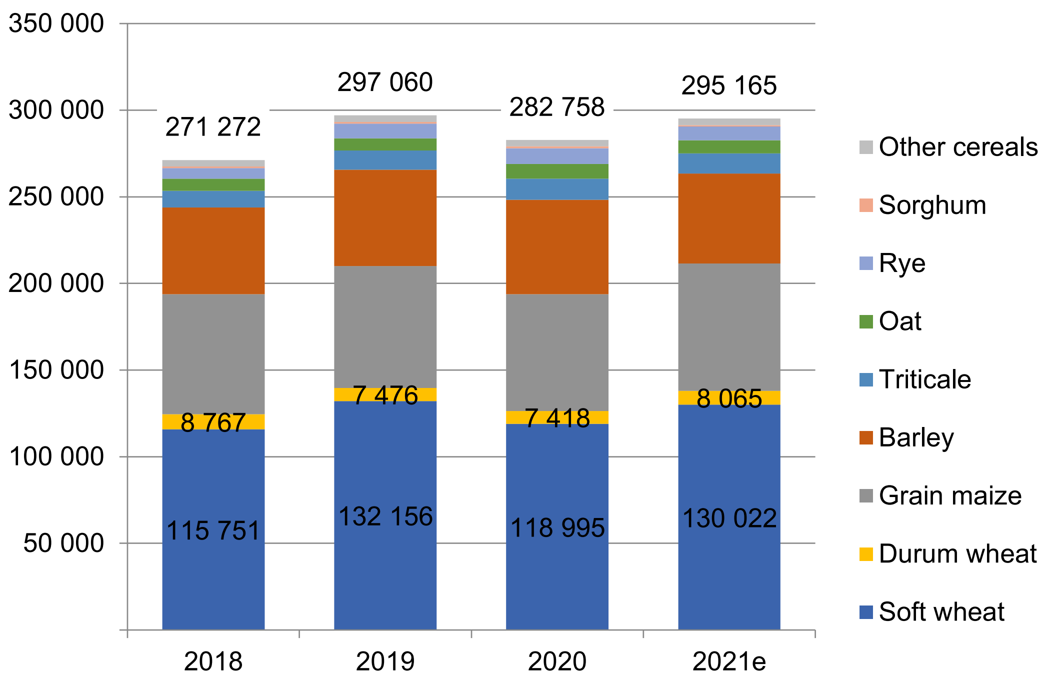
As specific statistics on the wheat bran production and trade are not readily available, to put into perspective the market of this by-product, the choice was made to provide broader statistics on the cereals and wheat production and trade. Wheat bran represents a smaller fraction of the total wheat production, usually around 15-25% by weight, depending on the final application. Therefore, the annual production of wheat bran could be grossly approximated to the 15-25% range of bran yield from total wheat production.

2.5.1.1. European cereals production

This section is to provide a short overview of the European cereal production, pointing out the main producing countries, as well as the main trends in terms of wheat trade between Europe and the rest of the world.

The histogram below shows the evolution of European production of cereals by species.

Figure 76: EU-27 gross production by selected crops (thousand tonnes)



Source: Eurostat, data extracted 2023

Wheat production is dominated by China (134 million tonnes in 2020). The EU-27 is the second main producer worldwide. In Europe, wheat production represents 46,8% of the European production of cereals. Wheat is the biggest cereal production in European Union. The temperate climate of northern and central Europe is conducive to high yields, though extreme temperatures and water shortages limit wheat yields.

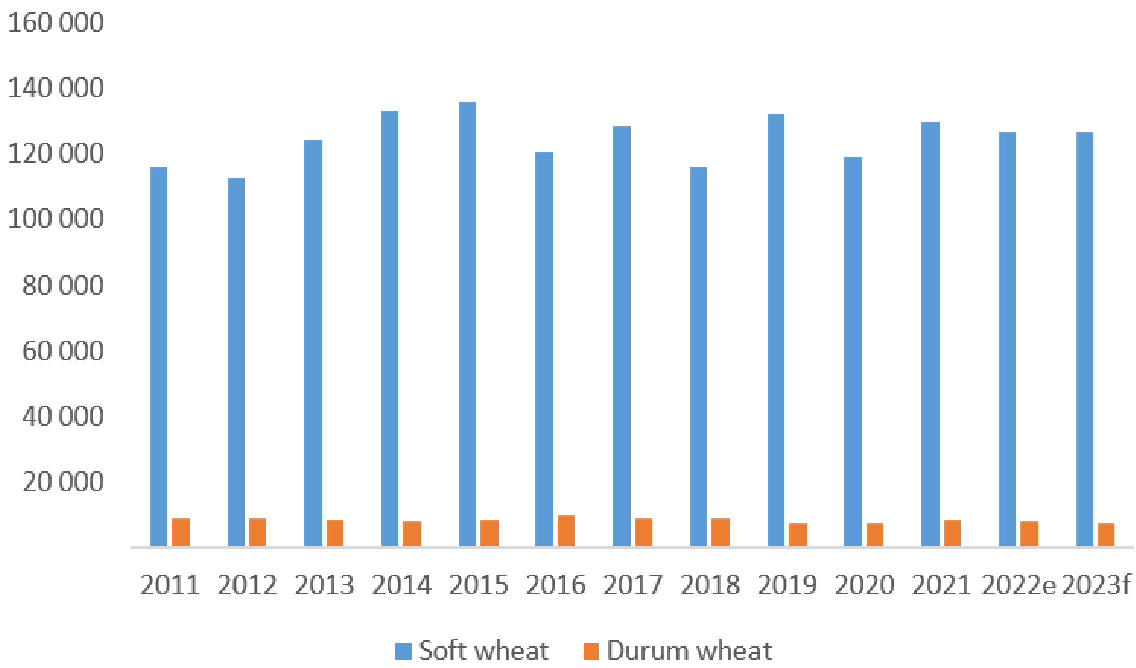
Two thirds of EU cereal production are intended for animal feed, in all its forms (granulate, ingredients, etc.), as cereals are the basis of the diet of many animal species (ruminants, poultry, etc.). In addition, the production of cereals represents a historical complementary production and revenue to animal breeding. Human consumption represents the second largest portion of cereal usage worldwide. Indeed, cereals have long been the basis of human nutrition. Wheat was first grown 10.000 years ago. Cereals are transformed into different forms (dough, bread, semolina, etc.) which are the basis of a large quantity of products. Finally, in recent years, cereals have been used also in the production of biofuels, notably ethanol and biodiesel, though the proportion of cereals used for this purpose remains relatively small compared to their use in food and animal feed.

2.5.1.2. Wheat production

Over time, two types of wheat crops have developed to dominate production: soft wheat and hard wheat. They have very different physicochemical characteristics and uses:

- The common wheat (or soft wheat) is by far the most cultivated. It is characterized by a high protein and gluten content. This type of wheat is used to make flour for bread and biscuit-type products.
- Durum wheat is known for its hardness, high protein content, intense yellow colour, nutty tasty and excellent cooking qualities. It is perfect for making dough, pasta, couscous, semolina, and bulghur.

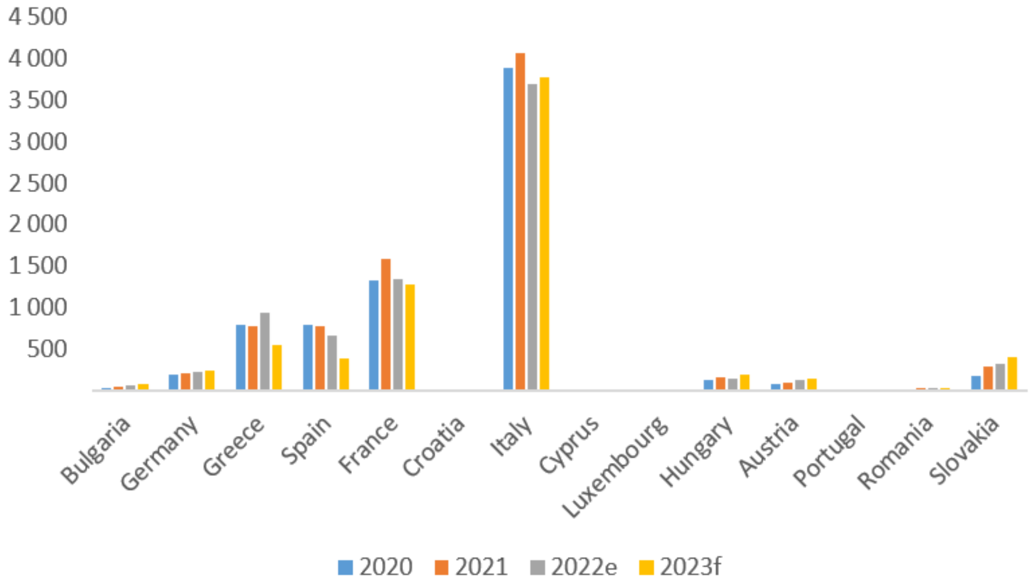
Figure 77: European wheat production by type



Source: Eurostat, 2023

In Europe, wheat production accounts for almost half of all cereal production, and is centred on soft wheat. Traditionally, soft wheat is used to produce bread flour, which is used in the food industry to make pastries, bread and some beverages, including beer.

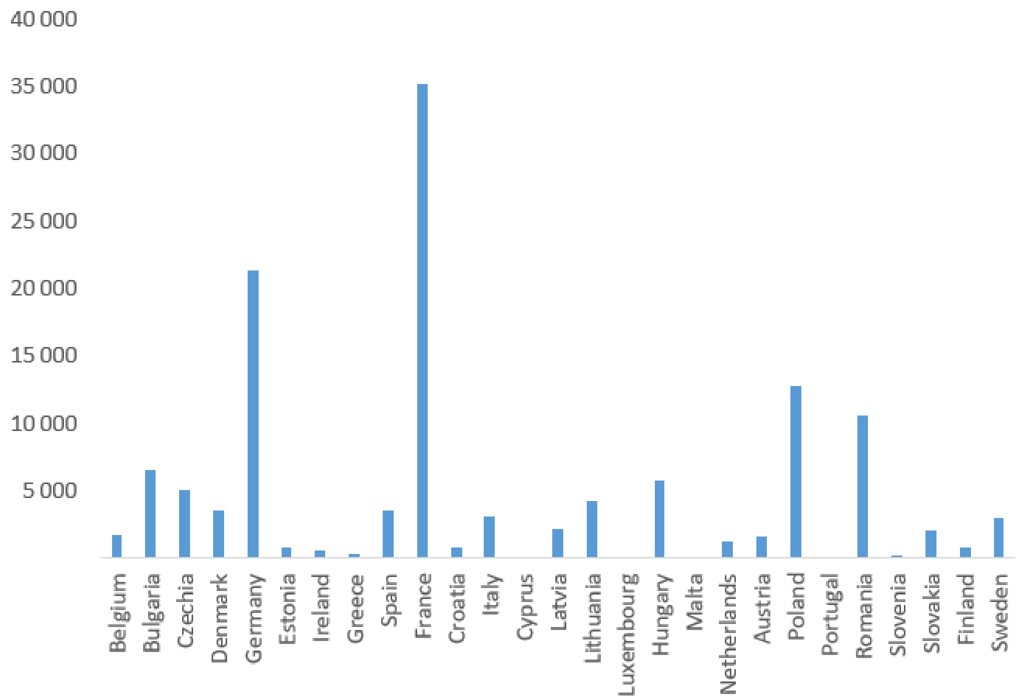
Figure 78: European durum wheat production by country (in thousand tonnes)



Source: Eurostat, 2023

Durum wheat represents only 2,6% of European cereal production and 5,6% of European wheat production. Production varies greatly from country to country. Durum wheat production is concentrated in a few European countries, with Italy accounting for over 50% of its production. France and Greece are respectively the second and third European countries with the highest hard wheat production (respectively 18% and 7,8%). Some regions of these countries (such as northern Italy and western France) possess climates conducive to wheat growth: moderate temperatures (between -6 and 20 degrees Celsius), warm weather before growth and sunny conditions during the final stages before wheat crop.

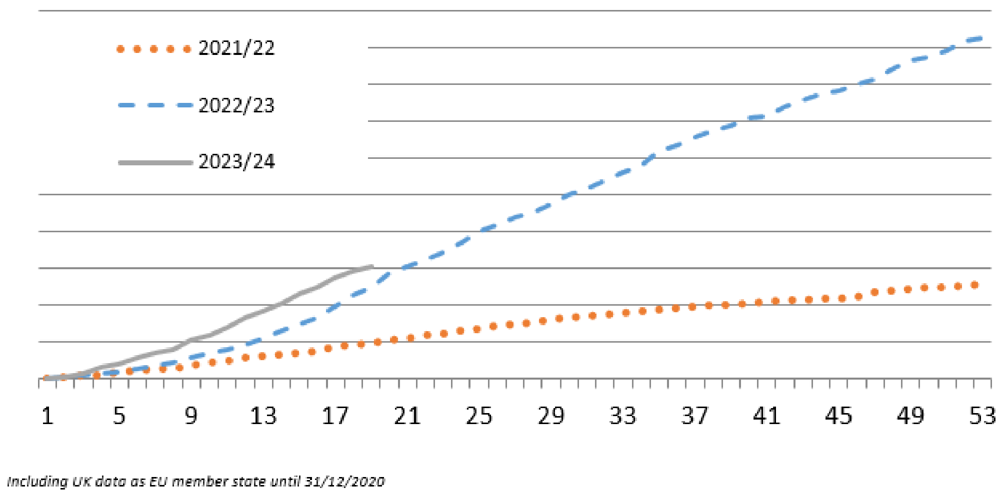
Figure 79: European common wheat production by country (in thousand tonnes, in 2023)



Source: Eurostat, 2023

Soft wheat is the most produced wheat in Europe. However, production varies greatly depending on the country. France, Germany and Poland are the three largest producers and represent nearly 55% of European production. Conversely, except for France, the leading countries in durum wheat are small producers of soft wheat. However, political choices, particularly in Italy where a policy of re-localisation of cereal production is being implemented, can modify this trend.

Figure 80: Import of common wheat per week (in tonnes, in 2023)



Source: Agridata.ec.europa.eu, data extracted 2023

The European Union is a major importer of common wheat (Figure 6). With a population of 450 million, the EU is the world's second largest consumer of wheat behind China. Spain and Belgium are Europe's biggest importers of common wheat.

Table 52: Country of origin of durum wheat imports

Origin	Tonnes	Share
Ukraine	1.952.472	63,6%
Canada	328.176	10,7%
Moldova	225.987	7,4%
Russia	193.446	6,3%
Serbia	140.716	4,6%

Source: Agridata.ec.europa.eu, data extracted 2023

Historically, imports came from Eastern Europe, but geopolitical conflicts have changed the countries of import. For decades, Ukraine was Europe's breadbasket, benefiting from a strategic geopolitical position (access to the Black Sea and the Mediterranean to facilitate export fertile and abundant land, proximity to major markets such as Russia and later the European Union, etc.). Ukrainian wheat is now rarer and other importing countries are currently favoured. However, Ukrainian production is not compensated by other importing countries.

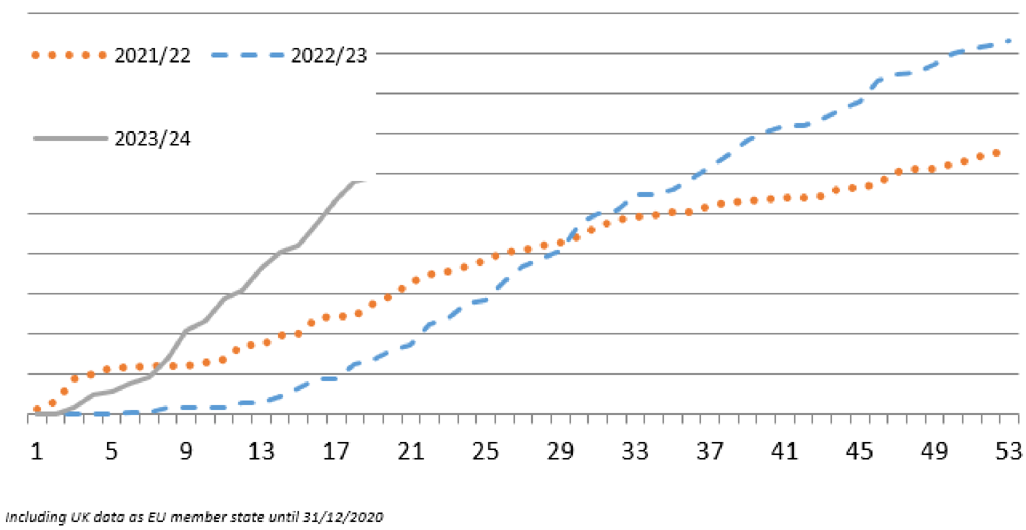
Table 53: Export of common wheat per week (in tonnes, in 2023)

Destination	Tonnes	Share
Morocco	1.740.911	16,1%
Nigeria	1.192.822	11,0%
Algeria	936.608	8,7%
South Africa	642.724	5,9%
Egypt	560.409	5,2%

Source: Agridata.ec.europa.eu, data extracted 2023

Europe is also an important export platform. For the 2022/2023 harvest, the European Union was the world's second largest wheat exporting region (soft and durum wheat combined), behind Russia but ahead of the United States and Australia. Europe exports mainly to North Africa, largely because of its history and geographical proximity. Romania, France and Poland are Europe's three main soft wheat exporters. These three countries account for almost 65% of the European Union's soft wheat exports.

Figure 81: Import of durum wheat per week (in tonnes)



Source: Agridata.ec.europa.eu, data extracted 2023

Europe exports almost 2 million tonnes of durum wheat every year. Wheat exports are highly variable from one year to the next, and depend on both meteorological and geopolitical factors.

Table 54: Soft wheat export countries

Origin	Tonnes	Share
Türkiye	535.053	45,3%
Russia	286.472	24,2%
Kazakhstan	154.581	13,1%
Canada	125.079	10,6%
United States of America	55.520	4,7%

Source: Agri-Food Data Portal on Europa webpage, data extracted 2023

Between 2017 and 2021, the EU-27 imported an average of 0,4 million tons of durum wheat. Unlike common wheat, durum wheat imports mainly come from non-European countries. The American continent is the main trading partner in this area. Indeed, it is also the main production area of durum wheat in the world. Durum wheat imports are expected to decline in the coming years. Indeed, by 2023, durum wheat imports are expected to decline by 50%. In the close future, India is forecasted to be the main supplier of durum wheat.

Wheat production in the B-Resilient partner regions

As mentioned in the methodology, B-Resilient consortium partners decided to focus the market analysis of the wheat bran value chain on 6 regions where either wheat production and milling are important for the regional economy, and, consequently, large amounts of wheat bran are available, or there is a specific attention for valorisation of this by-product: Pays de la Loire, Brittany and Normandy in France, Emilia Romagna in Italy, and Wallonia and Flanders, in Belgium.

i. Wallonia

Table 55: Wheat production in Wallonia

Area	16.901 sq km
Population	3.681.575 inhabitants (2023)
Wheat production	Data non available
% area	25% of regional farmland is used for arable farming
% of national production	65% of Belgian production

Source: data extracted from Statbel in 2023, interviews with manufactures

Wallonia is one of the three main regions of Belgium, alongside Flanders and Brussels. It is located in the southern part of the country and covers about 55% of the Belgian territory. Agriculture plays a significant role in the economy of Wallonia, with a substantial portion of its land dedicated to farming. The fertile land and suitable climate in certain areas of Wallonia make it favourable for cultivating wheat, contributing to its position as the largest wheat-producing region in Belgium. Indeed, the region represents around 65% of Belgian wheat production. However, the trend is towards a loss of used agricultural land. The region hosts 20 milling producers. The number tends to increase as the region tries to push re-localisation projects. In Wallonia, there are not enough grains transformers relative to the number of producers; as such, most of the value from transformation is generated by other regions.

ii. Flanders

Table 56: Wheat production in Flanders

Area	13.624 sq km
Population	6.774.807 inhabitants (01/01/2023)
wheat production	Data non available
% area	22% of regional farmland is used for arable farming
% of national production	35% of Belgian production

Source: data extracted from Statbel

Flanders is the northern region of Belgium. Although it is the most populated region of the country, it does not concentrate much of the country's agricultural production. Thus, historically, Flanders' wheat production represented around a third of Belgian production. Between 2018 and 2023, the agricultural area dedicated to wheat production lost nearly 25.000 hectares.

iii. Emilia-Romagna

Table 57: Wheat production in Emilia-Romagna

Area	22.510 sq km
Population	4,4 million inhabitants (2023)
Wheat production	Soft wheat: 3,072 million tonnes (2021) Durum wheat: 4,137 million tonnes (2021)
% area	30% of national farmland
% of national production	Data non available

Source: data extracted from Ismea Mercati, contributions from cluster C-ER

Emilia Romagna is an Italian region in Northern Italy, and holds considerable importance in the country agricultural sector. The production of wheat in Emilia-Romagna has considerable economic importance on many aspects, including that of the self-sufficiency of the national agrifood chain. Wheat production in the region is framed in an international context that is unfortunately rapidly and dramatically evolving for environmental and geo-political reasons, including due to the Russia-Ukraine war and its consequences on the availability of wheat on the international market and its obvious negative repercussions on the supply chain and the consumers.

