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Review

Bridging the Implementation Gap between Pomace Waste and Large-Scale Baker's Yeast Production

Josipa Lisičar Vukušić, Thomas Millenautzki and Stéphan Barbe *

Faculty of Applied Natural Sciences, Technische Hochschule Köln, Campus Leverkusen, Campuspl. 1, 51379 Leverkusen, Germany
* Correspondence: stephan.barbe@th-koeln.de

Abstract: The objectives set in the European Green Deal constitute the starting point of this review, which then focuses on the current implementation gap between agro-industrial wastes as resources for large-scale bioprocesses (e.g., baker's yeast, bioethanol, citric acid, and amino acids). This review highlights the current lack of sustainability of the post-harvest processing of grapes and apples. In light of the European Green Deal, industrial biotechnology often lacks sustainability as well. We reviewed the recent progress reported in the literature to enhance the valorization of grape and apple pomace and the current failure to implement this research in technical processes. Nevertheless, selected recent papers show new perspectives to bridge this gap by establishing close collaborations between academic teams and industrial partners. As a final outcome, for the first time, we drew a circular flow diagram that connects agriculture post-harvest transformation with the industrial biotechnology and other industries through the substantial valorization of apple and grape pomace into renewable energy (solid biofuels) and sugar extracts as feedstock for large-scale bioprocesses (production of baker's yeast industry, citric acid, bioethanol and amino acids). Finally, we discussed the requirements needed to achieve the successful bridging of the implementation gap between academic research and industrial innovation.

Keywords: European Green Deal; apple pomace; grape pomace; industrial biotechnology; feedstock; agro-industrial wastes; sustainability; circular economy

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1. Introduction

In December 2019, the European Union (EU) introduced the European Green Deal (EGD) as a paradigm shift in environmental and climate policy [1]. It represents the EU's most serious action to reach climate neutrality by 2050. Pressure is currently increasing to reduce the abstraction of water and resources from our ecosystem and the release of emissions in to the environment. In this context, Europe aims to become the leader in clean products and technologies, as well as to ensure a just and inclusive transition [2]. The EGD's main objective is achieving net carbon neutrality within the European Union by 2050 and disassociating the economic growth from resource consumption. This deal refers to a general policy strategy, outlining the ambitions and goals in different policy sectors. The EGD must be understood as an approach to solve the existing implementation gap between scientific progress and European actions. In order for this new policy to be timely implemented, existing regulations and standards from the following eight areas are now subject to profound revisions and new policies are already in place. The EGD focuses on these eight areas [3,4]:

(1) Climate neutral Europe; introducing the European Climate Law with the goal of reducing the greenhouse gas emissions;
(2) Clean energy transition by securing an affordable energy supply, developing a new energy market and prioritizing energy efficiency;
(3) New industrial strategies to promote a sustainable and circular economic model;

(4) Energy and resource efficiency in construction and renovating;
(5) Transition towards sustainable and smart transportation;
(6) Reaching a pollution-free environment with zero toxicity;
(7) "Farm to fork strategy"—environmentally sustainable food system;
(8) Conserving and re-establishing ecosystems and biodiversity.

Overall, the EGD represents a set of targets, intentions, and objectives tackling Europe's many environmental and climate-related challenges that will be implemented over the next ten years. The COVID-19 crisis has affected the EGD by drawing resources and attention away from environmental crises to some extent. However, the commitment to the EGD and the green transformation remains high [3].

The EGD's research area "Farm to fork strategy" aims to create guidelines for an environmentally sustainable food system. Among these goals is a target to reduce food waste [5]. It represents a critical issue, due to its large quantity, therefore creating insecurity in food supply chain. There is contamination of water sources, air, and soil occurring due to practices such as direct dumping on landfills as well as burning. Improper handling, technological issues, and consumer behavior result in approximately one-third of the world's total food production turning into waste. It is estimated that approximately 1300 million tons of food is wasted annually worldwide due to the processing methods, inadequate storage handling, harvesting, climate influence and consumer behavior [6]. The largest share of approximately 50% refers to fruit and vegetable processing waste. This waste is usually disposed without being previously processed, which results in the environmental pollution. Nevertheless, numerous research topics covered the analyses of these wastes and the results indicate they are a good source of fiber, minerals, vitamins and bioactive compounds [6].