Emilia-Romagna ranks among the top regions in Italy for wheat cultivation, particularly in the production of high-quality durum wheat. Between 2020 and 2021, the wheat production at national level has increased (notably for durum wheat), while for the same period, surfaces dedicated to the cultivation of common wheat and barley decreased. Yields were therefore higher on smaller surfaces. However, for 2022, the trend for the surface cultivated with durum and soft wheat is expected to reverse. With the war in Ukraine, it would have been essential that Italy indeed increase national wheat productivity, especially to allow for greater self-sufficiency in cereals for the country. However, wheat production in Italy by the end of 2022 was expected to decline by up to 15% due to droughts that impacted yields negatively throughout the country (Coldiretti, 2022). The forecast for 2022 estimated a drop in wheat production all around the country (ISTAT, 2022). As a result, the harvest (both soft and hard wheat combined) was expected to reach ca 6.5 million tonnes at national level, on a total cultivated area of 1.71 million hectares.

In 2021, the areas in Emilia-Romagna cultivating both soft and durum wheat increased in comparison with 2020 (ISTAT, 2022). The trend in 2022 was expected to be one of continuous growth (Confagricoltura, 2023). According to ISTAT data, in 2021, durum wheat production in the region reached 455.894 tonnes (304.007 tonnes in 2020), that of soft wheat increased to 1.135.873 tonnes (from 884.731 tonnes in 2020) and that of barley was stable at 132.702 tonnes (134.174 tonnes in 2020) (ISTAT, 2022).

In 2022, yields were expected to drop at least 20% compared to 2021, due to drought and high temperatures (Il Corriere di Romagna, 2022). Prices for the first half of 2022 experienced increases of 70-80% compared to the average prices of the last 10 years.

Priorities of the regional sector

Agronomic and genetic improvement advances offer innovative technical options relevant to ensure the agroecological transition, such as to allow an adequate income for farmers and an acceptable cost to the consumer, also offering healthier foods, with better nutritional profile and lower environmental impact. An example is the production of labelled foods such as organic, an expanding sector in Emilia-Romagna, but also integrated production to produce "zero residue" foods or cereals with characteristics required by industry such as high-quality durum wheat, soft bread-making, minor cereals such as einkorn low glycaemic index, barley rich in beta-glucans, etc.

iv. Pays de la Loire

Table 58: Wheat and bran production in Pays de la Loire

Area	32.082 sq km
Population	3,9 million inhabitants (2023)
Wheat production	2,7 million tonnes of soft bran (7 % of French harvest) 150.000 tonnes of durum bran
% area	45% of agriculture area is destinated to soft wheat (2021) 3% of agriculture area is destinated to durum wheat (2021).
% of national production	7% of French soft bran production 12% of French durum bran production

Source: data extracted from AGRESTE, Insee, Intercereal, interviews

The Pays de la Loire is a French region in Western France. In 2021, the Pays de la Loire was the fifth largest cereal-producing region in France. Almost 84 % of the farmland is destinated for the cultivation of wheat. The Pays de la Loire is the first French region for processing soft wheat into flour for the food industry and the second French region for processing wheat into pet food.

v. Normandy

Table 59: Wheat production in Normandy

Area	30.627 sq km
Population	3,317 million inhabitants (2023)
Wheat production	3,89 million tonnes of soft wheat (2022)
% area	72% of agricultural area
% of national production	11% of French production

Source : AGRESTE, Insee, Intercereal, FranceAgriMer, interviews

Normandy is also a region in Western France. It is the 7th largest French region for the production of cereals, with the 4th best yield in the country. 69% of the regional agricultural area in use is destined for cereal production. Normandy is the 5th largest French region for the production of soft wheat. 72% of the regional agricultural area in use is destined for soft wheat production. A durum wheat sector has been developing in the region since 2020. Normandy has France’s largest wheat export port. During the 2020/2021 crop season, 6,5 million tonnes of cereals were exported from Normandy’s ports.

vi. Brittany

Table 60: Wheat production in Brittany

Area	27.208 sq km
Population	3,43 million inhabitants (2023)
Wheat production	2,19 million tonnes
% area	52% of utilised agricultural area is destinated to soft wheat.
% of national production	5% of French wheat production, mainly soft wheat

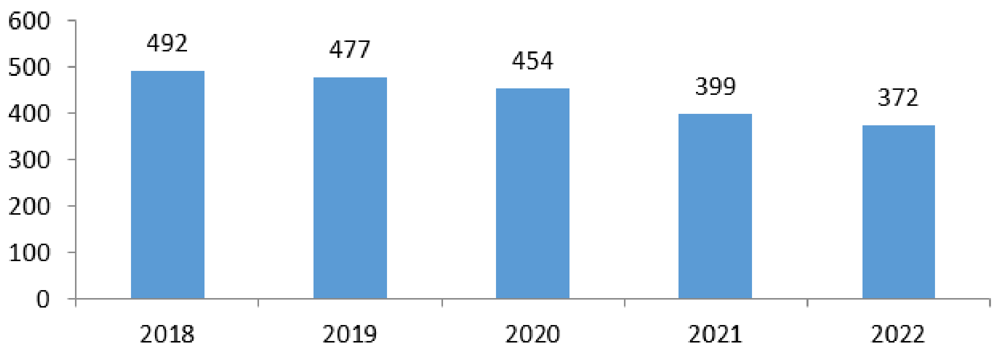
Source: AGRESTE, Insee, Intercereales, industrial interviews

Brittany is a region in the North-West of France. On average, it produces annually 4,5 million tonnes of cereals. Brittany's climate (abundant rainfall and mild winter temperatures) favours cereal production. Soft wheat and corn account for 75% of the regional cereal production. Brittany is France's leading processor in feed, and the region hosts 65 feed manufacturers on its territory. 99% of Britanny's cereal production is destined towards animal feed.

2.5.1.3. Wheat bran products

The wheat bran products market encompasses various goods derived from wheat bran, offering nutritional benefits and functional properties. Broader statistics extracted from the Mintel database allow for the appreciation in the trends in terms of consumer demand for wheat bran products.

Figure 82: Evolution of new wheat bran-based products by year

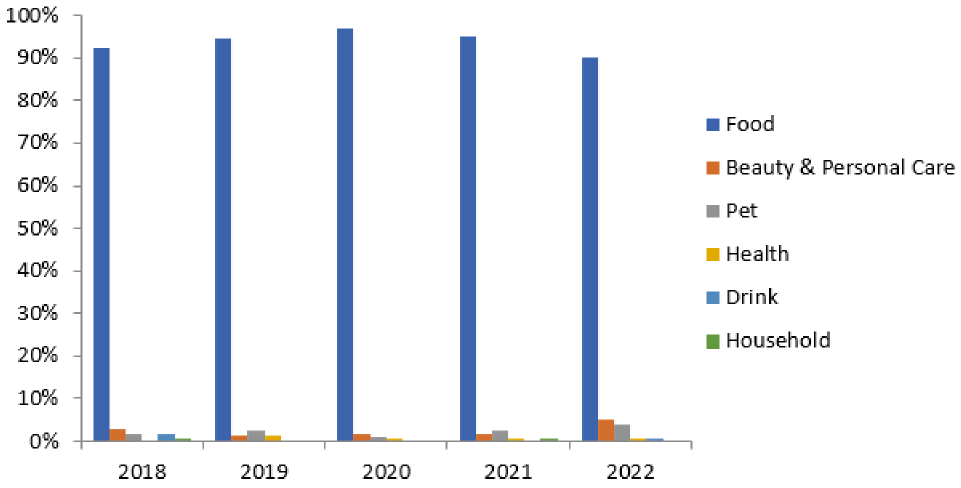


Source: data extracted from Mintel, 2023

NB: The chart above only includes first launches of new products. New formulations, new packaging, range extensions, etc. are not included.

Wheat bran product launches declined between 2018 and 2022 (figure above). Being rich in fibre, these products are mainly used in food and feed, though between 2021 and 2022 new launches in the beauty and personal care super-category outdid the new launches in the pet super-category (figure below).

Figure 83: Distribution of new wheat bran products launched by super-category and by year in Europe between 2018 and 2022

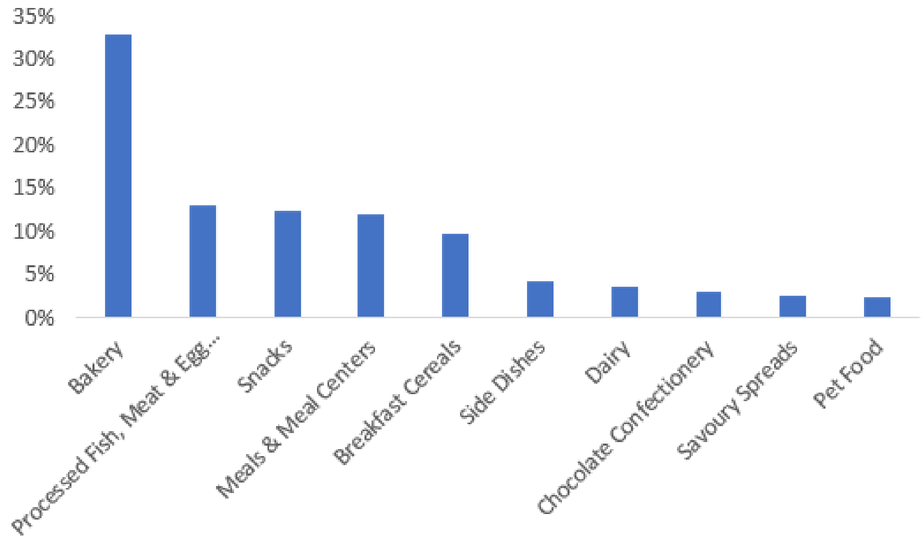


Source: Data extracted from Mintel, 2023

NB: The chart above only includes first launches of new products. New formulations, new packaging, range extensions, etc. are not included.

Indeed, over the period 2019-2022, more than 1200 new wheat bran products were launched in Europe. The human food sector accounts for most of these launches, but it is important to note the development of other markets, such as cosmetics which, although niche, is growing.

Figure 84: Distribution of new wheat bran products launched by category in Europe between 2018 and 2022



Source: Data extracted from Mintel, 2023

Bakery is the main category in which products containing wheat bran were launched during the years 2018-2022 (Figure 10), though the trend is declining. Pet Food and savoury spreads categories are increasing (Mintel data in November 2023). These categories mainly valorise whole bran or bran fibres.

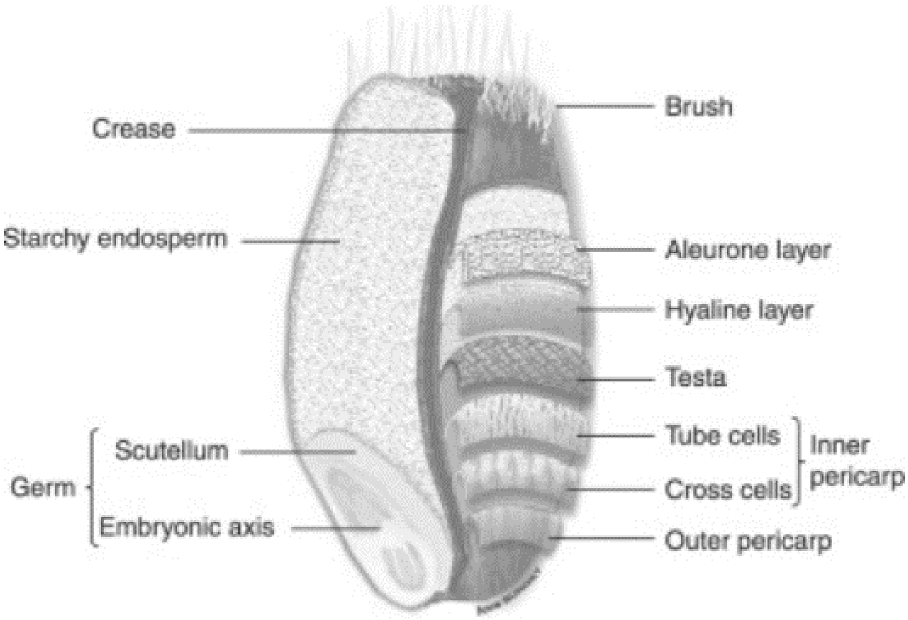
2.5.2. Botanical and anatomical data

Wheat bran is an abundant agricultural by-product, resulting from milling and biorefinery processes. It corresponds to the plant envelopes that surround and protect the wheat grains. Wheat is one of the most important staple grains in the world; wheat is manufactured in five continents, including more than 100 countries (Cheng *et al*., 2021). According to the FAO, the average consumption of wheat flour per capita in Europe was about 74 kilograms per year in 2019.

2.5.2.1. Physiology and quality

Wheat (*Triticum spp.*) is a member of the Grass family *Gramineae* (*Poaceae*). Wheat belongs to the straw grain family, with barley, oats, rye, and rice. This family is characterized by the presence of a stem where each is surmounted by indehiscent grains high in carbohydrates. Wheat bran is the outer hull of the wheat kernel; the bran comprises the outer layers of the grain including the pericarp, testa, and aleurone layer.

Figure 85: The different layers of wheat bran illustrated from aleurone to outer pericarp



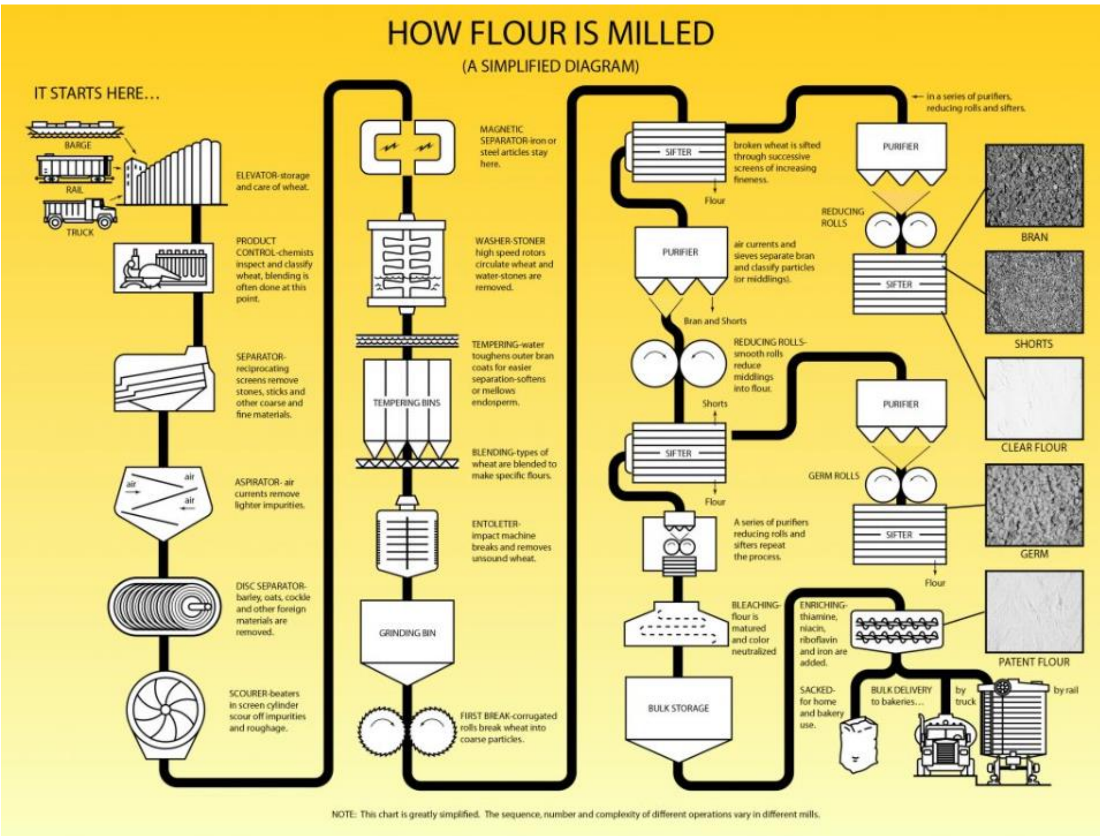
Source: Surget & Barron, 2005

2.5.2.2. Milling of wheat grains

Wheat bran is a by-product that results from the process of milling wheat grains into flour. Conventional milling of wheat grains is based on separating the endosperm from the bran layers and embryo. This produces white flour during milling. Other structures such as straleurone cells, the embryo and the other bran layers are removed to form the bran fraction.

Wheat is usually milled by roller milling, which delivers multiple product streams. The miller can combine their products into flour or bran fractions, although some processing is necessary for palatability, quality and nutrient bioavailability. There are about 600 types of flours in Europe. The theoretical proportion of bran extraction is estimated between 15% and 25% from wheat. This depends on the type of wheat, the type of flour produced (white or whole) and the process used depends on the final application. Thereby, the composition of wheat bran is very different and depends particularly on the mills. The following diagrams simplifies how flour is processed.

Figure 86: Simplified diagram of flour processing

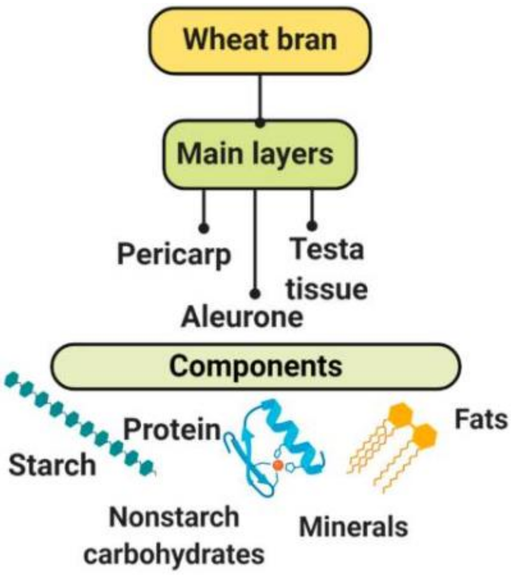


Source: Wheat Food Councils*, n.d.*

2.5.2.3. Wheat bran composition

Wheat bran is rich in dietary fibre, consisting of protein (13-18%), starch (14-25%), fat (3-4%), minerals (3-8%) and non-starch carbohydrates (55-60%) based on dry matter (Boudouma, 2009; DiLena *et al*., 1997; Dornez *et al*., 2006; Hemery *et al*., 2007).

Figure 87: Wheat bran layers and components distribution



Source: Katileviciute *et al*., 2019

Wheat bran proteins are essentially intracellular and localized in the cytoplasm of aleurone layer cells (Saulnier *et al*., 1995). These proteins are grouped into three families of molecules: albumins, globulins and glutelins. Starch is composed of two major compounds: amylose and amylopectin.

Wheat bran fats are composed mainly of linoleic, palmitic and stearic acids. Wheat bran is a source of many minerals: manganese, iron, zinc, potassium, phosphorus, etc. The non-starch carbohydrate fraction consists of arabinoxylan, cellulose and β-(1,3)-(1,4)-glucan (Hell *et al*., 2014).

Wheat bran is also a source of phenolic acids. Ferulic acid is the majority phenolic acid in wheat bran, followed by p-coumaric acid. There are also other phenolic compounds such as hydroxycinnamic, such as synapic, syringic, caffeic, vanillic and parahydroxybenzoic acids (Antoine *et al*., 2003).

In addition, wheat bran is particularly rich in vitamins (niacin, thiamine and riboflavin) which makes its nutritional quality interesting as well as its application prospects multitudinous. Wheat bran is rich in fibre and other noncaloric nutrients. The following tables indicate elemental composition, minerals, fatty-acids, vitamins and pigments, respectively for common and durum wheat bran.

Arabinoxylans are the predominant non-starch polysaccharides found in the structural matrix of cell walls in wheat grains, being present in large quantities in wheat bran, accounting for up to 15-20% of its composition. Arabinoxylans are major components of hemicellulosic fractions of cereals. They consist of a homopolymeric backbone chain of 1,4-linked-β-d-xylopyranose units, to which randomly branched O-acetyl-α-l-arabinofuranosyl are linked.