The present contribution focuses on lack of sustainability development in the large-scale process, such as industrial baker's yeast production and depicts recent advances achieved in sustainable valorization of waste originating from agricultural activities such as apple juice and wine production. This review is aiming to draft a circular economy approach and providing a way to achieve sustainable connections between the different industries.

2. Recent Advances in Sustainable Valorization of Apple and Grape Pomace as Problematic Agro-Industrial Wastes

In the last decade, efforts have been made trying to valorize agro-industrial wastes. This review focuses on grape pomace (by-product in winemaking), apple pomace (by-product in the production of apple juice) and the research made in the frame of their sustainable development.

Grape (*Vitis vinifera*) is one of the world's most widely cultivated fruit [7]. In the year 2021, over 70 million metric tons (MMT) were produced [8]. Approximately 50% of grapes are directed into winemaking, while the remaining 50% are being used as fresh and dried grapes [7]. During grape processing, in order to produce wine, large amounts of resources are utilized; not only water but also organic and inorganic fertilizers. In order to produce 1 L of wine, 1.3–1.5 kg of waste is generated (largely wastewater). Still, winemaking is seen as an eco-friendly process [9]. Grape pomace (GP) is the primary by-product in winemaking, approximately 20–25% of the total processed grape weight [10], which would amount to approximately 7 million tons. Its proximate chemical composition is presented in Table 1. The discharge of GP leads to environmental issues such as ground and surface water pollution, proliferation of organisms which can spread diseases, the depletion of oxygen in soil and groundwater, which may have an impact on local wildlife [11]. For a long time, GP was considered as waste/by-product. Traditionally, it has been utilized in the production of various distillates, used as fertilizer, as supplement in the animal nutrition or compost [7]. However, large quantities of GP, as a fertilizer with high organic content, disposed in landfills can exhibit harmful effects on biodegradation due to low pH and the presence of antibacterial substances (polyphenols). Although GP is rich in proteins it is reported that most of the animals are not able to successfully digest it and satisfy its dietary needs. Utilization of GP as a composting material showed non profitable and economic usage due to an absence of essential nutrients [11]. Nevertheless, the wine industry is definitely engaged in its responsibility to the environment, which is supported by increasing research found in the scientific publications [9,12–20]. Different utilizations and purposes of GP have been proposed in recent decades and can be observed in Table 2.

Table 1. Proximate chemical composition of grape pomace, apple pomace, cane and beet molasses based on dry weight (dry mass (DM), total dietary fiber (TDF), total polyphenolic content (TPC)); * adapted from [21], ** adapted from [22], *** adapted from [23].

Component	Grape Pomace (g/100 g DM) [11]	Apple Pomace (g/100 g DM) *	Cane Molasses (g/100 g DM) **	Beet Molasses (g/100 g DM) **	Vinasse (g/100 g DM) ***
Ash	1.73–9.10	0.54–6.58	13.14–20.99	8.79–25.02	27.02
Protein	3.57–14.17	3.21–6.12	2.86–11.99	14.47–21.10	21.71
Fat	1.14–13.90	1.30–4.21	–	–	–
TDF	17.28–88.70	5.07–55.15	–	–	–
TPC	0.28–8.70	–	–	–	–
Sucrose	–	4.10–6.26	50.48–86.67	62.88–89.38	–
Fructose	0.38–8.91	21.48–43.50	2.96–18.39	0.01–1.18	–
Glucose	0.21–26.34	21.05–21.26	1.67–15.54	0.03–2.65	–
Pectin	–	3.78–16.48	–	–	–

Apples (*Malus domestica* Borkh.) are the 4th most grown fruit worldwide (after oranges, bananas and grapes) [24]. In the year 2021, over 90 million tons were produced [8]. Fresh consumption accounts for 70–75% of the apples. From 5 to 30% of the world's total production is directed into production of various value-added products such as juice, wine, jams and dried product. However, the most necessitated apple product remains apple juice, which requires approximately 65% of the total amount of processed apple. In the production of apple juice, approximately 75% of apple fresh weight is extracted as juice, while approximately 25% is considered as food waste, i.e., apple pomace (AP) [24,25]. It is estimated that approximately 4 MMT/year of AP is generated. Although AP has been extensively researched for various purposes (Table 2), it is still an undervalued by-product used as animal feed or field fertilizer. However, AP's protein content is extremely low (Table 1) and therefore represents a poor nutritional supplement for animals [26]. AP is subjected to a fast fermentation by microbes, due to the AP's high content of water (>70%), sugars and organic acids. Therefore, direct disposal to the soil as field fertilizer with high organic content may cause the contamination of soil and water [27].