Once detached, the sugars from hemicellulose of wheat bran represent around 40 % of the dry weight (Aguedo *et* al., 2013). Their physicochemical properties define their functionality which can be beneficial in cereal-based products such as bread, where their addition could enhance the gluten matrix responsible for the aerated structure and quality of bread.

Table 61: Composition of common wheat bran

Elemental composition					
Parameter	**Gross**	**Dry**	**Unit**	**Another**	**Unit**
Dry matter	86.9	100	%		-
Crude proteins	15.3	17.6	%		-
Crude cellulose	9.2	10.5	%		-
Crude fat	3.3	3.8	%		-
Minerals	4.8	5.6	%		-
Insoluble ash	0.1	0.2	%		-
NDF	39.6	45.6	%		-
ADF	11.8	13.5	%		-
Lignin	3.4	3.9	%		-
plant cell walls	38.8	44.7	%		-
starch	19.4	22.3	%		-
starch, enzymatic method	16.3	18.7	%		-
total sugars	6.9	7.9	%		-
Raw energy (kcal)	3930	4520	kcal/kg		-
Raw energy (MJ)	16.4	18.9	MJ/kg		-
Minerals					
Parameter	**Gross**	**Dry**	**Unit**	**Another**	**Unit**
Calcium	1.2	1.4	g/kg		-
Phosphorus	9.5	11	g/kg		-
Phytic phosphorus	7.6	8.8	g/kg	80	% P
Magnesium	3.6	4.2	g/kg		-
Potassium	11.7	13.5	g/kg		-
Sodium	0.07	0.08	g/kg		-
Chlorine	0.8	0.9	g/kg		-
Sulfur	1.9	2.1	g/kg		-
Cations-anions balance	163	188	mEq/kg		-
Electrolytique balance	280	322	mEq/kg		-
Manganese	111	128	mg/kg		-
Zinc	76	87	mg/kg		-
Copper	11	13	mg/kg		-
Iron	143	165	mg/kg		-
Selenium	0.4	0.5	mg/kg		-
Cobalt	0.09	0.1	mg/kg		-
Molybdenum	1	2	mg/kg		-
Iodine	0	0	mg/kg		-

Fatty-acids					
Parameter	**Gross**	**Dry**	**Unit**	**Another**	**Unit**
C6+C8+C10 fatty acid	0	0	g/kg	0	% fat. acid
C12:0 lauric acid	0.02	0.02	g/kg	0.08	% fat. acid
C14:0 myristic acid	0.04	0.04	g/kg	0.1	% fat. acid
C16:0 palmitic acid	4.7	5.4	g/kg	17.8	% fat. acid
C16:1 palmitoleic acid	0.1	0.1	g/kg	0.4	% fat. acid
C18:0 stearic acid	0.2	0.2	g/kg	0.8	% fat. acid
C18:1 oleic acid	4	4.6	g/kg	15.2	% fat. acid
C18:2 linoleic acid	14.7	17	g/kg	56.4	% fat. acid
C18:3 linolenic acid	1.5	1.8	g/kg	5.9	% fat. acid
C18:4 stearidonic acid	0	0	g/kg	0	% fat. acid
C20:0 arachidic acid	0.05	0.06	g/kg	0.2	% fat. acid
C20:1 eicosenoic acid	0.3	0.4	g/kg	1.3	% fat. acid
C20:4 arachidonic acid	0	0	g/kg	0	% fat. acid
C20:5 eicosapentaenoic acid	0	0	g/kg	0	% fat. acid
C22:0 behenic acid	0	0	g/kg	0	% fat. acid
C22:1 erucic acid	0.1	0.2	g/kg	0.5	% fat. acid
C22:5 docosapentaenoic acid	0	0	g/kg	0	% fat. acid
C22:6 docosahexaenoic acid	0	0	g/kg	0	% fat. acid
C24:0 lignoceric acid	0	0	g/kg	0	% fat. acid
Total fatty acids	2.6	3	%	80	% m. fat
Vitamins and pigments					
Parameter	**Gross**	**Dry**	**Unit**	**Another**	**Unit**
Vitamin A	0.09	0.1	1000 UI/kg		-
Vitamin D	0	0	1000 UI/kg		-
Vitamin E	14.8	17	mg/kg		-
Vitamin K	0.5	0.5	mg/kg		-
Vitamin B1 thiamin	7.6	8.7	mg/kg		-
Vitamin B2 riboflavin	4	4.6	mg/kg		-
Vitamin B6 pyridoxin	9.8	11.3	mg/kg		-
Vitamin B12	0	0	µg/kg		-
Niacin	192	221	mg/kg		-
Pantothenic acid	28	32.3	mg/kg		-
Folic acid	0	0	mg/kg		-
Biotin	0.3	0.4	mg/kg		-
Vitamin C	0	0	mg/kg		-
Choline	744	856	mg/kg		-

Source: extracted from INRA-CIRAD-AFZ feed tables, n.d.

Table 62: Composition of durum wheat bran

Elemental composition					
Parameter	**Gross**	**Dry**	**Unit**	**Another**	**Unit**
Dry matter	86.6	100	%		-
Crude proteins	14.9	17.2	%		-
Crude cellulose	9.3	10.8	%		-
Crude fat	4.5	5.2	%		-
Minerals	4.5	5.2	%		-
Insoluble ash	0.1	0.1	%		-
NDF	40.2	46.5	%		-
ADF	12	13.8	%		-
Lignin	3.4	3.9	%		-
plant cell walls	39.5	45.6	%		-
starch	21.6	24.9	%		-
starch, enzymatic metho	18.3	21.1	%		-
total sugars	6.7	7.8	%		-
Raw energy (kcal)	3990	4600	kcal/kg		-
Raw energy (MJ)	16.7	19.3	MJ/kg		-
Minerals					
Parameter	**Gross**	**Dry**	**Unit**	**Another**	**Unit**
Calcium	1.2	1.3	g/kg		-
Phosphorus	9	10.4	g/kg		-
Phytic phosphorus	7.2	8.4	g/kg	80	% P
Magnesium	2.7	3.1	g/kg		-
Potassium	11.2	12.9	g/kg		-
Sodium	0.13	0.15	g/kg		-
Chlorine	0.8	0.9	g/kg		-
Sulfur	1.9	2.1	g/kg		-
Cations-anions balance	154	177	mEq/kg		-
Electrolytique balance	270	312	mEq/kg		-
Manganese	111	128	mg/kg		-
Zinc	76	87	mg/kg		-
Copper	11	13	mg/kg		-
Iron	143	165	mg/kg		-
Selenium	0.4	0.5	mg/kg		-
Cobalt	0.08	0.1	mg/kg		-
Molybdenum	1	2	mg/kg		-
Iodine	0	0	mg/kg		-

Fatty-acids					
Parameter	**Gross**	**Dry**	**Unit**	**Another**	**Unit**
C6+C8+C10 fatty acid	0	0	g/kg	0	% fat. acid
C12:0 lauric acid	0.03	0.03	g/kg	0.08	% fat. acid
C14:0 myristic acid	0.05	0.06	g/kg	0.1	% fat. acid
C16:0 palmitic acid	6.4	7,3	g/kg	17.8	% fat. acid
C16:1 palmitoleic acid	0.1	0.2	g/kg	0.4	% fat. acid
C18:0 stearic acid	0.3	0.3	g/kg	0.8	% fat. acid
C18:1 oleic acid	5.4	6.3	g/kg	15.2	% fat. acid
C18:2 linoleic acid	20.1	23.2	g/kg	56.4	% fat. acid
C18:3 linolenic acid	2.1	2.4	g/kg	5.9	% fat. acid
C18:4 stearidonic acid	0	0	g/kg	0	% fat. acid
C20:0 arachidic acid	0.07	0.08	g/kg	0.2	% fat. acid
C20:1 eicosenoic acid	0.5	0.5	g/kg	1.3	% fat. acid
C20:4 arachidonic acid	0	0	g/kg	0	% fat. acid
C20:5 eicosapentaenoic ac	0	0	g/kg	0	% fat. acid
C22:0 behenic acid	0	0	g/kg	0	% fat. acid
C22:1 erucic acid	0.2	0.2	g/kg	0.5	% fat. acid
C22:5 docosapentaenoic a	0	0	g/kg	0	% fat. acid
C22:6 docosahexaenoic ac	0	0	g/kg	0	% fat. acid
C24:0 lignoceric acid	0	0	g/kg	0	% fat. acid
Total fatty acids	3.6	4.1	%	80	% m. fat
Vitamins and pigments					
Parameter	**Gross**	**Dry**	**Unit**	**Another**	**Unit**
Vitamin A	0.09	0.1	1000 UI/kg		-
Vitamin D	0	0	1000 UI/kg		-
Vitamin E	14.8	17	mg/kg		-
Vitamin K	0.5	0.5	mg/kg		-
Vitamin B1 thiamin	7.5	8.7	mg/kg		-
Vitamin B2 riboflavin	4	4.6	mg/kg		-
Vitamin B6 pyridoxin	9.8	11.3	mg/kg		-
Vitamin B12	0	0	µg/kg		-
Niacin	191	221	mg/kg		-
Pantothenic acid	27.9	32.3	mg/kg		-
Folic acid	0	0	mg/kg		-
Biotin	0.3	0.4	mg/kg		-
Vitamin C	0	0	mg/kg		-
Choline	741	856	mg/kg		-

Source: extracted from INRA-CIRAD-AFZ feed tables, n.d.

2.5.3. Examples of wheat bran valorisation

Wheat bran is low-cost, and its composition provides many applications: feed, food, cosmetics, nutraceuticals, energy, etc.

Wheat bran is rich in several essential nutrients that offer various human health benefits: for instance, as a source of dietary fibre, it helps improve digestion. It is demonstrated that a sufficient intake of dietary fibre from wheat bran with appropriate physiological functions is beneficial to human health (Cheng *et al*., 2021). Wheat bran also minimizes the risk factors of coronary heart disease (Jensen *et al*., 2004) or colon cancer (Reddy *et al*., 2000).

Wheat bran's composition, rich in carbohydrates and other nutrients, also makes it a valuable substrate for various biotechnological applications, particularly in the production of enzymes and organic acids. Different treatments can be applied to wheat bran to modify its impact on functionality and nutritional and organoleptic properties, two of which are thermomechanical treatment or bioprocessing as fermentation and enzymatic treatments (Onipe *et al*., 2021). For example, wheat bran solid-state-fermentation with *L. rhamnosus* enacted a reduction in phytic acid content, whereas caffeic acid was notably present in fermented bran (Spaggiari *et al*., 2020).

Another example is in the bioprocessing of wheat bran, which significantly reduced the phytic acid in the bran, improving its antioxidant and flavour profile.

Wheat bran can also be processed and utilised in the creation of eco-friendly packaging products, as evidenced by BIOTREM, a Horizon 2020 project that allowed for the development of a process to make cutlery and plates from wheat bran.

Additional interesting examples of valorisation of wheat bran were illustrated by the ValBran Interreg project, which aimed to develop novel techniques for enhancing the value of wheat bran for applications in detergency, cosmetics, phytosanitary agents, and food additives. A surface-active agent has been discovered and produced as part of this project.

The literature reviews and the interviews conducted by the consortium partners involved in the wheat bran VC, allowed to identify 8 ways of valorisation:

- Feed
- Food
- Cosmetics
- Nutraceuticals
- Bioactive surfactants
- Enzyme production
- Pigments industry
- Biofuels, bioenergy

2.5.3.1. Feed

Around 50% of wheat bran resulting from wheat milling is used in animal feed (interviews). Being rich in insoluble fibres, it has the property of absorbing water. Since it is not a nutrient, it cannot be absorbed by the body. Thanks to its fibre-rich composition, wheat bran is a good protector of the animal's digestive system. It improves intestinal transit, particularly in monogastric animals, and helps animals to feel full over a long period. Wheat bran also contains various essential minerals and nutrients, such as iron, magnesium, phosphorus, and selenium that are beneficial for animal health and nutrition. Wheat bran is also rich in cellulose, and contains nitrogenous matter, fat and above all a large quantity of starch.

For animal feed, the maximum recommended inclusion rates of wheat bran are 10% in calves, 20% in dairy cows, 25% in beef cattle, 5% in lambs and 20% in ewes (Ewing, 1997). It has a slightly laxative effect, partly because the bran fibre is only moderately digested (Göhl, 1982).

Wheat bran is generally mixed with other pulps or protein sources (beetroot, maize, etc.) and used as a food kernel by processors. It is added to other protein sources to feed ruminants, but also poultry and pigs.

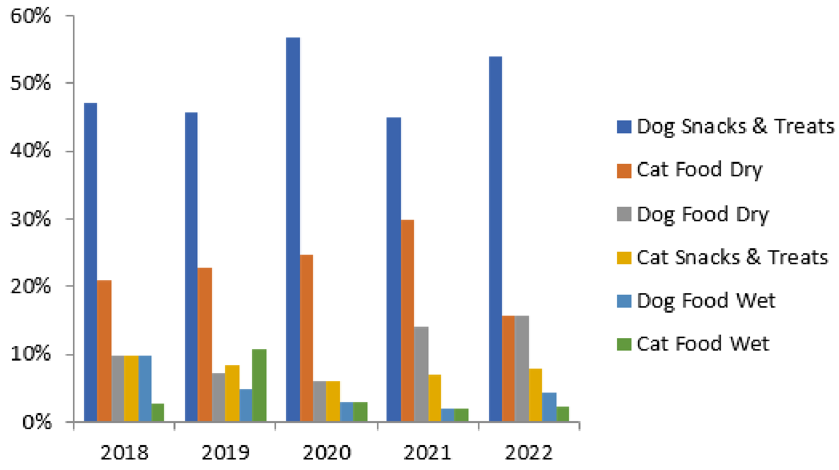
Indeed, wheat bran is a common ingredient in pig diets. It is usually palatable and can be fed to all classes of pigs with few problems. The main constraint is its high-fibre content, which reduces its energy density: the net energy content of wheat bran represents 60 and 65% of the net energy value of wheat for growing pigs and adult sows, respectively (Noblet *et al*., 2002). These energy values can be accurately estimated from measured chemical parameters (EvaPig, 2010). The bulkiness of wheat bran limits its use in diets formulated for physiological stages where dietary energy content must be maximized (starter and grower pigs, lactating sows) and/or for housing conditions where appetite is limited by environmental factors (poor sanitary status, warm climate). In contrast, wheat bran can be used as an energy dilutant during gestation to reduce hunger and improve welfare (Ramonet *et al*., 1999), health status (Meunier-Salaün *et al*., 2001) and reproductive performance (Matte *et al*., 1994).

The nutritive values of wheat bran for poultry found in tables and publications are highly variable, due to the wide range of products found under this name. However, whatever the origin, protein, starch and lipid contents are relatively low while the fibre content is high.

For rabbits, wheat bran is a valuable source of energy, digestible fibre, and protein. It is very frequently introduced into commercial diets (Lebas *et al*., 1984b; de Blas *et al*., 2010), and in reference diets in animal trials (Lebas *et al*., 2009). The inclusion level in experimental diets is frequently 45-50% or more. However, it can be up to 64-65%, in studies on wheat bran itself, or on ingredients replacing part of the wheat bran in control diets (Aduku *et al*., 1986; Berchiche *et al*., 2000; Blas *et al*., 2000a; Blas *et al*., 2000b; Fotso *et al*., 2000; Gidenne, 1987; Lakabi-Ioualitene *et al*., 2008; Lounaouci-Ouyed *et al*., 2011; Lounaouci-Ouyed *et al*., 2012; Gu *et al*., 2004; Parigi-Bini *et al*., 1984; Singh *et al*., 1997; Villamide *et al*., 1989). If necessary, wheat bran may represent more than 98% of the diet, without any problem (Robinson *et al*., 1986).

Wheat bran is also used in pet feed. According to Mintel, at least 400 products have been launched between 2018 and 2022 containing wheat bran in all its forms (flour, fibre, etc.). For cats and dogs, wheat bran is a source of fibre, which is particularly important for intestinal health. In fact, wheat bran limits the accumulation of harmful or irritating substances in the animal's intestine and colon, revitalising the animal's colon.

Figure 88: Products launched in the pet category containing wheat bran between 2018 and 2022



Source: data extracted from Mintel, 2023

The “dog snack and treats” category dominates the market for dog and cat feed. Here, wheat bran is used as a protein source or a texturing agent, but quantities are small.

An additional valorisation of wheat bran in animal feed is also being developed in entomoculture (also known as insect farming or insect rearing). Indeed, wheat bran is useful for feeding insects which will then be crushed to be transformed into insect meal or consumable insects. Wheat bran helps to stabilize humidity in the insect environment and improves the habitation of insects, including locusts and crickets. A research line identified during the interviews carried out in France involves the treatment of wheat bran with ozone, to enhancement its nutritional value for insects.

Limitations to the valorisation of wheat bran for animal feed:

- Wheat bran does provide certain nutritional benefits and can be a cost-effective component in animal feed, though its economic value might vary based on its role within feed formulations, its market price, and the availability of alternative feed ingredients offering a more comprehensive nutrient profile.
- Wheat bran is indeed just one part of the wheat kernel, specifically the outer layer, and it is commonly used as a component in animal feed formulations rather than being the sole source of nutrition.
- The investment in equipment and facilities for processing wheat bran into animal feed represents a substantial initial capital expenditure, which largely impacts on the economic feasibility of these types of projects. Costs are high and margins are tight for manufacturers, limiting the interest of producing feed from wheat bran. This issue was notably raised during interviews conducted with French stakeholders.
- The geographical proximity to end-users and livestock is a significant factor in the valorisation of wheat bran. Wheat bran, being less dense compared to flour, presents challenges when transported over longer distances.
- Valorising wheat bran in insect farming can face several challenges, notably in terms of nutritional balance, digestibility (some insects might struggle to digest certain components of wheat bran, limiting its efficiency as a sole or primary feed source), contaminants and pesticides (a presence of pesticides in wheat bran can affect insect health and development); production scale and consistency (scaling up wheat bran production consistently to meet the demands of insect farming operations can be challenging, as the availability and consistency of supply might vary, impacting the reliability of wheat bran as a feed source); and economic viability.
- One economic challenge raised by a French company is the fact that wheat bran represents 70% of the value of wheat.

2.5.3.2. Food

Food is also a historical way of valorisation of wheat bran. According to the European Flour Millers, there are some 600 types of flour in Europe, classified into 2 categories: durum wheat flour (notably used to obtain semolina) and soft wheat flour (which is used to make bread, pastries, etc.). Each type of flour is subdivided according to the fineness of the grind ranging from T45 to T150.

Wheat bran is used in wheat flour for multiple reasons. First, its hydrophilic properties help to maintain a constant level of humidity, playing a significant role in maintaining consistent moisture levels. In addition, as already mentioned, wheat bran is also known for its digestive properties for humans, primarily due to its high dietary fibre content. Cellulose fibres help digestion by filling the digestive tract and improves digestive health. However, excessive consumption can cause irritation of the colon.

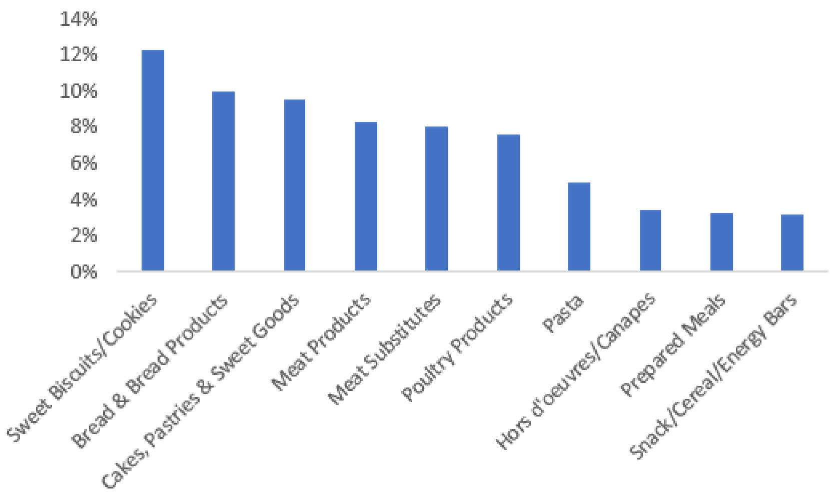
Wheat bran can also be added to wheat flour to increase the dietary fibre content of biscuits (Sudha *et al*., 2007), and it can be used in vegetarian steak. Moreover, wheat bran can serve as a carrier for cell immobilization in probiotic yogurt production. by *L. casei* in combination *with L. bulgaricus*. Indeed, wheat bran helps to maintain the viability of cells through storage at 4°C (Terpou *et al*., 2017). Thanks to its high nutrient contents, wheat bran can also be exploited for use in development of gluten-free products. In this case, pre-treatment using peptidase enzyme is needed to degrade gluten content.