The direct disposal of apple and grape pomace as food waste represents a substantial loss of valuable biomass, which could be further processed and bio-converted into different value-added products [26]. However, the production of only one product from processing the large amount of these wastes is not economically profitable. Therefore, the efforts need to be made in exploring the additional applications as well as alternative products [28].

3. The Lack of Sustainability in Large-Scale Bioprocesses: Baker's Yeast Production as a Representative Example

This paragraph briefly explains some of the most important large-scale bioprocesses and their importance in the market. These are the production of bioethanol, citric acid, amino acids and baker's yeast, which require large amounts of resources. The microbial growth involved in these highly efficient processes require considerable quantities of organic carbon, which is usually supplied as sucrose, maltodextrin or glucose. The production of ethanol as a biofuel is associated with the substantial utilization of natural resources, including water, soil erosion and the required arable land for sugar beet and sugarcane cultivation (Figure 1a) [29]. Nowadays, bioethanol is mostly produced from grain starch or sugar crops (sugarcane, sweet sorghum) in the USA, China and Brazil. As an example, bioethanol in Brazil is mainly produced with sugarcane. The main production technology is very mature and includes pretreatment (cleaning and cutting) of sugarcane, extraction and concentration of sugarcane juice, ethanol fermentation, ethanol distillation and dehydration. Based on the environmental life cycle impact and energy balance assessment, from 1 t of sugarcane, 86.5 L of fuel ethanol is produced, 84 MJ of electricity, 150 kg of sucrose and other valuable by-products, which in return has capacity advantage and economic benefits [30]. With over 30 billion L produced in 2019, Brazilian bioethanol stands out as one of the most prominent biofuels produced on a large scale [31].