In addition, pasta supplemented with aqueous bran extract showed significantly higher antioxidant activity and phenolic content than the control and good overall sensory properties (Pasqualone *et al*., 2015).

Interviews carried out with manufacturers highlighted that the quality of the bran depends on the wheat quality, as well as the storage conditions, in particular the humidity in the wheat storage area. For optimum quality, wheat bran (and wheat) must be stored in specific conditions (around 15% humidity). Below this rate, wheat bran is too dry and breaks easily, above this rate, wheat bran is too wet and increase the chances of rotting.

Consumed wheat bran is most often used in processed products. Almost 3000 products have been launched between 2018 and 2022 (see figure below).

Figure 89: Distribution of products launched between 2018 and 2022 containing wheat bran in Food category



Source: data extracted from Mintel, 2023

Limitations to the valorisation of wheat bran for food:

- Excessive consumption of wheat bran increases nutritional deficiencies in humans. Wheat bran is rich in fibres but poor in sugar, vitamin C or B12, which are very important for human health. Moreover, fibres contained in wheat bran can cause gastric problems. In high doses, wheat bran causes gastric irritation and liquid stools.
- The food industry is facing a structural decline in industrial margins, particularly in France.
- A research centre interviewed in Italy highlighted that one of the challenges of using wheat bran as food is hygiene issues; because the bran is the external part of the wheat grain, it is more exposed to external contamination by mycotoxins, heavy metals, pollutants.

Finally, one current research axe emerged from the interviews carried out in Emilia Romagna focuses on valorising the use of wholegrains more than separating the bran from the refined flour. Wholegrain products are offered by the food industry because they are perceived as healthier than refined products by the consumers due to their dietary fibre content and bioactive substances (phenolics, carotenoids, lignans, etc.).

The International Association for Cereal Science and Technology (ICC) (which gathers members from all over the world) has set up a working group on a global definition of a whole grain (raw materials) and on the definition of a whole grain food within the Whole Grain Initiative aimed at promoting the consumption of wholegrains.

2.5.3.3. Cosmetics

Wheat bran holds potential for utilisation in cosmetic products due to its beneficial properties for skin and hair care:

- Exfoliation: Wheat bran's fine particles make it an excellent natural exfoliant. When incorporated into skincare products like scrubs or masks, it helps remove dead skin cells, promoting smoother and brighter skin.
- Moisturisation: The high fibre content in wheat bran can help retain moisture. Its inclusion in lotions, creams, or masks can assist in hydrating and nourishing the skin.
- Anti-inflammatory Properties: Wheat bran contains compounds known for their anti-inflammatory properties, which can help soothe irritated or sensitive skin.
- Antioxidants: Wheat bran contains antioxidants, such as vitamin E, which can protect the skin from free radical damage, contributing to anti-aging effects.
- Hair Care: Wheat bran can be used in hair care products, such as shampoos or masks, to help exfoliate the scalp, remove excess oil, and promote healthy hair growth.

The University of Reading conducted research on the extraction of ferulic acid from wheat bran. Ferulic acid is an antioxidant widely used in the field of skincare or suncare. Kadalys, a French brand, uses wheat bran in the form of an extract, and Hristina Cosmetics, a brand from Bulgaria, has developed a wheat bran face peel. Wheat bran is also used to make anti-ageing cream for treatment of irregularities in skin.

Triticum vulgare bran extract is also used in cosmetics, as a:

- Skin conditioning agent, playing a pivotal role in topical skin treatments. Indeed, conditioning agents are essential for maintaining and improving the skin's health, appearance, and resilience against various external factors, including their impact on melanocyte tolerance. Melanocytes are the cells responsible for producing melanin, the pigment that gives skin its colour. Skin conditioning agents also prevent skin dehydration. The use of *Triticum vulgare* bran extract as skin conditioning agent is nevertheless challenging. The use of emollients and humectants means the formulation needs to be balanced to maintain stability and efficacy.
- Skin protectant, by creating a protective barrier on the skin to defend it from harmful substances, irritants, allergens, pathogens that can cause various inflammatory conditions.

Skin protectants can also improve the natural skin barrier and in most cases more than one is needed to achieve an effective result.

The process of obtaining wheat bran as a cosmetic ingredient involves several steps:

Figure 90: Process for the valorisation of wheat bran as a cosmetic ingredient

Milling and Separation

- Wheat bran is obtained during the milling process of wheat grains. It is the outer layer that is separated from the endosperm and germ during milling.

Cleaning and Refinement

- After separation, the bran undergoes cleaning to remove impurities and foreign materials. It might also go through refining processes to achieve desired purity levels

Extraction or Processing

- Depending on the intended use in cosmetics, the bran might undergo various extraction or processing methods to extract specific components or enhance certain properties. This can involve solvent extraction, enzymatic treatments, or other processes to obtain the desired extract or form of wheat bran

Formulation

- The extracted or processed wheat bran is then formulated into cosmetic ingredients. This involves blending, combining, or refining the material to create the final cosmetic ingredient in the desired form (powder, extract, oil, etc.) suitable for incorporation into cosmetic formulations

Quality Control

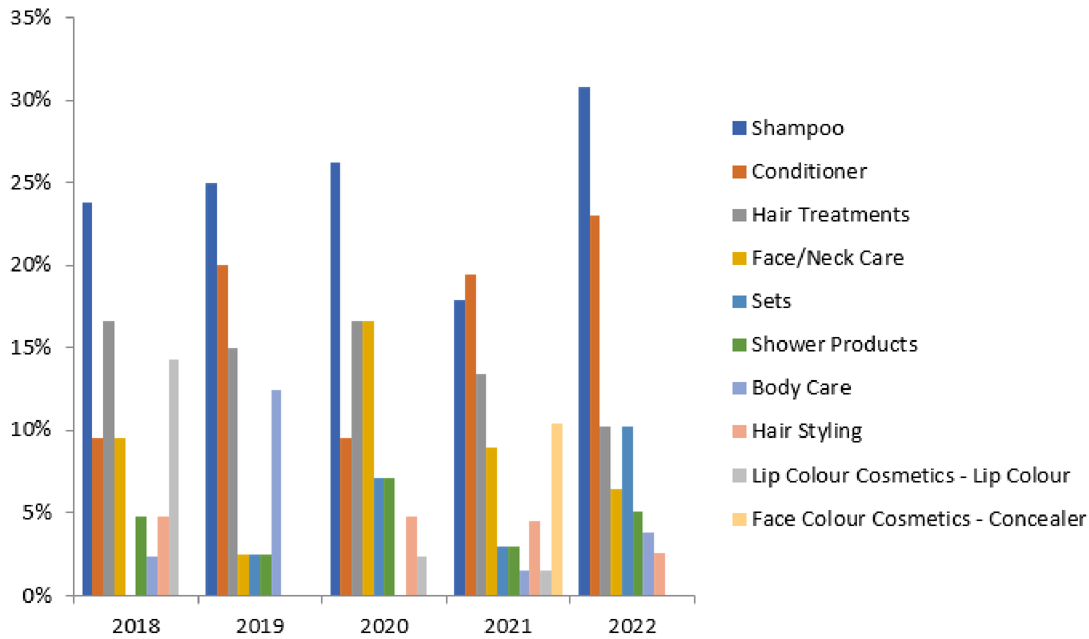
- Throughout these processes, quality control measures are implemented to ensure the purity, safety, and efficacy of the wheat bran-derived ingredient. This includes testing for contaminants, stability, and adherence to regulatory standards

Packaging and Distribution

- The finalised wheat bran-derived cosmetic ingredient is packaged according to industry standards and distributed to cosmetic manufacturers or suppliers for use in various skincare, haircare, or cosmetic formulations

According to Mintel, nearly 270 products including wheat bran ingredients have been launched between 2018 and 2022. The distribution is described as follows:

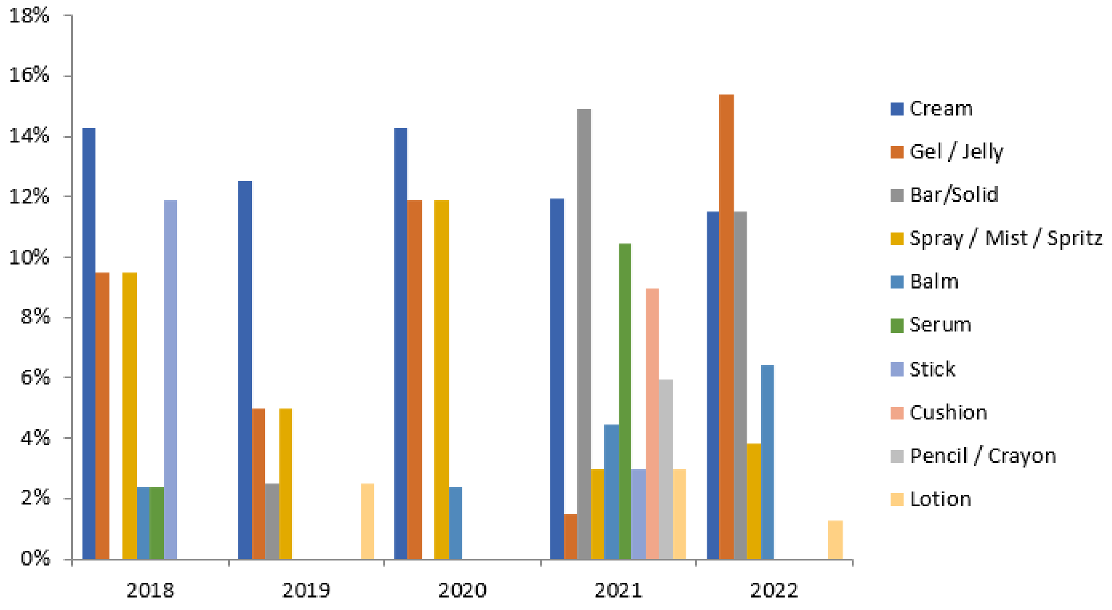
Figure 91: Distribution of products launched between 2018 and 2022 in the cosmetics category



Source: data from Mintel, 2023

Triticum Vulgare extract is mainly used in cosmetic creams. Indeed, it has anti-inflammatory properties and is an interesting skin care agent.

Figure 92: Distribution of products launched containing Triticum Vulgare Extract between 2018 and 2022 in the cosmetics category



Source: data from Mintel, 2023

Limitations to the valorisation of wheat bran for cosmetics:

- While cosmetic ingredients derived from wheat bran offer various benefits, there are some limitations associated with their use, related namely to:
  - Potential Allergies: Individuals with wheat or gluten allergies may experience adverse reactions to cosmetic products containing wheat-derived ingredients. This limits the suitability of wheat bran-based ingredients for certain users.
  - Fragrance and Colour: Wheat-derived ingredients may have natural fragrances or colours that could impact the sensory attributes of cosmetic formulations, potentially limiting their use in certain products.
- The economic viability of cosmetic ingredients obtained from wheat bran is an issue. The process of obtaining cosmetic-grade ingredients from wheat bran may involve extraction, refinement, and purification methods, impacting production costs. There is a need to optimize extraction techniques to ensure efficiency and reduce costs to ensure the economic feasibility of using bio-sourced ingredients, instead of synthesized molecules, which are cheaper for manufacturers.
- The quantity of wheat bran used in cosmetics is typically small, as only small amounts of biomass are needed to extract the interesting molecules. This limits the amount of biomass recycled.

2.5.3.4. Nutraceuticals

Nutraceuticals are products blending aspects of nutrition and pharmaceuticals for health benefits. The valorisation of wheat bran in nutraceuticals involves leveraging its nutritional composition and potential health benefits in specialized food or supplement formulations. Here are ways wheat bran can be valorised in nutraceuticals:

- Dietary fiber source: wheat bran is rich in dietary fibre, particularly insoluble fibres like cellulose and hemicellulose. It can be incorporated into nutraceutical products to increase fibre content, promoting digestive health, and potentially reducing the risk of certain diseases.

- Functional ingredients: extracts or bioactive compounds derived from wheat bran, such as phenolic compounds, antioxidants, and vitamins, can be isolated and concentrated for use as functional ingredients in nutraceutical formulations. These components may offer potential health benefits, such as antioxidant and anti-inflammatory properties.
- Cholesterol management: components of wheat bran, like beta-glucans, have been associated with potential cholesterol-lowering effects. Valorising these compounds in nutraceuticals aimed at cardiovascular health could be beneficial.
- Blood sugar regulation: Some components of wheat bran may aid in blood sugar control. Utilising these compounds in nutraceuticals designed for managing blood sugar levels could be explored.
- Weight management: The high fibre content of wheat bran may promote satiety, aiding in weight management. It can be incorporated into formulations intended for appetite control or weight loss.
- Prebiotic properties: The fibre in wheat bran can serve as a probiotic, supporting the growth of beneficial gut bacteria. Nutraceuticals promoting gut health and immunity could benefit from these properties.

Limitations to the valorisation of wheat bran for nutraceuticals:

- As in cosmetics, the quantity of wheat bran used for nutraceuticals is limited. The main constraint to the use of wheat bran-derived ingredients in nutraceuticals is the cost-effectiveness, for manufacturers. The cost of extraction, purification, and formulation often outweighs the benefits, impacting profitability.

Addressing these challenges require innovations in extraction techniques, demonstrating specific health benefits unique to wheat bran compounds, and optimising formulations to ensure effective dosages without compromising cost-effectiveness. Finding ways to maximize the health benefits derived from wheat bran while addressing manufacturing challenges could enhance its potential use in nutraceuticals.

2.5.3.5. Bioactive surfactant

Wheat bran, as the major processing by-product of wheat (25% of original weight) (Neves *et al*., 2006), is a mixture of abundant nutrients and bioactive components including protein (15–22%), starch (10–20%), lignin (4–8%) and dietary fibre (36–52%) (Kaur *et al*., 2019).

At present, too little use is made of the carbohydrates that make up the bulk of wheat bran to produce high added-value molecules. They are mainly used in animal feed.

The Interreg *ValBran* project has sought to exploit such carbohydrates to produce bio sourced surface-active molecules. These molecules are used in a variety of sectors, including cosmetics, household detergents and agrochemicals. The project aimed to produce non-ionic surfactants of plant origin such as APGs (alkyl polyglycosides) and sugar esters, which would replace molecules of fossil origin. The entire value chain would then be as follows:

Figure 93: Process for valorisation of wheat bran as a bioactive surfactant

Source: ValBran, n.d.

The ValBran project developed joint approach to biotechnologies to develop a synthesis path of alkyl glycosides and ester sugar. Bioactives molecules can be produced by chemically or enzymatically grafting a lipophilic part of plant origin (e.g., fatty acid) to a hydrophilic part of plant origin (e.g., sugar).

Compared to fossil-based surfactants produced under drastic conditions (high temperature, chemical catalysis) biosurfactants are synthesized by enzymes under mild reaction conditions (moderate temperature, absence of chemical analysis).

Limitations to the valorisation of wheat bran for bioactive surfactants:

- The economic profitability of this biomass recovery is limited. Production yields for biosurfactants are relatively low given the investment required to produce this type of molecule. In addition, these biosurfactants require manufacturers to develop new formulas, which means additional research and development costs. Finally, designers of finished products have little idea of the added value of switching from traditional surfactants to plant-based surfactants.
- Consumers have limited knowledge of this type of ingredient, and more generally of the importance of surfactants of plant or non-plant origin.
- There are no standards for biosurfactants.
- A major technical problem is the downstream processing of microbial biosurfactants, which is complicated and requires innovation.

2.5.3.6. Additional ways of valorisation

The scientific bibliography has made it possible to identify three additional ways of valorising wheat bran, which were not mentioned during interviews conducted by the B-Resilient consortium partners.

Substrate for enzyme production

Wheat bran, due to its composition rich in cellulose, hemicellulose, and lignin, serves as a potential substrate for enzyme production through processes like solid-state fermentation. Wheat bran is a nitrogen source for production of protease, amylase or glucoamylase (Javed *et al*., 2012). Also, wheat bran could be used as an inducer for enzymes by participating in complex substrates (Sindhu *et al*., 2009).

In biotechnological applications, especially in enzyme production, wheat bran can be utilized in several ways:

- Solid-State Fermentation (SSF): wheat bran provides a suitable substrate for SSF, a fermentation method where microorganisms grow on a solid material without free-flowing water. Microorganisms, such as fungi or bacteria, are cultivated on the wheat bran substrate to produce various enzymes.
- Enzyme production: the enzymes generated during SSF on wheat bran can include cellulases, hemicellulases, ligninases, and other hydrolytic enzymes. These enzymes have potential industrial applications in biofuel production, textile processing, food processing, and waste treatment, among others.
- Biorefinery: wheat bran enzymatic hydrolysis can be part of the biorefinery process, where its cellulose and hemicellulose components are broken down into fermentable sugars. These sugars can then be utilised for bioethanol production or other bio-based products.
- Waste valorisation: using wheat bran as a substrate for enzyme production contributes to the valorisation of agricultural waste, reducing its environmental impact and providing added value by converting it into valuable enzyme products.

Pigment industry

From the scientific literature review emerged a potential use of wheat bran in the pigment industry, that was not mentioned during the interviews conducted either with manufactures or with research centres. Natural pigments can be obtained from wheat bran, by using selected microorganisms such as *Ashbya gossypii* (producing ribloflavie), *Chitinophaga pinensis* (producing flexirubin), *Chromobacterium vaccinii* (violacein) and *Gordona alkanivorans* (carotenoids) (Cassarini *et al*., 2021).

Wheat bran has multiple uses within the pigment industry:

- Natural colouring agent: wheat bran contains phenolic compounds, flavonoids, and other natural compounds that can act as colorants. Extracts from wheat bran can be used as natural dyes or pigments in various industries, including textiles, food, cosmetics, and even paints.
- Bio-based colorants: extracts derived from wheat bran can serve as bio-based alternatives to synthetic dyes and pigments. These natural colorants are environmentally friendly and can appeal to consumers seeking sustainable and eco-friendly products.
- Cosmetics and food industry: wheat bran extracts may be used to impart natural colours to cosmetics, such as lipsticks or eye shadows, and food products, including beverages, baked goods, or sauces, as a natural food colouring agent.
- Textile applications: wheat bran extracts might be utilised in the textile industry for dyeing fabrics. They can potentially provide a range of colours and shades, offering a natural alternative to synthetic dyes.

- Research and Development: ongoing research explores the potential of wheat bran extracts in pigment production, aiming to optimize extraction methods, enhance colour stability, and expand their application in various industries.

Bioenergy

Wheat bran can also be used in bioenergy production, notably bioethanol, biobutanol or biohydrogen, by providing lignocellulosic material (Hawkes *et al.*, 2008; Palmarola-Adrados *et al.*, 2004).

- Bioethanol production: wheat bran contains carbohydrates, including cellulose and hemicellulose, which can be converted into fermentable sugars. These sugars serve as a substrate for fermentation by yeast or bacteria to produce ethanol, then used as a biofuel.
- Biogas production: through anaerobic digestion, wheat bran can be broken down by microorganisms to produce biogas, primarily composed of methane and carbon dioxide. This biogas can be used for electricity generation or as a heating fuel.
- Biofuel feedstock: wheat bran, along with other lignocellulosic materials, can serve as a feedstock for the production of advanced biofuels, such as bio-based hydrocarbons or biodiesel, through processes like thermochemical conversion or enzymatic hydrolysis.
- Biorefinery applications: wheat bran, when processed in biorefineries, can be part of a larger process aimed at extracting valuable components like sugars for bioenergy production while simultaneously producing other bio-based products like biochemicals, biomaterials, or bio-based polymers.

3% of the European cereals production is destined for biofuel. During the interviews, only a French manufacturer mentioned that bran (and wheat bran) can be used in methanogenesis. Indeed, bran grain has a high methanogenic potential. Bran grain’s methanogenic potential is estimated to 382 Nm^3 CH_4 per ton of dry matter and 340 Nm^3 CH_4 per ton of fresh matter. By comparison, apple methanogenic potential is 387 Nm^3 per ton of dry matter and 56 Nm^3 CH_4 per ton of fresh matter.

Using wheat bran as a feedstock in bioenergy production has several limitations:

- Low sugar content: wheat bran contains cellulose, hemicellulose, and lignin, but its sugar content, which serves as a substrate for biofuel production, might be relatively lower compared to other biomass sources. This limitation impacts the yield of fermentable sugars needed for bioethanol production.
- Complex composition: the structural complexity of wheat bran, particularly its lignocellulosic nature, makes the breakdown of its components into fermentable sugars more challenging and energy intensive. This complexity hinders efficient enzymatic hydrolysis processes.
- Enzyme efficiency: enzymes used to break down wheat bran's components into sugars often face challenges due to the presence of lignin, which can inhibit enzyme activity, reducing the efficiency of the conversion process.
- Cost of pretreatment: effective pretreatment methods are required to improve enzymatic accessibility and enhance the efficiency of sugar extraction from wheat bran. These pretreatment processes, however, can be costly and energy-intensive, impacting the overall economic viability of bioenergy production.
- Competition with food and feed: using wheat bran for bioenergy competes with its utilisation in animal feed and human consumption. Balancing its use for bioenergy against its role as a valuable nutritional component creates challenges in resource allocation.
- Seasonal and regional variability: availability of wheat bran as a feedstock can vary seasonally and regionally, impacting its consistent supply for large-scale bioenergy production.
- Regulatory constraints: regulatory policies related to land use, agricultural waste management, and bioenergy production might pose limitations or constraints on utilising wheat bran for bioenergy, affecting its feasibility.

3. Conclusions

The report presents an in-depth analysis of five key value chains: brewery spent grain, grapes and wine-making by-products, apples, whey from milk and cheese, and wheat bran. Each has been studied using a common methodology combining literature reviews, market data, surveys of regional stakeholders, and targeted interviews with companies and research centers.

Main findings

These biomasses represent significant secondary flows in the European agri-food industry, which are often underutilized.

There are many potential uses for them: animal feed, energy (biogas, bioethanol), nutrition and health (functional ingredients), cosmetics, bio-based materials, etc.

The opportunities are real, but remain limited by technological barriers (conversion yields, costly processes), regulatory barriers (food safety, environmental standards), and economic barriers (low profitability, competition with traditional food uses).

Impact for B-Resilient project

The work has made it possible to:

- co-create a knowledge base with the companies, research centers, and clusters involved;
- generate content for dissemination (articles, newsletters, events) and fuel dialogue with regional authorities;
- promote networking between cross-sectoral actors, paving the way for new collaborative projects and the construction of circular economic models;
- for some clusters, it offered the opportunity to contact with a wide range of members (and non-members), in order to gain a better understanding of the challenges related to the valorization of co-products - both in general and within the targeted value chains.

Follow up and future steps

The information in the various reports comes from different sources and its availability and updating vary significantly from region to region. Despite these differences, the reports provide a valuable knowledge base and will support certain clusters in conducting more detailed analyses of their own regional value chains. For instance, the ATE cluster requested funding from its own regional authorities to carry out a comprehensive study of all the value chains developed in B-Resilient – something that had never before been documented at regional level. The study will begin in October 2025 and run for six months.

Overall, the report concludes that the valorization of agri-food co-products is a major strategic lever for enhancing the resilience, sustainability, and competitiveness of European SMEs, provided that the technical, regulatory, and economic obstacles that still hinder their optimal exploitation are removed. In this respect, by acting as connectors, facilitators and amplifiers, clusters play a major role in helping companies to overcome the barriers highlighted, reducing risks for SMEs, opening new opportunities, and ensuring that innovation translates into real market impact. The B-Resilient project is a clear example of how this support can be offered by clusters to their ecosystems.

The studies are now available on the I4CE (Ingredients for a Circular Economy) platform and are open to access to all EU innovators in the bioeconomy and circular economy sectors. The information they contain will provide a solid basis for future R&D projects, helping to keep pace with rapid technological and markets developments while ensuring that the content remains up to date. This work will strengthen the resilience of the European agri-food SMEs and accelerate the transition towards a circular bioeconomy.

4. Bibliography

4.1. Brewery spent grains

Aboukila, E. (2019). Use of Spent Grains, Cheese Whey, Gypsum, And Compost for Reclamation of Sodic Soils and Improvement of Corn Seed Germination. Alexandria Science Exchange Journal, 40(2), 312-326. https://doi.org/10.21608/ASEJAIQJSAE.2019.34188

Aboukila, E.F., Nassar, I.N., Rashad, M., Hafez, M., & Norton, J.B. (2018). Reclamation of calcareous soil and improvement of squash growth using brewers' spent grain and compost. Journal of the Saudi Society of Agricultural Sciences, 17(4), 390-397. https://doi.org/10.1016/j.jssas.2016.09.005

AGRESTE (2024). Agreste, la statistique agricole. https://agreste.agriculture.gouv.fr/agreste-web/

Aliyu, S., & Bala, M. (2011). Brewer's spent grain: A review of its potentials and applications. African Journal of Biotechnology, 10(3), 324-331. https://doi.org/10.5897/AJBx10.006 https://doi.org/10.5897/AJBx10.006

Belibasakis, N.G., & Tsirgogianni, D. (1996). Effects of wet brewers grains on milk yield, milk composition and blood components of dairy cows in hot weather. Animal Feed Science and Technology, 57(3), 175-181. https://doi.org/10.1016/0377-8401(95)00860-8

Bisaria, R., Madan, M., & Vasudevan, P. (1997). Utilisation of agro-residues as animal feed through bioconversion. Bioresource Technology, 59(1), 5-8. https://doi.org/10.1016/S0960-8524(96)00140-X

Brewers of Europe (2022). Beer trends. https://brewersofeurope.eu/

Briggs, D.E. (1978). Barley (2nd ed.). Chapman and Hall.

Buffington, J. (2014). The Economic Potential of Brewer's Spent Grain (BSG) as a Biomass Feedstock. Advances in Chemical Engineering and Science, 4(3), 308-318. http://dx.doi.org/10.4236/aces.2014.43034

Chambres d'Agriculture Auvergne-Rhône-Alpes (2024). Filière brassicole. https://aura.chambres-agriculture.fr/notre-agriculture/agriculture-en-auvergne-rhone-alpes/filieres-vegetales/filiere-brassicole/

Dessalew, G., Beyene, A., Nebiyu, A., & Ruelle, M.L. (2017). Use of industrial diatomite wastes from beer production to improve soil fertility and cereal yields. Journal of Cleaner Production, 157(2017), 22-29. https://doi.org/10.1016/j.jclepro.2017.04.116

Diptee, R., Smith, J.P., Alli, I., & Khanizadeh, S. (1989). Application of response surface methodology in protein extraction studies from brewer's spent grain. Journal of Food Processing and Preservation, 13(6), 457-474. https://doi.org/10.1111/j.1745-4549.1989.tb00119.x

Egbert, G. (2008). Barley. [Seminar entry]. Food for Thought: The Science, Culture & Politics of Food. Clinton, NY. https://academics.hamilton.edu/foodforthought/Our_Research_files/barley.pdf

EUROMALT (2024). Euromalt statistics. https://www.euromalt.be/euromalt-statistics

EUROSTAT (2023). Beer production back to pre-pandemic level. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230803-1

Gan, Q., Allen, S.J., & Taylor, G. (2002). Design and operation of an integrated membrane reactor for enzymatic cellulose hydrolysis. Biochemical Engineering Journal, 12(3), 223-229. https://doi.org/10.1016/S1369-703X(02)00072-4

Garcia-Garcia, G., Stone, J., & Rahimifard, S. (2019). Opportunities for waste valorisation in the food industry – A case study with four UK food manufacturers. Journal of Cleaner Production, 211(2019), 1339-1356. https://doi.org/10.1016/j.jclepro.2018.11.269

Gargulak, J.D., & Lebo, S.E. (2000). Commercial use of lignin-based materials. In Glasser, W.G., Northey R.A., & Schultz, T.P. (Eds.) Lignin: Historical, Biological, and Material Perspectives (1st ed., Vol. 742, pp. 304-320). American Chemical Society. https://doi.org/10.1021/bk-2000-0742.ch015

Graf, E. (1992). Antioxidant potential of ferulic acid. Free Radical Biology and Medicine, 13(4), 435-448. https://doi.org/10.1016/0891-5849(92)90184-I

Institut National de la statistique et des études économiques (2024). Institut national de la statistique et des études économiques. https://www.insee.fr/fr/accueil

Ishiwaki, N., Murayama, H., Awayama, H., Kanauchi, O., & Sato, T. (2000). Development of high value uses of spent grain by fractionation technology. Technical Quarterly Master Brewers Association, 37(2000), 261-265.

Jay, A.J., Parker, M., Faulks, R., Husband, F., Wilde, P., Smith, A.C., Baulds, C.B., & Waldron, K.W. (2008). A systematic micro-dissection of brewers' spent grain. Journal of Cereal Science, 47(2), 357-364. https://doi.org/10.1016/j.jcs.2007.05.006

Johnson, P., Paliwal, J., & Cenkowski, S. (2010). Issues with utilisation of brewers' spent grain. Stewart Postharvest Review, 4(2), 1-8. https://doi.org/10.2212/spr.2010.4.2

Khidzir, K.M., Noorlidah, A., & Agamuthu, P. (2010). Brewery Spent Grain: Chemical Characteristics and utilization as an Enzyme Substrate. Malaysian Journal of Science, 29(1), 41-51. https://doi.org/10.22452/mjs.vol29no1.7

Ktenioudaki, A., Chaurin, V., Reis, S.F., & Gallagher, E. (2012). Brewer's spent grain as a functional ingredient for breadsticks. International Journal of Food Science and Technology, 47(2012), 1765-1771. https://doi.org/10.1111/j.1365-2621.2012.03032.x

Ktenioudaki, A., Crofton, E., Scannell, A.G.M., Hannon, J.A., Kilcawley, K.N., & Gallagher, E. (2013). Sensory properties and aromatic composition of baked snacks containing brewer's spent grain. Journal of Cereal Science, 57(3), 384-390. https://doi.org/10.1016/j.jcs.2013.01.009

Lorente, A., Remón, J., Budarin, V.L., Sánchez-Verdú, P., Moreno, A., & Clark, J.H. (2019). Analysis and optimization of a novel "bio-brewery" approach: Production of bio-fuels and bio-chemicals by microwave-assisted, hydrothermal liquefaction of brewers' spent grains. Energy Conversion and Management, 185(2019), 410-430. https://doi.org/

Mintel (2024). Brewery spent grains. Mintel Portal. https://portal.mintel.com/

Mitsuyama, K., Saiki, T., Kanauchi, O., Iwanaga, T., Tomiyasu, N., Nishiyama, T., Tateishi, H., Shirachi, A., Ide, M., Suzuki, A., Noguchi, K., Ikeda, H., Toyonaga, A., & Sata, M. (1998). Treatment of ulcerative colitis with germinated barley foodstuff feeding: a pilot study. Alimentary Pharmacology & Therapeutics, 12(12), 1225-1230. https://doi.org/10.1046/j.1365-2036.1998.00432.x

Moreirinha, C., Vilela, C., Silva, N.H.C.S., Pinto, R.J.B., Almeida, A., Rocha, M.A.M., Coelho, E., Coimbra, M.A., Silvestre, A.J.D., & Freire, C.S.R. (2020). Antioxydant and antimicrobial films based on brewers spent grain arabinoxylans, nanocellulose and feuloyated compounds for active packaging. Food Hyrocolloids, 108(105836). https://doi.org/10.1016/j.foodhyd.2020.105836

Mukasafari, M.A., Ambula, M.K., Karege, C., & King'ori, A.M. (2017). Effects of substituting sow and weaner meal with brewers' spent grains on the performance of growing pigs in Rwanda. Tropical Animal Health and Production, 50(2017), 393-398. https://doi.org/10.1007/s11250-017-1446-x

Mussatto, S. (2014). Brewer's spent grain: a valuable feedstock for industrial applications. Journal of the Science of Food and Agriculture, 94(7), 1264-1275. https://doi.org/10.1002/jsfa.6486

Mussatto, S., Dragone G., & Roberto I.C. (2006). Brewers' spent grain: generation, characteristics and potential applications. Journal of Cereal Science, 43(1), 1-14. https://doi.org/10.1016/j.jcs.2005.06.001

Mussatto, S., Fernandes, M., Milagres, A.M.F., & Roberto I.C. (2008). Effect of hemicellulose and lignin on enzymatic hydrolysis of cellulose from brewer's spent grain. Enzyme and Microbial Technology, 43(2), 124-129. https://doi.org/10.1016/j.enzmictec.2007.11.006

Mussatto, S., Fernandes, M., & Roberto, I.C. (2007). Lignin recovery from brewer's spent grain black liquor. Carbohydrate Polymers, 70(2), 218-223. https://doi.org/10.1016/ j.carbpol.2007.03.021

Mussatto, S., Fernandes, M., Rocha, G.J.M., Órfão, J.J.M., Teixeira, J.A., & Roberto I.C. (2010). Production, characterization and application of activated carbon from brewer's spent grain lignin. Bioresource Technology, 101(7), 2450-2457. https://doi.org/10.1016/ j.biortech.2009.11.025

Naibaho, J., & Korzeniowska, M. (2021). The variability of physcio-chemical properties of brewery spent grain from 8 different breweries. Heliyon, 7(2021), 1-9. https://doi.org/10.1016/ j.heliyon.2021.e06583

Native Plant Trust. (2024). Hordeum vulgare – common barley. https://gobotany.nativeplanttrust.org/species/hordeum/vulgare/

Nigam, P.S. (2017). An overview: Recyling of solid barley waste generated as a by-product in distillery and brewery. Waste Management, 62(2017), 255-261. https://doi.org/10.1016/ j.wasman.2017.02.018

Outeiriño Rodriguez, D. (2022). Biorefinery of brewery wastes to produce bioactive molecules with food interest (bacteriocins and biosurfactants) (Publication No. 11093/3455) [Doctoral dissertation, Universida de Vigo]. Repositorio institucional da UVigo https://www.investigo.biblioteca.uvigo.es/xmlui/handle/11093/3455

Reis, S.F., Gullón, B., Gullón, P., Ferreira, S., Maia, C.J., Alonso, J.L., Domingues, F.C., & Abu-Ghannam, N. (2014). Evaluation of the prebiotic potential of arabinoxylans from brewer's spent grain. Applied Microbiology and Biotechnology, 98(22), 9365-9373. https://doi.org/10.1007/s00253-014-6009-8

Robertson, J.A., I'Anson, K.J.A., Treimo, J., Faulds, C.B., Brocklehurst, T.F., Eijsink, V.G.H., & Waldron, K.W. (2010). Profiling brewers' spent grain for composition and microbial ecology at the site of production. LWT – Food Science and Technology, 43(6), 890-896. https://doi.org/10.1016/j.lwt.2010.01.019

Saito, K., Miamoto, K.I., & Katsukura, M. (1993). Influence of external additives on the preservation of carthamin red colour: An introductory test for utilizing carthamin as a herbal colorant of processed foods. Zeitschrift für Lebensmittel-Untersuchung und Forschung, 196(1993), 259-260. https://doi.org/10.1007/BF01202744

San Martín, D., Iñarra, B., Ibarruri, J., Gutierrez, M., Fenollosa, R., Estevez, A., Miguel Martínez, J., De Smet, A-M., & Zufía, J. (2023). Beer by-products as an alternative protein source for nutraceuticals and aquaculture feeds. AZTI – Centro de Investigación Marina y Alimentaria. https://www.azti.es/en/subproductos-de-cerveza-como-fuente-de-proteina-alternativa/

Santos, F., & Curvelo, A.A.S. (2001). Recovery of lignins from kraft liquors. Proceedings of the Sixth Brazilian Symposium on the Chemistry of Lignins and Other Wood Components, Brazil, 7(2001), 386-391.

Serghat, S., Mathlouthi, M., Hoopman, T., & Birch, G.G. (1992). Solute-solvent interactions and the sweet taste of small carbohydrates. Part 1: Effect of solvent polarity on solution properties. Food Chemistry, 45(1), 25-32. https://doi.org/10.1016/0308-8146(92)90007-O

Sperandio, G., Amoriello, T., Carbone, K., Fedrizzi, M., Monteleone, A., Tarangioli, S., & Pagano, M. (2017). Increasing the Value of Spent Grain from Craft Microbreweries for Energy Purposes. Chemical Engineering Transactions, 58(2017), 487-492. https://doi.org/10.3303/CET1758082

SUSFOOD2 (2024). Biotransformation of brewers' spent grain: increased functionality for novel food applications. https://susfood-db-era.net/main/content/funbrew

Szponar, B., Pawlik, K.J., Gamian, A., & Szwajcer Dey, E. (2003). Protein fraction of barley spent grain as a new simple medium for growth and sporulation of soil actinobacteria. Biotechnology Letters, 25(2003), 1717-1721. https://doi.org/10.1023/A:1026046403010

Zeko-Pivač, A., Tišma, M., Žnidaršič-Plazl, P., Kulisic, B., Sakellaris, G., Hao, J., & Planinić, M. (2022). The Potental of Brewer's Spent Grain in the Circular Bioeconomy: State of the Art and Future Perspectives. Frontiers in Bioengineering and Biotechnology, 10(2022), 1-15. https://doi.org/10.3389/fbioe.2022.870744

4.2. Grapes and winemaking

A.Roman-Benn, C.A. Contador, Man-Wah Li, Hon-Ming Lam, Kong Ah-hen, Pilar E. Ulloa, M.C. Ravanal, Pectin: An overview of sources, extraction and applications in food products, biomedical, pharmaceutical and environmental issues

Abolfazl Taherzadeh Fini, Abolfazl Fattahi, Bioethanol Production from Agricultural Wastes in Iran, 2009

Aprifel, https://www.aprifel.com/fr/

Bueno J. M., Sáez-Plaza P., Ramos-Escudero F., Jiménez A. M., Fett R. & Asuero A. G., 2012. Analysis and antioxidant capacity of anthocyanin pigments. Part II: Chemical structure, color, and intake of anthocyanins. Crit. Rev. Anal. Chem. 42 (2), 126–151.

Centre for the Promotion of Imports, https://www.cbi.eu

Coombe, B. G. (1995). Adoption of a system for identifying grapevine growth stages, (1994), 104–110.

Diego Rafael Martins Flores, Patrícia Alves Franco da Fonseca, Janaína Schmitt, Cléber José Tonetto, Adriano Garcia Rosado Junior, Rodrigo K. Hammerschmitt, Daniela B. Facco, Gustavo Brunetto, José Laerte Nörnberg, Lambs fed with increasing levels of grape pomace silage: Effects on productive performance, carcass characteristics, and blood parameters

Direction générale des Douanes et des Droits indirects (DGDDI) – Production 2019 commercialisable, 2020

Emilia Romagna region, "Nasce "Legàmi di Vite", un importante contratto di sviluppo "green" nel comparto vitivinicolo" https://agricoltura.regione.emilia-romagna.it/notizie/2022/agosto/nasce-legami-di-vite-importante-contratto-di-sviluppo-green-comparto-vitivinicolo

En-Qin Xia, Gui-Fang Deng, Ya-Jun Guo and Hua-Bin Li, Biological Activities of polyphenols from Grapes, doi: 10.3390/ijms11020622

European Parliament, The EU wine sector https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/751399/EPRS_BRI(2023)751399_EN.pdf

F.Monlau, A. Barakat, J-P Steyer, H. Carrère, 2012, Comparison of seven types of thermo-chemical pretreatments on the structural features and anaerobic digestion of sunflower stalks

Fraige, K., Pereira-Filho, E. R., & Carrilho, E. (2014). Fingerprinting of anthocyanins from grapes produced in Brazil using HPLC-DAD-MS and exploratory analysis by principal component analysis. Food Chemistry, 145, 395–403. https://doi.org/10.1016/j.foodchem.2013.08.066

G.Mazza, 1995, Anthocyanins in grapes and grape products

Gheorghe C, Marculescu C, Badea A, Dinca C, Apostol T (2009) Effect of pyrolysis conditions on bio-char production from biomass. In: 3rd WSEAS Int Conf on renewable energy sources, pp 239–41

CORDIS database, https://cordis.europa.eu/

Eurostat, https://ec.europa.eu/eurostat/fr/

Mémento Fruits & Légumes, https://memento.ctifl.fr/

International Organisation of Vine and Wine, https://www.oiv.int/

Jean H. El Achkar, Thomas Lendormi, Zeina Hobaika, Dominique Salameh, Nicolas Louka, Richard G. Maroun, Jean-Louis Lanoisellé, Anaerobic digestion of grape pomace: Biochemical characterization of the fractions and methane production in batch and continuous digesters

Johannes Lehamann,2007, Bio-energy in the black

Korkie, Janse, Viljoen-Bloom, 2002, Utilising Grape Pomace for Ethanol Production

Miller, A. J., & Gross, B. L. (2011). From forest to field: Perennial fruit crop domestication. American Journal of Botany, 98(9), 1389–1414. https://doi.org/10.3732/ajb.1000522

N.Limareva, L.Donchenko and L.Vlaschik, 2019, Comparative Evaluation of Properties of Pectin

Substances in Pomace of Grape Varieties for Development of Functional Foods

P.J. Moate, S.R.O. Williams, V.A. Torok, M.C. Hannah, B.E. Ribaux, M.H. Tavendale, R.J. Eckard, J.L. Jacobs, M.J. Auldist, W.J. Wales, Grape marc reduces methane emissions when fed to dairy cows

Pastrana-Bonilla E, Akoh CC, Sellappan S, Krewer G. Phenolic content and antioxidant capacity of muscadine grapes. J. Agric. Food Chem. 2003;51:5497–4503.