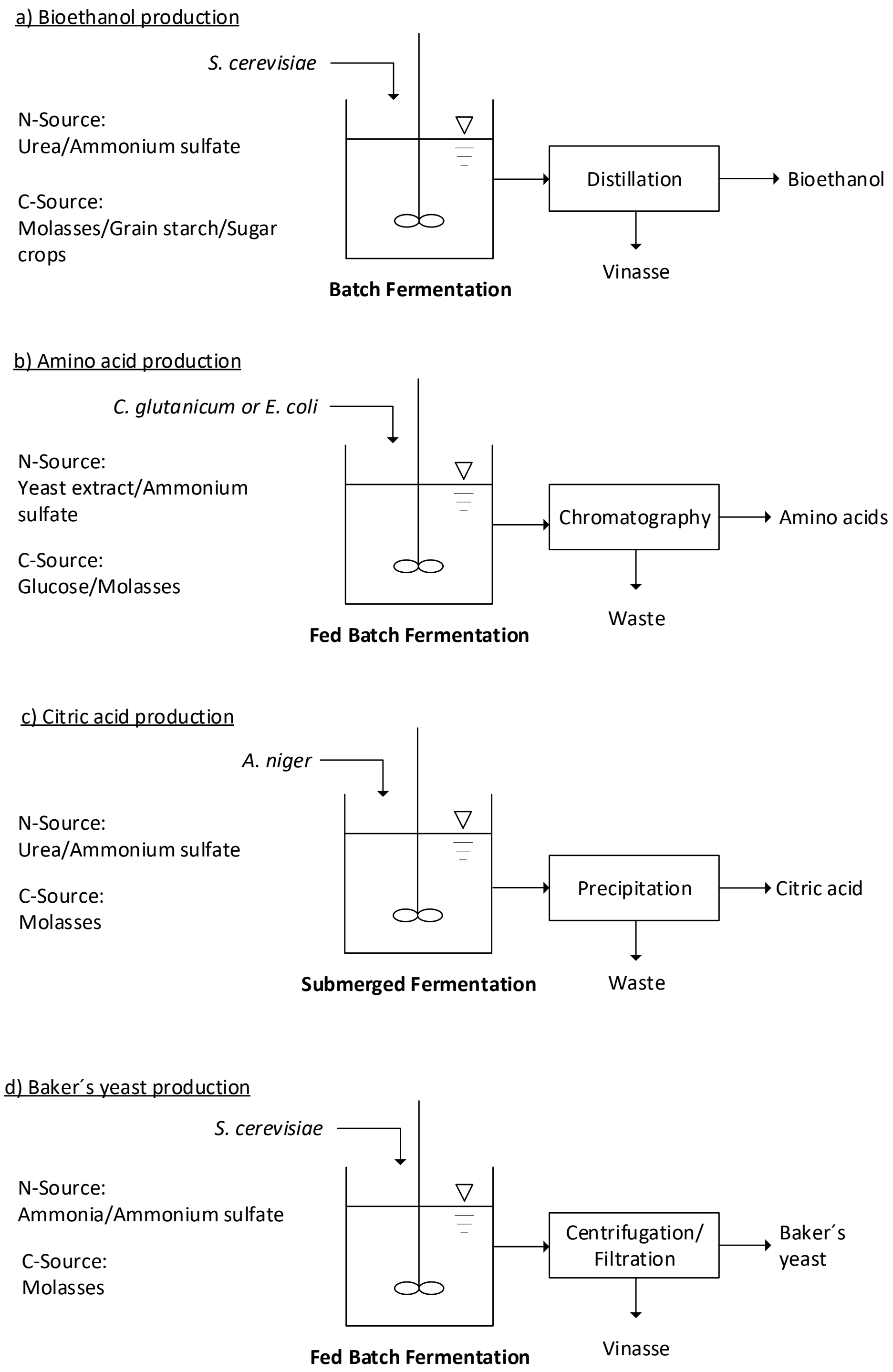

Figure 1. Flow diagrams for the production of bioethanol, amino acids, citric acid, and baker's yeast.

One of the most important organic acids widely used in pharmaceutical food, beverage, detergents, and cosmetics is citric acid. Industrially, it is produced by filamentous fungus *Aspergillus niger* on a medium containing molasses without any additional ammonium salts (Figure 1c) [32]. To reduce the cost of production, efforts have been made in utilizing the agricultural waste and by-products in the production of citric acid. This includes the following: coffee husk, rice bran, wheat bran, carrot waste, cassava bagasse, banana peel, vegetable wastes, sugarcane bagasse, tapioca, whey, rice straw, coconut husk, brewery wastes, rotting fruits, corn cob, orange peel, kiwifruit peel, pineapple peel, grape and apple pomace. The production of citric acid by fermentation is steadily growing with an annual rate of 5%. It is estimated that the global production is approximately 736,000 tones/year, with the market reaching over 3 billion USD by 2023 [32].

One of the major fields of industrial biotechnology and large-scale processes is industrial amino acid production (Figure 1b). They are widely used in seasoning and other food use, but also as ingredients in animal nutrients, pharmaceuticals, and cosmetics. The first amino acid to be commercialized was monosodium glutamate. A major revolution was the discovery of glutamate fermentation by *Corynebacterium glutamicu*, proving it is possible to produce amino acids in large amounts at low prices. At the beginning, glucose, fructose, and sucrose are used as a carbon source. However, after the discovery of an alternative method of biotin limitation, a more economically desirable source of molasses was used. Nowadays, the amino acid industrial fermentation sector is huge, so more than 5 million metric tons/year are produced worldwide [33]. Global demand is expected to grow with an annual growth rate of 5.6% in the period of 2017–2022 and will reach USD 25.6 billion by 2022 [34].

Table 2. Different purposes for grape pomace and apple pomace applications.

Waste	Application	Literature
Grape pomace	As source of bioactive compounds (phenolics) used in pharmaceutical, cosmetic and food industries	[7,35–39]
	As source of dietary fiber (as dietary supplement, dough improver, alternative source of antioxidants and dietary fiber for yogurt, for the fortification of meat and fish products)	[7,11,36,40–42]
	In the production of bioethanol	[39,43–45]
	In the production of baker's yeast	[10,46]
	In the production of lactic acid	[47,48]
Apple pomace	Green extraction of bioactive compounds:	[49–53]
	- extraction of pectin	[6,25–28,49,50,54–60]
	- extraction of polyphenols	[6,49,58]
	As solid biofuel	[25,27,28]
	As source of dietary fiber (used in baked food products)	[61–63]
	As functional ingredient in food products:	[6]
	- bakery products	[6,26,58,60,64,65]
	- meat products	[6,50,54,64,66–68]
	- dairy products	[6,24,61,69]
	In the production of citric acid	[6,26,70–74]
	In the production of baker's yeast	[25,75,76]

Baker's yeast production is an industrial process (Figure 1d), which has been both theoretically and technically very well described in the literature [77–80]. Industrial baker's yeast production involves multiple stages with variations in generation numbers, aeration levels and bioreactor types. As main carbon source, molasses is used and it is usually diluted, clarified, and sterilized before micro and macroelements, along with vitamins, are added. The initial cultivation of the pure culture starts in small flasks (less than 5 L) and is followed by two larger-scale stages (1140–26,500 L), lasting 13 to 24 h each. The main biomass production occurs in the so-called final trade cultivation, with large vessels (37,900 L to over 283,900 L) being carefully aerated. To prevent the Crabtree effect, molasses is added in a controlled manner to maintain low sugar concentrations (fed-batch). Molasses is usually supplemented with ammonium salts, phosphoric acid, and magnesium salts. The vitamin solution is dosed into the bioreactor. The final trade cultivation lasts 11 to 15 h, yielding 15,000 to 100,000 kg of compressed yeast per batch. Afterward, separation occurs in centrifugal separators and rotary vacuum filters in order to concentrate the yeast. The resulting cake is mixed with water, oil, and emulsifiers, extruded into blocks, wrapped, and cooled to below 8 °C [81,82]. Baker's yeast sector represents a huge market with annual production of 2.3 MMT worldwide [83]. Considering the large amount of molasses and other resources, such as water and electric energy, that needs to be directed into this production [23] and the waste it is generating (the production of 1 metric ton of baker's yeast generates approximately 60–130 metric tons of wastewater [84]), the producers need to start thinking about integrating the economical circularity. Although the process has been dramatically optimized over recent decades, mostly in the direction of producing high amounts of yeast biomass as fast as possible and at the lowest cost [77,81], more efforts are needed in developing new strategies in order to contribute to the goals of EGD. Nevertheless, research has been conducted regarding the sustainability improvement in the baker's yeast production and is focused on exploring alternative raw materials [10,25,46,75,76,85–87] and wastewater treatment [23,84,88,89]. However, very little of these outputs was implemented in the real industrial surroundings.

After mentioning some of the most important large-scale processes and the size of their markets, efforts need to be made in exploring the sustainability aspect of these productions. In this regard, the three primary products mentioned in Figures 1 and 2 (apple, grape and sugar beet) are taken as a starting point for the following discussion about the lack of sustainability and the links with the large-scale bioprocesses. Sugar beet is the main raw material involved in the European sugar production. The associated transformation is well optimized leading to the production of sugar (and specialty sugars), molasses and sugar beet pomace. The latter is further transformed into pellets for animal feeding. Because of its high sugar, protein and amino acid contents (Table 1), molasses is the most widely used raw material for industrial bioproductions. It was considered as a waste product of the sugar industry for a long time. Nowadays, it is termed as a by-product due to its low price compared to the other sugar sources and the presence of minerals, organic and inorganic compounds. Molasses is used in the production of alcohol, organic acid and single cell proteins [90]. From 2016 to 2018, sugar production worldwide increased steadily. Brazil, India and Thailand were the most important producers of sugarcane (33, 28 and 12 million tons of sugarcane were produced, respectively). The European Union is the world's largest producer of sugar beets (17 million tons). Since 2006, sugar beet production in Italy has dropped drastically, from 8.6% to 3.9% of the European Union (EU) production due to the EU reform, which liberalized the sugar market in all of Europe [91]. The volatile molasses market [81], descending trend of sugar market prices as well as increasing energy prices are an immediate threat to the survival of some sugar industry [92]. All large-scale productions associated with molasses are currently facing problems in terms of raw material supply and, consequently, the demand for alternative feedstocks is increasing.