Prescott, L.M., Harley, J.P. and Klein, D.A. (1993) Microbiology. 2nd Edition, Wm. C. Brown Publishers, Dubuque, 588-591.

Roya Kolahdouz Mohammadi, Tahereh Arablou,Resveratrol and endometriosis: In vitro and animal studiesand underlying mechanisms (Review),Biomedicine & Pharmacotherapy,Volume 91,2017,ISSN 0753-3322

Schieber, A. ; Stintzing, F. C. ; Carle, R., 2001. By-products of plant food processing as a source of functional compounds-recent developments. Trends in Food Science & Technology, 12: 401–413

Sheau-Chung Tang, Jen-Hung Yang, Dual effects of Alpha-Hydroxy Acids on the Skin

Shrikhande AJ. Wine by-products with health benefits. Food Res. Internat. 2000;33:469–474

Juliano Garavaglia, Melissa M. Markoski, Aline Oliveira and Aline Marcadenti, 2016, “Grape Seed Oil Compounds : Biological and Chemical Actions for Health

Sunil Kumar Prajapati, Deepak Kumar Rawat, Bimlesh Kumar Prajapati, The Production Techniques of Biochar and Amendment for Global Climate Change Mitigation, Carbon Sequestration and Waste Management

TechniLoire, « Les différents types de biodéchets vitivinicoles et voies de valorisation », https://techniloire.com/fiche-technique/les-differents-types-de-biodechets-vitivinicoles-et-voies-de-valorisation

Teixeira, António & Eiras-Dias, José & Castellarin, Simone Diego & Gerós, Hernâni. (2013). Berry Phenolics of Grapevine under Challenging Environments. International journal of molecular sciences. 14. 18711-39. 10.3390/ijms140918711.

X. Liu, R. Bayard, H. Benbelkacem, P. Buffière, R. Gourdon, Evaluation of the correlations between biodegradability of lignocellulosic feedstocks in anaerobic digestion process and their biochemical characteristics

4.3. Apple

"Results and Replicable Roadmap AlpBioEco, Analysis of the bio-based value-chains apples, walnuts and herbs", published by AlpBioEco project, InnoCamp Sigmaringen, Sigmaringen, May 2019.

Agreste, https://agreste.agriculture.gouv.fr/agreste-web/

Al Daccache M, Koubaa M, Maroun RG, Salameh D, Louka N, Vorobiev E. Impact of the Physicochemical Composition and Microbial Diversity in Apple Juice Fermentation Process: A Review. Molecules. 2020 Aug 13;25(16):3698. doi: 10.3390/molecules25163698. PMID: 32823772; PMCID: PMC7464816.

Amiot-Carlin, M.J., Caillavet, F., Causse, M., Combris, P., Dallongeville, J., Padilla, M. and Soler, L.G. (2007) Les fruits et légumes dans l'alimentation, Enjeux et déterminants de la consommation. Expertise Scientifique Collective, 80, 26-32.

Ampese, L. C., et al. (2022) Valorization of apple pomace for biogas production: a leading anaerobic biorefinery approach for a circular bioeconomy. Biomass Conversion and Biorefinery. doi.org/10.1007/s13399-022-03534-6

Aprifel https://www.aprifel.com/fr/

Bhushan and Gupta 2013 Apple Pomace: Source of Dietary Fibre and Antioxidant for Food Fortification

Bhushan S, Kalia K, Sharma M, Singh B, Ahuja PS. Processing of apple pomace for bioactive molecules. Crit Rev Biotechnol. 2008;28(4):285-96. doi: 10.1080/07388550802368895. PMID: 19051107.

Choi, Kim et al. 2016, Distribution of Microorganisms in Cheongyang Red Pepper Sausage and Effect of Central Temperature on Quality Characteristics of Sausage

Crawshaw, R., 2004. Co-product feeds: animal feeds from the food and drinks industries. Nothingham University Press

D. Malenica, Marko Kass, Rajeev Bhat, 2022,Sustainable Management and Valorization of Agri-Food Industrial Wastes and By-Products as Animal Feed: For Ruminants, Non-Ruminants and as Poultry Feed

Dhillon, Kaur et al. 2012Optimization of cellulase-free xylanase production by alkalophilic Cellulosimicrobium sp. CKMX1 in solid-state fermentation of apple pomace using central composite design and response surface methodology

Dhillon, Kaur et al. 2013 Bioproduction and extraction optimization of citric acid from Aspergillus niger by rotating drum type solid-state bioreactor

Direction générale de l'Agriculture, des Ressources naturelles et de l'Environnement du Service public de Wallonie, Elleuch, Bedigian et al. 2011 Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review

Eurostat https://ec.europa.eu/eurostat/fr/

FranceAgriMer https://www.franceagrimer.fr/

Givens, D. I. ; Brunnen, J. M., 1987. Nutritive value of naked oats for ruminants. Anim. Feed Sci. Technol., 18: 83-87

Gołębiewska E, Kalinowska M, Yildiz G. Sustainable

Guiné, R.P.F.; Barroca, M.J.; Coldea, T.E.; Bartkiene, E.; Anjos, O. Apple Fermented Products: An Overview of Technology, Properties and Health Effects. Processes 2021, 9, 223. https://doi.org/10.3390/pr9020223

Gustafsson J., Landberg M., Bátori V., Åkesson D., Taherzadeh M.J., Zamani A. Development of bio-based films and 3D objects from apple pomace. Polymers. 2019;11:289. doi: 10.3390/polym11020289

Gustafsson J., Landberg M., Bátori V., Åkesson D., Taherzadeh M.J., Zamani A. Development of bio-based films and 3D objects from apple pomace. Polymers. 2019;11:289. doi: 10.3390/polym11020289

Hang, Lee et al, 1981, Production of Alcohol from Apple Pomace, https://journals.asm.org/doi/abs/10.1128/aem.42.6.1128-1129.1981

Hellier R., Esnault R. et Lance C., 2000. Formation des fruits et des graines. Dans Physiologie végétale. 2-Développement; Dunod, Ed.; pp 220-239

Benoit Rouillé (Institut de l'Elevage), Valérie Heuzé (AFZ), Gilles Tran (AFZ). Marc de pomme et pommes de retrait (Co-produits), publié le 22/05/2023 par https://idele.fr/comite-national-des-coproduits/publications/detail?tx_atolidelecontenus_publicationdetail%5Baction%5D=showArticle&tx_atolidelecontenus_publicationdetail%5Bcontroller%5D=Detail&tx_atolidelecontenus_publicationdetail%5Bpublication%5D=18877&cHash=da0bb0ec9e85f616b649d3ab8407a28f

Insee, https://www.insee.fr/fr/accueil

Jewell, W. J. and R. J. Cummings (1984). Apple pomace energy and solids recovery. Journal of Food Science 49(2): 407-410.

Jonhston J. W., Hewett E. W. et Hertog M. L. A. T. M., 2002. Postharvest softening of apple (Malus domestica) fruit: a review. New Zealand Journal of Crop and Horticultural Science, 30, 145-160

Kafilzadeh, F.; Tassoli, G.; Maleki, A., 2008. Kinetics of digestion and fermentation of apple pomace from juice and puree making. Res. J. Biol. Sci., 3 (10): 1143-1146

Kalia, V. C., A. Kumar, S. R. Jain and A. P. Joshi (1992). Biomethanation of plant materials. Bioresource Technology 41(3): 209-212.

Kapoor, Panwar et al. 2016 Chapter 3 - Bioprocesses for Enzyme Production Using Agro-Industrial Wastes: Technical Challenges and Commercialization Potential

Kennedy, P. M. ; Lowry, J. B. ; Conlan, L. L., 1999. Isolation of grass cell walls as neutral detergent fibre increases their fermentability for rumen micro-organisms. J. Sci. Food Agric., 79 (4): 544-548

Kosseva et al., 2013. Elsevier Inc.

Larissa Castro Ampese, William Gustavo Sganzeria, Henrique Ziero, Josiel Martins Costa, 2022, Valorization of apple pomace for biogas production: a leading anaerobic biorefinery approach for a circular bioeconomy

Liu H., Kumar V., Jia L., Sarsaiya S., Kumar D., Juneja A., Zhang Z., Sindhu R., Binod P., Bhatia S.K., et al. Biopolymer poly-hydroxyalkanoates (PHA) production from apple industrial waste residues: A review. Chemosphere. 2021;284:131427. doi: 10.1016/j.chemosphere.2021.131427.

Maiti, S., G. Gallastegui, G. Suresh, S. J. Sarma, S. K. Brar, P. Drogui, Y. LeBihan, G. Buelna, M. Verma and C. R. Soccol (2018). Hydrolytic pre-treatment methods for enhanced biobutanol production from agro-industrial wastes. Bioresource Technology 249: 673.

Miceli-Garcia 2014, PECTIN FROM APPLE POMACE: EXTRACTION, CHARACTERIZATION, AND UTILIZATION IN ENCAPSULATING ALPHA-TOCOPHEROL ACETATE

Multon J. L. et Davenas J., 1985. Qu'est-ce que la qualité d'un produit alimentaire et quels en sont les opérateurs? Dans La qualité des produits alimentaires, politique, incitations, gestion et contrôle; Lavoisier: Paris; pp 1-26.

Muriel Colin-Henrion. De la pomme à la pomme transformée : impact du procédé sur deux composés d'intérêt nutritionnel Caractérisation physique et sensorielle des produits transformés. domain_other. Université d'Angers, 2008. Français. ffNNT : ff. fftel-00351179

R. Chris Skinner, Derek C. Warren, Minahal Naveed, Garima Agarwal, Vagner A. Benedito, Janet C. Tou, 2019, Apple pomace improves liver and adipose inflammatory and antioxidant status in young female rats consuming a Western diet

Rabetafika, Bchir et al. 2014) Fractionation of apple by-products as source of new ingredients: Current situation and perspectives

Renard CM, Baron A, Guyot S, Drilleau JF. Interactions between apple cell walls and native apple polyphenols: quantification and some consequences. Int J Biol Macromol. 2001 Aug 20;29(2):115-25. doi: 10.1016/s0141-8130(01)00155-6. PMID: 11518583.

Roy et al., 2013. Rapport d'étude, Ch. Agr. Bretagne, Pôle Porcs

S. Auclair, 2008, Apple polyphenols and the prevention of atherosclerosis: study in murine models and in humans

Shalika Rana, Smita Kapoor ; Ajay Rana ; Y. S. Dhaliwal, Shashi Bhushan, 2021, Industrial Apple Pomace as a Bioresource for Food and Agro Industries

Shalika Rana, Smita Kapoor, Ajay Rana, Y.S Dhaliwal & Shashi Bhushan, 2022, Industrial Apple Pomace as a Bioresource for Food and Agro Industries

Shalini, R.; Gupta, D. K., 2010. Utilization of pomace from apple processing industries: a review. J. Food Sci. Technol., 47 (4): 365–371

StatBel, https://statbel.fgov.be/fr

Sudha, M. L., B. V. and K. Leelavathi (2007). Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. Food Chemistry 104: 686-692.

Sudha, M. L., Baskaran, V.; Leelavathi, K., 2007. Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. Food Chemistry, 104 (2): 686-692 - https://doi.org/10.1016/j.foodchem.2006.12.016

Tsao R, Yang R, Young JC, Zhu H. Polyphenolic profiles in eight apple cultivars using high-performance liquid chromatography (HPLC). J Agric Food Chem. 2003 Oct 8;51(21):6347-53. doi: 10.1021/jf0346298. PMID: 14518966.

Vendruscolo, Albuquerque et al. 2008, Apple pomace: a versatile substrate for biotechnological applications, DOI: 10.1080/07388550801913840

Vidot K, Devaux MF, Alvarado C, Guyot S, Jamme F, Gaillard C, Siret R, Lahaye M. Phenolic distribution in apple epidermal and outer cortex tissue by multispectral deep-UV autofluorescence cryo-imaging. Plant Sci. 2019 Jun;283:51-59. doi: 10.1016/j.plantsci.2019.02.003.

Welke JE, Hoeltz E, Dottori HA, Noll I B (2009) Effect of processing stages of apple juice concentrate on patulin levels - https://doi.org/10.1016/j.foodcont.2008.02.001

Wu, Sanguansri et al. 2014, The batch adsorption of the epigallocatechin gallate onto apple pomace

Zlatanović, S., Ostojić, S., Micić, D., Rankov, S., Dodevska, M., Vukosavljević, P., & Gorjanović, S. (2019). Thermal behaviour and degradation kinetics of apple pomace flours. Thermochimica Acta, 673, 17–25.

4.4. Cheese and cheese whey

Aboukila, E.F. (2019). Use of Spent Grains, Cheese Whey, Gypsum, and Compost for Reclamation of Sodic Soils and Improvement of Corn Seed Germination. Alexandria Science Exchange Journal, 40(2), 312-326. https://doi.org/10.21608/asejaiqjsae.2019.34188

Anderson, M.J., Lamb, R.C., Mickelsen, C.H., & Wiscombe, R.L. (1974). Feeding Liquid Whey to Dairy Cattle. Journal of Dairy Science, 57(10), 1206-1210. https://doi.org/10.3168/jds.S0022-0302(74)85038-1

ASINCAR (2020). Revalorización de suero de pequeñas queserías. Valorización de suero. http://valorizaciondesuero.es/

Asunis, F., De Gioannis, G., Dessì, P., Isipato, M., Lens, P.N.L., Muntoni, A., Polettini, A., Pomi, R., Rossi, A., & Spiga, D. (2020). The dairy biorefinery: Integrating treatment processes for cheese whey valorisation. Journal of Environmental Management, 276(2020), 1-15. https://doi.org/10.1016/j.jenvman.2020.111240

Bandler, D.K. (2023). Cheese making. Brittanica. https://www.britannica.com/topic/cheese-making

Bioga Business Technology Cluster of Life Sciences (2021). CETIM presenta al mercado soluciones comerciales sostenibles para resolver problemas ambientales de los sectores lácteo, forestal y tratamiento de aguas. BioTech Spain. https://biotech-spain.com/es/articles/cetim-presenta-al-mercado-soluciones-comerciales-sostenibles-para-resolver-problemas-ambientales-de-los-sectores-l-cteo-forestal-y-tratamiento-de-aguas/

Circular Bio-based Europe (2024). AgriChemWhey. Circular Bio-based Europe Joint Undertaking. https://www.cbe.europa.eu/projects/agrichemwhey

Clal.it (2024). Per capita consumption of Milk, Butter, Cheese, Skimmed Milk Powder (SMP) and Whole Milk Powder (WMP) over the last 5 years (per capita consumption) [Data set]. Clal.it. https://www.clal.it/en/?section=tabs_consumi_procapite

Clal.it (2023). EU-27: Dairy Export total [Data set]. Clal.it. https://www.clal.it/en/

index.php?section=dairyPROD_DWT_me_UE

COMEXT (2024). EU Dairy Extra-trade – January-March 2024 [Data set]. Eurostat. https://ec.europa.eu/eurostat/comext/newxtweb/mainxtnet.do

Encyclopaedia Brittanica (2014). Cheese production [Diagram]. Encyclopaedia Britannica. https://cdn.britannica.com/91/78591-050-858019AF/cheese-making-process.jpg

Eurostat (2023a). Cow's milk collection and products obtained – monthly data (apro_mk_colm) [Data set]. Eurostat. https://doi.org/10.2908/APRO_MK_COLM

Eurostat (2023b). Production and use of milk (million tonnes, EU, 2022) [Diagram]. Eurostat. https://ec.europa.eu/eurostat/statistics-explained/images/7/79/Production_and_use_of_milk_

%28million_tonnes%2C_EU%2C_2022%29_15-11-2023_v2.png

FAO (2023). Dairy Market Review – Emerging trends and outlook in 2023. Rome. https://openknowledge.fao.org/server/api/core/bitstreams/68f7f25d-b3cb-418e-b04d-5708e5bcea1e/content

Fassina, P., Quadros Nunes, G., Scherer Adami, F., Goettert, M.I., & Volken de Souza, C.F. (2019). Importance of Cheese Whey Processing: Supplements for Sports Activities – a Review. Polish Journal of Food and Nutrition Sciences, 69(1), 83-99. https://doi.org/10.31883/pjfns-2019-0008

Galacteum (2020). Discover our dairy product range. Dairylac S.L. https://www.galacteum.com/en/dairy-products/

Ha, E., & Zemel, M.B. (2003). Functional properties of whey, whey components, and essential amino acids: mechanisms underlying health benefits for active people (review). The Journal of Nutritional Biochemistry, 14(5), 251-258. https://doi.org/10.1016/S0955-2863(03)00030-5

Hijos de Rivera (2022). Fábrica de cervezas Estrella Galicia lanza su Milk Stout, una innovadora cerveza elaborada en colaboración con granjas gallegas. Corporación Hijos de Rivera. https://corporacionhijosderivera.com/fabrica-de-cervezas-estrella-galicia-milk-stout/

Kosikowski, F.V. (1979). Whey Utilization and Whey Products. Journal of Dairy Science, 62(7), 1149-1160. https://doi.org/10.3168/jds.S0022-0302(79)83389-5

MASA (2022). Producción y destino de leche en las explotaciones agrarias. Ministerio de Agricultura, Pesca y Alimentación. https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/

cuadros_c-i_2022_tcm30-673153.pdf

Mintel (2024). Dairy products and by-products. Mintel portal. https://portal.mintel.com/

Mollea, C., Marmo, L., & Bosco, F. (2013). Valorisation of Cheese Whey, a By-Product from the Dairy Industry. In Muzzalupo, I. (Eds.), Food Industry. Intechopen. https://www.intechopen.com/

chapters/42000

Prolactea (2024). Productos Food, ingredientes para una alimentación saludable. Prolactea. https://prolactea.es/productos-food/

Ryan, M.P. (2016). The biotechnological potential of whey. Reviews in Environmental Science and Bio/Technology, 15(3), 479-498. https://doi.org/10.1007/s11157-016-9402-1

Sik, B., Buzás, H., Kapcsándi, V., Lakatos, E., Daróczi, F., & Székelyhidi, R. (2023). Antioxidants and polyphenol content of different milk and dairy products. Journal of King Saud University – Science, 35(7), 1-6. https://doi.org/10.1016/j.jksus.2023.102839

Soumati, B., Atmani, M., Benabderrahmane, A., & Benjelloun, M. (2023). Whey Valorization – Innovative Strategies for Sustainable Development and Value-Added Product Creation. Journal of Ecological Engineering, 24(10), 86-104. https://doi.org/10.12911/22998993/169505

Statbel (2024). Industrie laitière. Statbel. https://statbel.fgov.be/fr/themes/agriculture-peche/industrie-laitiere

Tsakali, E., Petrotos, K., D’Allessandro, A., & Goulas, P. (2010). A review on whey composition and the methods used for its utilization for food and pharmaceutical products. [Conference presentation]. 6th International Conference on Simulation and Modelling in the Food and Bio-Industry FOODSIM, Braganca, Portugal. https://cmapspublic3.ihmc.us/rid=1N1Y36LJ0-25HNYDD-CMTW/Tsakalietal.-2010-Areviewonwheycompositionandthemethodsused.pdf

USDA (2019a). Whey, sweet, fluid. U.S. Department of Agriculture. https://fdc.nal.usda.gov/fdc-app.html#/food-details/171282/nutrients

USDA (2019b). Whey, acid, fluid. U.S. Department of Agriculture. https://fdc.nal.usda.gov/fdc-app.html#/food-details/170885/nutrients

Venetsaneas, N., Antonopoulou, G., Stamatelatou, K., Kornaros, M., & Lybertos, G. (2009). Using cheese whey for hydrogen and methane generation in a two-stage continuous process with alternative pH controlling approaches. Bioresource Technology, 100(15), 3713-3717. https://doi.org/10.1016/j.biortech.2009.01.025

Webb, B.H., & Whittier, E.O. (1948). The Utilization of Whey: A Review. Journal of Dairy Science, 31(2), 139-164. https://doi.org/10.3168/jds.S0022-0302(48)92188-2

Wheypack (2024). Reducción de las emisiones de CO2 mediante el uso de PHB obtenido a partir de suero lácteo: demostración en el envasado de productos lácteos. Wheypack Project. http://www.wheypack.eu/esp/descripcion.html

Zandona, E., Blažić, M., & Jambrak, A.R. (2021). Whey Utilisation: Sustainable Uses and Environmental Approach. Food Technology & Biotechnology, 59(2), 147-161. https://doi.org/10.17113/

ftb.59.02.21.6968

4.5. Wheat bran

Agri-food Data Portal https://agridata.ec.europa.eu/

Boudouma, D. (2009). Chemical composition of the durum wheat bran produced by industrial algerian mills. Livestock Research forRural Development, 21(10).Buckeridge, M. S., Crombie, H. J

Aduku, A. O. ; Okoh, P. N. ; Njoku, P. C. ; Orjichie, E. A. ; Aganga, A. A. ; Dim, N. I., 1986. Evaluation of cowpea (Vigna unguiculata) and peanut (Arachis hypogaea) haulms as feedstuffs for weanling rabbits in a tropical environment (Nigeria). J. Appl. Rabbit Res., 9 (4): 178-180

Antoine, C., Peyron, S., Mabille, F., Lapierre, C., Bouchet, B., Abecassis, J., Rouau, X., 2003. Individual contribution of grain outer layers and their cell wall structure to the mechanical properties of wheat bran. Journal of Agricultural and Food Chemistry, 51, 2026-2033.

Berchiche, M. ; Kadi, S. A. ; Lebas, F., 2000. Valorisation of wheat by-products by growing rabbits of local Algerian population. 7th World Rabbit Congress, Valencia, Vol. C : 119-124

Blas, E. ; Fernandez-Carmona, J. ; Cervera, C. ; Pascual, J. J., 2000. Nutritive value of coarse and fine wheat brans for rabbits. Anim. Feed Sci. Technol., 88 (3-4): 239-251

Cassarini M, Besaury L, Rémond C. Valorisation of wheat bran to produce natural pigments using selected microorganisms. J Biotechnol. 2021 Sep 20;339:81-92. doi: 10.1016/j.jbiotec.2021.08.003. Epub 2021 Aug 6. PMID: 34364925.

Data processed into diagram by ChatGPT

Cheng W, Qian H 2021 Wheat bran, as the resource of dietary fiber: a review DOI: 10.1080/10408398.2021.1913399

Committee, D. F. D. 2001. The definition of dietary fiber. Cereal Foods World 46 (3):112.

Curtis, B., S. Rajaram, and H. Macpherson. 2002. Bread wheat: Improvement and production. Rome: FAO.

Deroover, L., Y. Tie, J. Verspreet, C. M. Courtin, and K. Verbeke. 2020. Modifying wheat bran to improve its health benefits. Critical Reviews in Food Science and Nutrition 60 (7):1104–22. doi: 10.1080/ 10408398.2018.1558394.

Didactic ValBran project report, https://www.wheatbransurfactants.eu/fr/

Diekmann, F. 2009. Wheat. Journal of Agricultural & Food Information 10 (4):289–99. doi: 10.1080/10496500903245404

DiLena, G., Vivanti, V., & Quaglia, G. B. (1997). Amino acid composition of wheat milling by-products after bioconversion by edible fungi mycelia. Nahrung-Food, 41(5), 285e288.

Dornez, E., Gebruers, K., Wiame, S., Delcour, J. A., & Courtin, C. M.(2006). Insight into the distribution of arabinoxylans, endoxylanases, and endoxylanase inhibitors in industrial wheat roller mill streams. Journal of Agricultural and Food Chemistry, 54(22), 8521e8529. http://dx.doi.org/10.1021/Jf061728n

EvaPig, 2010. EvaPig: A calculator of energy, amino acid and phosphorus values of ingredients and diets for growing and adult pigs. INRA, Ajinomoto Eurolysine SAS, AFZ

Eurostat https://ec.europa.eu/eurostat/fr/

Fotso, J. M.; Fomunyam, R. T.; Ndoping, B. N., 2000. Protein and energy sources for rabbit diets in Cameroon. 1 - protein sources. World Rabbit Science, 8 (2): 57-60

FranceAgriMer https://www.franceagrimer.fr/

Gidenne, T., 1987. Apparent digestibility of high-lignin diets in the growing rabbit : transit and digesta flow measurements in different parts of the digestive tract. Ann. Zootech., 36 (2): 95-108

Göhl, B., 1982. Les aliments du bétail sous les tropiques. FAO, Division de Production et Santé Animale, Roma, Italy

Gu, Z. L. ; Bai, Y. F. ; Chen, B. J. ; Huo, G. C. ; Zhao, C., 2004. Effect of protein level on lactating performance, daily gain and fur density in rex rabbit. Proceedings of the 8th World Rabbit Congress, September 7-10, 2004, Puebla, Mexico: 1289-1294

Hawkes F.R., Forsey H., Premier G.C., Dinsdale R.M., Hawkes D.L., Guwy A.J., Maddy J., Cherryman S., Shine J., Auty D. Fermentative production of hydrogen from a wheat flour industry co-product. Bioresour. Technol. 2008;99:5020–5029. doi: 10.1016/j.biortech.2007.09.010.

Hemery, Y., Rouau, X., Lullien-Pellerin, V., Barron, C., & Abecassis, J. (2007). Dry processes to develop wheat fractions and products with enhanced nutritional quality. Journal of Cereal Science, 46(3), 327e347. ttp://dx.doi.org/10.1016/ J.Jcs.2007.09.008.

Intercéréales, https://www.intercereales.com/

INRA-CIRAD-AFZ feed tables, https://www.feedtables.com/

J. Hell et al. / Trends in Food Science & Technology 35 (2014) 102e113

Javed M.M., Zahoor S., Shafaat S., Mehmooda I., Gul A., Rasheed H., Bukhari S.A.I., Aftab M.N. Wheat bran as a brown gold: Nutritious value and its biotechnological applications. Afr. J. Microbiol. Res. 2012;6:724–733. doi: 10.5897/AJMR11.035.

Jensen M.K., Koh-Banerjee P., Hu F.B., Franz M., Sampson L., Gronbaek M., Rimm E.B. Intakes of whole grains, bran, and germ and the risk of coronary heart disease in men. Am. J. Clin. Nutr. 2004;80:1492–1499. doi: 10.1093/ajcn/80.6.1492

Katileviciute A, Plakys G, Budreviciute A, Onder K, Damiati S, Kodzius R. A Sight to Wheat Bran: High Value-Added Products. Biomolecules. 2019 Dec 17;9(12):887. doi: 10.3390/biom9120887. PMID: 31861140; PMCID: PMC6995506.

Lakabi-Ioualitene, D. ; Lounaouci-Ouyed, G. ; M. ; B. ; Lebas, F. ; Fortun-Lamothe, L., 2008. The effects of the complete replacement of barley and soybean meal with hard wheat by-products on diet digestibility, growth and slaughter traits of a local Algerian rabbit population. World Rabbit Sci., 16 (2): 99-106

Lebas, F. ; Tinel, B. ; Loupiac, B., 1984. Survey of commercial rabbit feeds. Relations between components. Cuniculture, 8 (5): 240-244

Lebas, F.; Renouf, B., 2009. Raw materials utilization and feeding techniques: new contributions in the 9th World Rabbit Congress. Journée d'étude ASFC « Vérone - Ombres & Lumières » 5 février 2009: 30-36

Lounaouci-Ouyed, G. ; Berchiche, M. ; Gidenne T., 2011. Effects of incorporation of high levels (50-60%) of hard wheat bran on mortality, digestibility, growth and body composition of rabbits of white population under Algerian conditions of production. In Proc. 14èmes Journ. Rech. Cunicole, 22-23 Novembre 2011, Le Mans, France: 13-16

Lounaouci-Ouyed, G. ; Berchiche, M. ; Lebas F., 2012. Effects of gradual incorporation (40 to 60%) of hard wheat bran, in simplified bran-alfalfa-maize diets, on viability, growth and slaughter traits of rabbits of white population under Algerian context. In Proc. 10th World Rabbit Congress, 3-6 September 2012, Sharm El-Sheikh, Egypt: 903-907

M. A. Neves, Toshinori Kimura, N. Shimizu, K. Shiiba Production of alcohol by simultaneous saccharification and fermentation of low-grade wheat flour

M.L. Sudha et al. 2007 Influence of fibre from different cereals on the rheological characteristics of wheat flour dough and on biscuit quality Food Chemistry

Marco Spaggiari, Annalisa Ricci, Luca Calani, Letizia Bresciani, Erasmo Neviani, Chiara Dall'Asta, Camilla Lazzi, Gianni Galaverna, Solid state lactic acid fermentation: A strategy to improve wheat bran functionality, LWT,Volume 118,2020,108668,ISSN 0023-6438,https://doi.org/10.1016/j.lwt.2019.108668.

Meunier-Salaün, M. C. ; Edwards, S. A. ; Robert, S., 2001. Effect of dietary fibre on the behaviour and health of the restricted fed sow. Anim. Feed. Sci. Technol., 90 (1-2): 53-69, https://doi.org/10.1016/S0377-8401(01)00196-1

Noblet, J.; Sève, B.; Jondreville, C., 2002. Valeur nutritive pour le porc. In: Tables de composition et de valeur nutritive des matières premières destinées aux animaux d'élevage (Eds. Sauvant, D., Perez J. M., Tran, G.), p. 301, INRA-AFZ, Paris

Onipe OO, Ramashia SE, Jideani AIO. Wheat Bran Modifications for Enhanced Nutrition and Functionality in Selected Food Products. Molecules. 2021 Jun 26;26(13):3918. doi: 10.3390/molecules26133918. PMID: 34206885; PMCID: PMC8271396.

Palmarola-Adrados B., Choteborska P., Galbe M., Zacchi G. Ethanol production from non-starch carbohydrates of wheat bran. Bioresour. Technol. 2005;96:843–850. doi: 10.1016/j.biortech.2004.07.004.

Parigi-Bini, R. ; Cinetto, M. ; Carotta, N., 1984. Digestibility and nutritive value of Leucaena leucocephala in growing rabbits. 3rd World Rabbit Congress, Rome, 1: 399-407

Pasqualone A., Delvecchio L.N., Gambacorta G., Laddomada B., Urso V., Mazzaglia A., Ruisi P., di Miceli G. Effect of supplementation with wheat bran aqueous extracts obtained by ultrasound-assisted technologies on the sensory properties and the antioxidant activity of dry pasta. Nat. Prod. Commun. 2015

Ramonet, Y. ; Meunier-Salaün, M. C. ; Dourmad, J. Y., 1999. High-fiber diets in pregnant sows : digestive utilization and effects on behavior of the animals. J. Anim. Sci., 77 (3): 591-599

Rawan Zeitoun. Procédés de fractionnement de la matière végétale : application à la production des polysaccharides du son et de la paille de blé. Autre. Institut National Polytechnique de Toulouse - INPT, 2011. Français. ffNNT : 2011INPT0017ff. fftel-04231153

Reddy B.S., Hirose Y., Cohen L.A., Simi B., Cooma I., Rao C.V. Preventive potential of wheat bran fractions against experimental colon carcinogenesis: Implications for human colon cancer prevention. Cancer Res. 2000;60:4792–4797.

Robinson, K. L. ; Cheeke, P. R. ; Kelly, J. D. ; Patton, N. M., 1986. Effect of fine grinding and supplementation with hay on the digestibility of wheat bran by rabbits. J. Appl. Rabbit Res., 9 (4): 166-167

Saulnier, L., Marot, C., Chanliaud, E., Thibault, J.F., 1995. Cell wall polysaccharide interactions in maize bran. Carbohydrate Polymers, 26, 279-287

Sibakov J, ... Poutanen k, in Fibre-Rich and Wholegrain Foods, 2013

Sindhu R., Suprabha G.N., Shashidhar S. Purification and characterization of α-amylase from Penicillium janthinellum (NCIM 4960) and its application in detergent industry. Afr. J. Microbiol. Res. 2009;3:498–503

Singh, P. ; Pathak, N. N. ; Biswas, J. C., 1997. Performance of broiler rabbit (Soviet Chinchilla * Grey Giant) fed low grain concentrate. World Rabbit Science, 6 (2): 223-225

Statbel

Terpou A., Bekatorou A., Kanellaki M., Koutinas A.A., Nigam P. Enhanced probiotic viability and aromatic profile of yogurts produced using wheat bran (Triticum aestivum) as cell immobilization carrier. Process Biochem. 2017;55:1–10. doi: 10.1016/j.procbio.2017.01.013

Villamide, M. J. ; De Blas, J. C. ; Carabano, R., 1989. Nutritive value of cereal by-products for rabbits. 2. Wheat bran, corn gluten feed and dried distillers grains and solubles. J. Appl. Rabbit Res., 12 (3): 152-155

Wen Cheng;Yujie Sun;Mingcong Fan;Yan Li;Li Wang;Haifeng Qian; (2021). Wheat bran, as the resource of dietary fiber: a review . Critical Reviews in Food Science and Nutrition, (), –. doi:10.1080/10408398.2021.1913399

Wheat Food Councils, How Flour is Milled, https://www.wheatfoods.org/how-flour-is-milled/

5. ANNEX

5.1. Questionnaires

5.1.1. Questionnaire 1 (to project partners): Selection of biomass and by-products for further analysis

The purpose of this questionnaire is to identify the by-products issued from the value chains (VCs) previously identified where the partnership has an interest to push further the analysis and explore innovative valorisations.

Considering the constraints in terms of time and resources available, the scope of our research must be narrowed. Thus, the questions below will help INA staff to collect the interests of each partner, compare the replies and propose a reasonable number of by-products to explore.

In order to proceed with a first selection, please provide us with your replies by the end of September. In case more by-products are identified per VC and it is not possible to propose a common solution, INA will come back to the partners involved in the same VC to find an agreement.

1. Select/Highlight the 2 VCs that are the most interesting for your clusterse/enterprises.
   A. Apple
   B. Dairy
   C. Grapes wine & Winemaking
   D. Wheat bran
   E. Brewery's Spent Grain
   F. Stone fruits
2. For every VC selected, please let us know THE by product which you would like to explore
3. For every by-product, please let us know its origin in the value chain

(If it is issued from an industrial process, please let us know the type)

4. For every by-product selected, what motivates your choice? Please elaborate (ex. Volume of by product available in your region/enterprises; added value; technological constraints etc.)
5. For every by-product selected, what is its current use? What possible types of valorisation have your already identified? Please elaborate
6. For every by-product selected, what are the constraints to its valorisation? Please elaborate *(ex. Technological, legislative, economic, etc.)*

5.1.1.1. Questionnaire 2 (to VCs actors): Contribution to market studies from regional VC actors

Brewery's spent grains

Project partner organization	
VC	Brewery's spent grains
By-product	malt bagasse

The purpose of this document is to drive your contribution to the market study and VC report on "Brewery's spent grains", as well as to provide guidance on the information to collect from your VC members.

The document is split in 3 parts

- Section 1: Context information about the Brewery's spent grains VC
- Section 2: questionnaire for business representatives/enterprises
- Section 3: questionnaire for Research organizations/TTO/technical centres

We aim to collect as much information as possible from all possible sources. So, if you already have the information to any of the questions we imagined for the enterprises and/or technical centres, just share it with us and skip the question during the interview.

i. Section 1: Context information about the Brewery's spent grains VC and apple pomace

As agreed during the SC meeting, the update of the market study every VC report will include a specific section to provide a presentation of the regional context of the VC and relative by product. The intent of this section will be to provide the reader with a general overview of each region that chose to work on the Brewery's spent grains VC and contextualize the choice of working on this particular by-product.

The intent is not to be exhaustive as regional sections will be short (we expect between one-two pages max). So, for instance, if you have no data on the overall turnover, just skip it and try to provide different data to let us understand how important is wheat bran from the economic point of view in your region.

The type of data/information we are looking for, are:

- National and/or regional production of barley for beer production + imports of barley for beer production. In case different grains are used for beer production, please provide similar information
- Overall trends in terms of barley malt production and subsequent beer production in the past 5 years (is it shrinking? Is it increasing?)
- number and type of regional breweries (are there more large enterprises or small enterprises?) what is the overall turnover generated at regional level ? what is the average trend in the past 5 years?
- What are the existing projects in terms of brewery's spent grain valorisation, with a focus on malt bagasse? (please give us a short description for each process identified)

We believe that section 1 can be completed by the cluster partner, with overall data issued from desk research. However, if you are not able to cover all the data, you can always address some of the questions above to your companies, to get an estimation.

Context information

ii. Section 2: questionnaire for enterprises

The intent of this section is to guide your interviews to companies processing brewery's spent grains.

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below. If companies are not ready to share all the data we ask, try to get estimations or just drop the question.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather the testimonies of at least 2 different companies.

Please fill one table for each interview you perform

General information	
Name of company*	
Type and size of organization*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
Does your production of brewery spent grains (relative to total residues) align with the average 85% we found in the literature? (i.e. 85% of your residues are brewery spent grains). If different, please share your experience	
What are the ingredients/molecules of brewery spent grains that you are able to valorise (if any) ? Try to quantify how much they represent with respect to the initial product (i.e. we are looking to understand how much of the residue your are able to valorise VS the final loss)	
Are there any additional by-products of your brewery process? If so, are you able to valorise them and how Try to quantify how much they represent with respect to the initial product (i.e. we are looking to understand how much of the residue you are able to valorise VS the final loss). The partnership has already identified the following types of valorization: • Feed • Energy (biogas and biochar) • Food (Flour) • Cosmetics	

• Packaging and paper What is/are the most interesting ones for your company? Why? Did you know about all the types of valorisation mentioned? Are they relevant, in your opinion, for your company/ your region? (If yes, which ones? If not, why? Would you be interested in exploring any of the different types mentioned? Are you aware of any additional way of valorisation which you would be interested to explore?	
What is the final product loss for brewery-spent grans? How much does it represent in terms of turnover?	
What are the obstacles to the valorisation of the product losses? (for every obstacle identified, please ask to elaborate the reply, and order by their perceived importance)	
Additional comments, remarks, etc	
*compulsory information	

iii. Section 3: questionnaire for research organizations/TTO/technical centres

The intent of this section is to guide your interviews to research organizations/TTO/technical centres

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather at least one testimony for this type of public

Please fill one table for each interview you perform

General information	
Name of organization*	
Type*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	

What are the major research axes in the valorisation of brewery spent grains? Why research is oriented there? Who are the regional actors you collaborate with on these topics? Are there any other actors at national/European level you collaborate with on these topics? Please, ask to elaborate the replies	
What are the major molecules of brewery spent grains (if from multiple grains, please detail the molecule/ per grain)? What are the potential applications of such molecules (cosmetics, nutritional ingredients, energy..?) ? Please, ask to elaborate the replies.	
What are the challenges faced by the valorisation of brewery spent grains? (technical, legal, economic..) Please, ask to elaborate the replies.	
Additional comments, remarks, etc	
*compulsory information	

Diary and cheese whey

Project partner organization	
VC	Dairy
By-product	Cheese whey

The purpose of this document is to drive your contribution to the market study and VC report on "Diary", as well as to provide guidance on the information to collect from your VC members.

The documents is split in 3 parts

- Section 1: Context information about the Dairy VC
- Section 2: questionnaire for business representatives/enterprises
- Section 3: questionnaire for Research organizations/TTO/technical centres

We aim to collect as much information as possible from all possible sources. So, if you already have the information to any of the questions we imagined for the enterprises and/or technical centres, just share it with us and skip the question during the interview.

i. Section 1: Context information about the Dairy VC and cheese whey

As agreed during the SC meeting, the update of the market study every VC report will include a specific section to provide a presentation of the regional context of the VC and relative by product. The intent of this section will be to provide the reader with a general overview of each region that chose to work on the Dairy VC and contextualize the choice of working on cheese whey.

The intent is not to be exhaustive as regional sections will be short (we expect between one-two pages max). So, for instance, if you have no data on the overall turnover, just skip it and try to provide different data to let us understand how important is cheese whey from the economic point of view in your region.

Please note that we will focus our initial investigation on cheese not made with cheese whey (i.e. the production of cheeses like ricotta, anthotyros, mató, xynonizithra, manouri are outside the scope of the preliminary market research)

The type of data/information we are looking for, are:

- National and/or regional production of milk and cheese (not made with cheese whey), with differentiation according to type of milk (cow, sheep, goat); Overall trends over the past 5 years (is production shrinking? Is it increasing?)
- number and type of regional cheese (not made with cheese whey), producers (are there more large enterprises or small enterprises?) what is the overall turnover generated at regional level ? what is the average trend in the past 5 years?
- What are the existing projects in terms of valorisation of cheese (not made with cheese whey) production by-products? How is cheese whey optimized? (please give us a short description for each process identified)

We believe that section 1 can be completed by the cluster partner, with overall data issued from a desk research. However, if you are not able to cover all the data, you can always address some of the questions above to your companies, to get an estimation.

Context information

ii. Section 2: questionnaire for enterprises

The intent of this section is to guide your interviews to companies processing milk for cheese (not made with cheese whey).

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below. If companies are not ready to share all the data we ask, try to get estimations or just drop the question.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather the testimonies of at least 2 different companies.

Please fill one table for each interview you perform

General information	
Name of company*	
Type and size of organization*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO

Questions	
What is the average volume of cheese whey obtained from your original cheese production?	
Do you subsequently use the leftover cheese whey for the production of new cheese? If so, do you still have any remaining cheese whey? If yes, what is that remaining volume? (i.e. we are looking to understand how much of the residue you are able to valorise VS the final loss)	
What is the "animal" origin of your cheese whey (cow, sheep, goat, mix?) Today, how do you optimize your residual cheese whey?	
The partnership have already identified the following types of valorization: • Food (for cheese production) – is there any other cheese whey-based final product that you have already explored? • Nutritional supplements • Feed • Soil fertilizer What is/are the most interesting ones for your company? Why? Did you know about all the types of valorisation mentioned? Are they relevant, in your opinion, for your company/ your region? If yes, which ones? If not, why? Would you be interested in exploring any of the different types mentioned? Are you aware of any additional way of valorisation which you would be interested to explore?	
What is the final cheese whey product loss? How much does it represent in terms of turnover?	
What are the obstacles to the valorisation of the product losses? (for every obstacle identified, please ask to elaborate the reply, and order by their perceived importance)	
Additional comments, remarks, etc	

*compulsory information

iii. Section 3: questionnaire for research organizations/TTO/technical centres

The intent of this section is to guide your interviews to research organizations/TTO/technical centres

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather at least one testimony for this type of public

Please fill one table for each interview you perform

General information	
Name of organization*	
Type*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
What are the major research axes in the valorisation of cheese whey? Why research is oriented there? Who are the regional actors you collaborate with on these topics? Are there any other actors at national/European level you collaborate with on these topics? Please, ask to elaborate the replies	
What are the major molecules of cheese whey (if from multiple animal sources, please detail the breakdown per animal)? What are the potential applications of such molecules (nutritional ingredients, energy..?) Please, ask to elaborate the replies.	
What are the challenges faced by the valorisation of cheese whey? (technical, legal, economic..) Please, ask to elaborate the replies.	
Additional comments, remarks, etc	
*compulsory information	

Grapes and winemaking

Project partner organization	
VC	Grapes and winemaking
By-product	pomace

The purpose of this document is to drive your contribution to the market study and VC report on “Grape and winemaking”, as well as to provide guidance on the information to collect from your VC members.

The document is split in 3 parts:

- Section 1: Context information about the Grapes and winemaking VC and the selected by-product, grape pomace
- Section 2: questionnaire for business representatives/enterprises
- Section 3: questionnaire for Research organizations/TTO/technical centres

We aim to collect as much information as possible from all possible sources. So, if you already have the information to any of the questions we imagined for the enterprises and/or technical centres, just share it with us and skip the question.

i. Section 1: Context information about the Apple VC and apple pomace

As agreed during the SC meeting, the update of the market study every VC report will include a specific section to provide a presentation of the regional context of the VC and relative by product.

The intent of this section will be to provide the reader with a general overview of each region that chose to work on the apple VC and contextualize the choice of working on this particular biomass and relative by-product.

The intent is not to be exhaustive as regional sections will be quite short (we expect 1-2 pages max). So, for instance, if you have no data on the extension of the vineyards surface area, just skip it and try to provide different data to let us understand how important the commercial growing of grapes is in your region.

The type of data/information we are looking for, are:

Concerning grape growing (production) and harvest

- National and/or regional production of grapes (tonnes) ;
- Overall trends in terms of production in the past 5 harvests (is it shrinking? Is it increasing?)
- Regional vineyards surface area (ha) and possibly, its evolution in the past 5 years (general trends are fine)
- number and type of regional grape producers and winemakers (are there more large exploitations or small farmers?) what is the overall turnover generated at regional level ? what is the average trend in the past 5 years?

Concerning winemaking

- How many wine producers do you have in your region? What is the wine production (hectolitres) in your region?
- What are the existing by-projects of winemaking that you have already identified (ex. Wine sediments, which molecules are used in the cosmetic sector for instance, etc) (please give us a short description for each process identified)
- What are the existing projects in terms of grape pomace valorisation? (ex. Recovery of bioactive molecules, such as polyphenols, flavonoids, tannins, etc) (please give us a short description for each process identified)

We believe that section 1 can be completed by the cluster partner, with overall data issued from a desk research. However, if you are not able to cover all the data, you can always address some of the questions above to your companies, to get an estimation.

Context information

ii. Section 2: questionnaire for enterprises

The intent of this section is to guide your interviews to companies dealing with grape pomace (winemakers, distillery plants, labs/enterprises specialized in the extraction of molecules from grape pomace, etc.).

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below. We tested the questionnaire ourselves already twice, and we observed that not all the companies are ready to share all the data we ask. If this happens, ask for estimations or just drop the question.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather the testimonies of at least 2 different companies.

Please fill one table for each interview you perform

General information	
Name of company*	
Type and size of organization*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
How much does grape pomace represent with respect to the initial weight of grape? (in other words, for instance, out of 1 tonne of grape, what is % of grape pomace ? (an estimation is fine)	
What are the other ingredients/by-products of **grape** that you are able to valorise (if any) ? Try to quantify how much they represent with respect to the initial weight of grape	
What are the ingredients/by-products of **grape pomace** that you are able to valorise (if any) ? Try to quantify how much they represent with respect to the initial weight of grape pomace	

What initiatives have already been undertaken to valorize the grape pomace? (ex. Target a new sector? Adopt new technologies to reduce the by-product?	
What is the final grape product loss ? what is the part of grape pomace that you are **not** able to value? How much does it represent in terms of weight and/or turnover?	
What are the obstacles/challenges to the valorisation of the product losses? (for every obstacle identified, please ask to elaborate the reply)	
Additional comments, remarks, etc	
*compulsory information	

iii. Section 3: questionnaire for research organizations/TTO/technical centres

The intent of this section is to guide your interviews to research organizations/TTO/technical centres

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather at least one testimony for this type of public

Please fill one table for each interview you perform

General information	
Name of organization*	
Type*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
What are the by-products issued by grape on which you work on?	
What are the main elements of grape pomace? What its chemical composition of grape pomace? What are the major molecules? What are the potential	

applications of such molecules (cosmetics, nutritional ingredients, pharma?)? Please, ask to elaborate the replies.	
What are the major research axes in this concerning the valorisation of grape pomace ? Who are the regional actors you collaborate with on these topics? Are there any other actors at national/European level you collaborate with on these topics? Please, ask to elaborate the replies	
What are the challenges faced by the valorisation of grape pomace in the next 5 years (ex. biomass availability, technological constraints ? Please, ask to elaborate the replies.	
Additional comments, remarks, etc	
*compulsory information	

Apple

Project partner organization	
VC	Apple
By-product	Apple pomace

The purpose of this document is to drive your contribution to the market study and VC report on “Apple”, as well as to provide guidance on the information to collect from your VC members.

The document is split in 3 parts:

- Section 1: Context information about the Apple VC and the selected by-product, apple pomace
- Section 2: questionnaire for business representatives/enterprises
- Section 3: questionnaire for Research organizations/TTO/technical centres

We aim to collect as much information as possible from all possible sources. So, if you already have the information to any of the questions we imagined for the enterprises and/or technical centres, just share it with us and skip the question.

i. Section 1: Context information about the Apple VC and apple pomace

As agreed during the SC meeting, the update of the market study every VC report will include a specific section to provide a presentation of the regional context of the VC and relative by product. The intent of this section will be to provide the reader with a general overview of each region that chose to work on the apple VC and contextualize the choice of working on this particular biomass and relative by-product.

The intent is not to be exhaustive as regional sections will be quite short (we expect 1-2 pages max). So, for instance, if you have no data on the extension of the commercial apple *orchard* surface *area*, just skip it and try to provide different data to let us understand how important is the commercial growing of apples in your region.

The type of data/information we are looking for, are:

Concerning apple growing (production) and harvest

- National and/or regional production of apples (tonnes) ;
- Overall trends in terms of production in the past 5 harvests (is it shrinking? Is it increasing?)
- Regional commercial apple orchard surface area (ha) and possibly, its evolution in the past 5 years (general trends are fine)
- number and type of regional apple producers (are there more large exploitations or small farmers?) what is the overall turnover generated at regional level ? what is the average trend in the past 5 years?

Concerning apple processing

- What are the types of apple processing processes existing in your region? (ex. Cider? Juice? Pomace? Etc) What are the major apple production process? what is the importance of each one? (ex. X % of Juice; Y% of cider, etc)
- How many apple processing enterprises do you have in your region?
- What are the existing projects in terms of apple valorisation? (ex. Apple pomace valorization as flour, etc) (please give us a short description for each process identified)

We believe that section 1 can be completed by the cluster partner, with overall data issued from a desk research. However, if your are not able to cover all the data, you can always address some of the questions above to your companies, to get an estimation.

Context information

ii. Section 2: questionnaire for enterprises

The intent of this section is to guide your interviews to apple processing companies.

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below. We tested the questionnaire ourselves already twice, and we observed that not all the companies are ready to share all the data we ask. If this happens, ask for estimations or just drop the question.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather the testimonies of at least 2 different companies.

Please fill one table for each interview you perform

General information	
Name of company*	
Type and size of organization*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO

Questions	
How much does it represent the apple pomace with respect to the apple (in other words, for instance, for every kg of apple, what is the % of apple pomace ? (an estimation is fine)	
What are the other ingredients/by-products of apple that you are able to valorise (if any) ? Try to quantify how much they represent with respect to the initial product	
What are the ingredients/by-products of apple pomace that you are able to valorise (if any) ? Try to quantify how much they represent with respect to the initial product (apple pomace)	
What is the final apple product loss ? How much does it represent in terms of weight and/or turnover?	
What are the obstacles to the valorisation of the product losses? (for every obstacle identified, please ask to elaborate the reply)	
What initiatives have already been undertaken to valorize the apple pomace? (ex. Target a new sector? Adopt new technologies to reduce the by-product?)	
What are the main challenges for the future valorisation of apple by-products, and notably the apple pomace? (R&D? new technologies? Supply?) (please elaborate the reply)	
Additional comments, remarks, etc	
*compulsory information	

iii. Section 3: questionnaire for research organizations/TTO/technical centres

The intent of this section is to guide your interviews to research organizations/TTO/technical centres

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather at least one testimony for this type of public

Please fill one table for each interview you perform

General information	
Name of organization*	
Type*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
What are the by-products issued by apple on which you work ?	
What are the major research axes in this concerning the valorization of apple pomace ? Who are the regional actors you collaborate with on these topics? Are there any other actors at national/European level you collaborate with on these topics? Please, ask to elaborate the replies Please, ask to elaborate the replies.	
What is the chemical composition of apple pomace? What are the major molecules? What are the potential applications of such molecules (cosmetics, nutritional ingredients, pharma?)? Please, ask to elaborate the replies.	
What are the challenges faced by the valorisation of apple pomace in the next 5 years (ex. biomass availability, technological constraints ? Please, ask to elaborate the replies.	
Additional comments, remarks, etc	
*compulsory information	

Dairy

Project partner organization	
VC	Dairy
By-product	Cheese whey

The purpose of this document is to drive your contribution to the market study and VC report on “Dairy”, as well as to provide guidance on the information to collect from your VC members.

The document is split in 3 parts

- Section 1: Context information about the Dairy VC
- Section 2: questionnaire for business representatives/enterprises
- Section 3: questionnaire for Research organizations/TTO/technical centres

We aim to collect as much information as possible from all possible sources. So, if you already have the information to any of the questions we imagined for the enterprises and/or technical centres, just share it with us and skip the question during the interview.

i. Section 1: Context information about the Dairy VC and cheese whey

As agreed during the SC meeting, the update of the market study every VC report will include a specific section to provide a presentation of the regional context of the VC and relative by product. The intent of this section will be to provide the reader with a general overview of each region that chose to work on the Dairy VC and contextualize the choice of working on cheese whey.

The intent is not to be exhaustive as regional sections will be short (we expect between one-two pages max). So, for instance, if you have no data on the overall turnover, just skip it and try to provide different data to let us understand how important is cheese whey from the economic point of view in your region.

Please note that we will focus our initial investigation on cheese not made with cheese whey (i.e. the production of cheeses like ricotta, anthotyros, mató, xynonizithra, manouri are outside the scope of the preliminary market research)

The type of data/information we are looking for, are:

Concerning

- National and/or regional production of milk and cheese (<u>not made with cheese whey</u>), with differentiation according to type of milk (cow, sheep, goat); Overall trends over the past 5 years (is production shrinking? Is it increasing?)
- number and type of regional cheese (<u>not made with cheese whey</u>), producers (are there more large enterprises or small enterprises?) what is the overall turnover generated at regional level ? what is the average trend in the past 5 years?
- What are the existing projects in terms of valorisation of cheese (<u>not made with cheese whey</u>) production by-products? How is cheese whey optimized? (please give us <u>a short description</u> for each process identified)

We believe that section 1 can be completed by the cluster partner, with overall data issued from a desk research. However, if you are not able to cover all the data, you can always address some of the questions above to your companies, to get an estimation.

Context information

ii. Section 2: questionnaire for enterprises

The intent of this section is to guide your interviews to companies processing milk for cheese (<u>not made with cheese whey</u>).

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below. If companies are not ready to share all the data we ask, try to get estimations or just drop the question.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather the testimonies of at least 2 different companies.

Please fill one table for each interview you perform

General information	
Name of company*	
Type and size of organization*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
What is the average volume of cheese whey obtained from your original cheese production?	
Do you subsequently use the leftover cheese whey for the production of new cheese? If so, do you still have any remaining cheese whey? If yes, what is that remaining volume? (i.e. we are looking to understand how much of the residue you are able to valorise VS the final loss)	
What is the “animal” origin of your cheese whey (cow, sheep, goat, mix?) Today, how do you optimize your residual cheese whey?	
The partnership has already identified the following types of valorization: • Food (for cheese production) – is there any other cheese whey-based final product that you have already explored? • Nutritional supplements • Feed • Soil fertilizer What is/are the most interesting ones for your company? Why? Did you know about all the types of valorisation mentioned? Are they relevant, in your opinion, for your company/ your region? If yes, which ones? If not, why? Would you be interested in exploring any of the different types mentioned? Are you aware of any additional way of valorisation which you would be interested to explore?	
What is the final cheese whey product loss? How much does it represent in terms of turnover?	
What are the obstacles to the valorisation of the product losses? (for every obstacle identified,	

please ask to elaborate the reply, and order by their perceived importance)	
Additional comments, remarks, etc	
*compulsory information	

iii. Section 3: questionnaire for research organizations/TTO/technical centres

The intent of this section is to guide your interviews to research organizations/TTO/technical centres

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather at least one testimony for this type of public

Please fill one table for each interview you perform

General information	
Name of organization*	
Type*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
What are the major research axes in the valorisation of cheese whey? Why research is oriented there? Who are the regional actors you collaborate with on these topics? Are there any other actors at national/European level you collaborate with on these topics? Please, ask to elaborate the replies	
What are the major molecules of cheese whey (if from multiple animal sources, please detail the breakdown per animal)? What are the potential applications of such molecules (nutritional ingredients, energy..?) Please, ask to elaborate the replies.	
What are the challenges faced by the valorisation of cheese whey? (technical, legal, economic..) Please, ask to elaborate the replies.	
Additional comments, remarks, etc	

*compulsory information

Wheat bran

Project partner organization	
VC	Wheat bran
By-product	Wheat bran

The purpose of this document is to drive your contribution to the market study and VC report on "Wheat bran", as well as to provide guidance on the information to collect from your VC members.

The document is split in 3 parts

- Section 1: Context information about the Wheat bran VC
- Section 2: questionnaire for business representatives/enterprises
- Section 3: questionnaire for Research organizations/TTO/technical centres

We aim to collect as much information as possible from all possible sources. So, if you already have the information to any of the questions we imagined for the enterprises and/or technical centres, just share it with us and skip the question during the interview.

i. Section 1: Context information about the Apple VC and apple pomace

As agreed during the SC meeting, the update of the market study every VC report will include a specific section to provide a presentation of the regional context of the VC and relative by product. The intent of this section will be to provide the reader with a general overview of each region that chose to work on the wheat bran VC and contextualize the choice of working on this particular by-product.

The intent is not to be exhaustive as regional sections will be short (we expect between one-two pages max). So, for instance, if you have no data on the overall turnover, just skip it and try to provide different data to let us understand how important is wheat bran from the economic point of view in your region.

The type of data/information we are looking for, are:

- National and/or regional production of milling/flour production + wheat bran (if data for the latter exists) (tonnes) ;
- Overall trends in terms of milling/flour production + wheat bran in the past 5 years (is it shrinking? Is it increasing?)
- number and type of regional milling/flour producers + wheat bran (are there more large enterprises or small enterprises?) what is the overall turnover generated at regional level ? what is the average trend in the past 5 years?
- Can you detail the industrial process which generates wheat bran ?
- What are the existing projects in terms of wheat bran valorisation? (please give us a short description for each process identified)

We believe that section 1 can be completed by the cluster partner, with overall data issued from a desk research. However, if your are not able to cover all the data, you can always address some of the questions above to your companies, to get an estimation.

Context information

ii. Section 2: questionnaire for enterprises

The intent of this section is to guide your interviews to companies processing wheat bran.

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below. If companies are not ready to share all the data we ask, try to get estimations or just drop the question.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather the testimonies of at least 2 different companies.

Please fill one table for each interview you perform

General information	
Name of company*	
Type and size of organization*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
How much does wheat bran represent with respect to the flour (original product) (in other words, for instance, for every tons of flours, what is the % of wheat bran ? (an estimation is fine)	
What are the ingredients of wheat bran that you are able to valorise (if any) ? Try to quantify how much they represent with respect to the initial product	
How wheat bran is valorized today by your company? The partnership have already identified the following types of valorization: • Feed • Energy • Flour • Food (fiber supplement), use in insect production What is/are the most interesting ones for your company? Why? Did you know about all the types of valorisation mentioned? Are they relevant, in your opinion, for your company/ your region? (If yes, which ones? If not, why? Would you be interested in exploring any of the different types mentioned?	

Are you aware of any additional way of valorisation which you would be interested to explore?	
What is the final product loss for wheat bran ? How much does it represent in terms of weight and/or turnover?	
What are the obstacles to the valorisation of the product losses? (for every obstacle identified, please ask to elaborate the reply)	
Additional comments, remarks, etc	
*compulsory information	

iii. Section 3: questionnaire for research organizations/TTO/technical centres

The intent of this section is to guide your interviews to research organizations/TTO/technical centres

You can decide to interview your members in written, by phone, in person, etc. In our opinion, the best way to gather quality information, is to establish a bilateral talk, where you try to gather as much information as possible on the topics mentioned below.

While there is not a precise number of interviews/per partner to achieve, we recommend to gather at least one testimony for this type of public

Please fill one table for each interview you perform

General information	
Name of organization*	
Type*	
Agreement to be mentioned in the VC report that will be shared with the EC and project partners *	YES/NO
Questions	
What are the major research axes in the valorisation of wheat bran? Why research is oriented there? Who are the regional actors you collaborate with on these topics? Are there any other actors at national/European level you collaborate with on these topics? Please, ask to elaborate the replies Please, ask to elaborate the replies.	
What is the chemical composition of what bran? What are the major molecules? What are the potential applications of such molecules (cosmetics, nutritional ingredients, pharma?) ? Please, ask to elaborate the replies.	

What are the challenges faced by the valorisation of wheat bran? (technical, legal, economic..) Please, ask to elaborate the replies.	
Additional comments, remarks, etc	
*compulsory information	