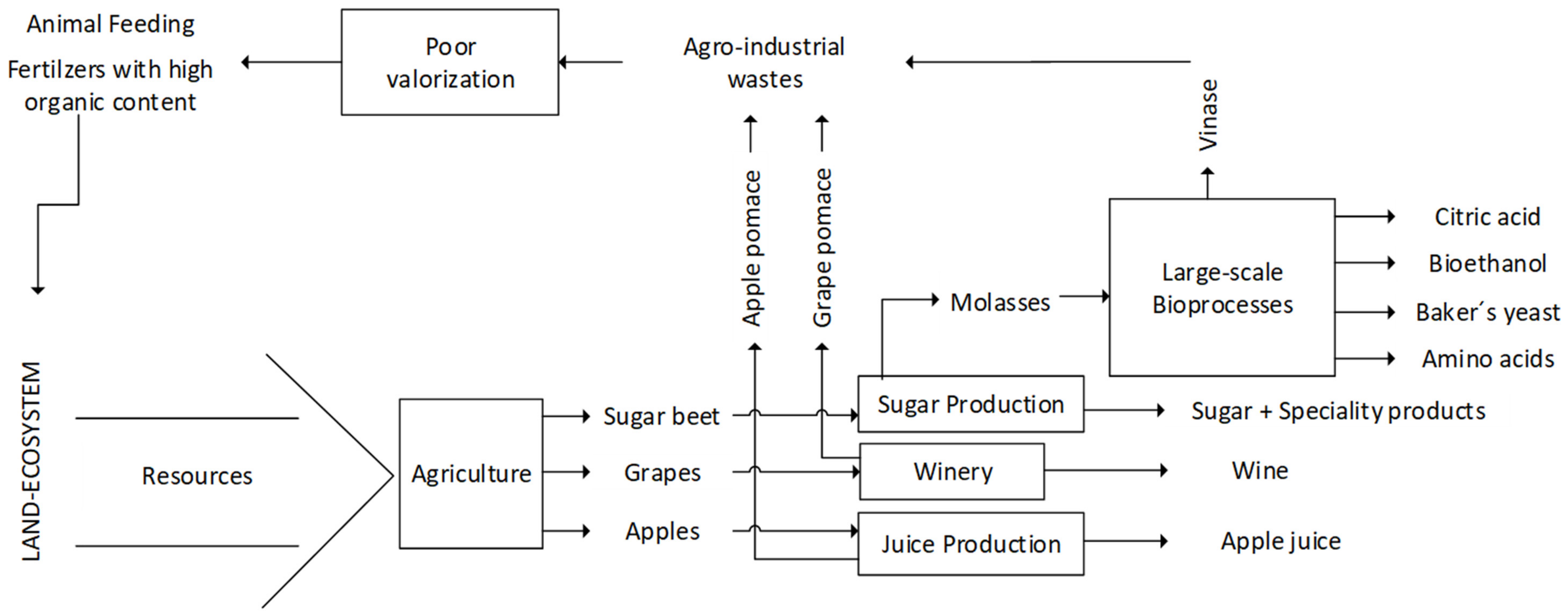

Figure 2. The implementation gap between agro-industrial wastes (fruit pomace/sugar beet vinasse) and large-scale bioprocesses. Apple juice production and wine making still work in a linear fashion while industrial bio-productions often lack adequate sustainability.

The production of apple juice and winemaking are still considered as linear economy systems, although a lot of research has been carried out to enhance the valorization of the corresponding by-product/waste (Table 2). Apple and grape pomaces are both highly available streams exhibiting high sugar contents (Table 1). They undergo rapid fermentation and cannot be stored for long. It is preferable to stabilize and process these fractions as soon as possible. As presented in Table 1, the compositions of apple and grape pomaces are comparable with beet and cane molasses making those very suitable raw materials for the preparation of alternative feedstocks. The efficient aqueous extraction of sugar from fruit pomace is not very challenging but effort is still needed for the proper assessment the resulting sugar extracts in a real industrial surrounding and by considering the other key aspects like logistics, quality standards, available infrastructures and resources. The large-scale bioprocesses mentioned in Figure 1 are highly optimized high-yield processes. For example, state-of-the-art industrial baker's yeast production requires the precise dosage of sugar during the fed-batch fermentation to avoid the Crabtree effect as well as the control of the fermentative capacity and the protein/dry matter content of the produced yeast. The challenges rely on the sustainable and cost-efficient production of sugar extract that can be easily transported and has a long storage capacity. The final step is to define to which extent the generated sugar extract can be used to substitute molasses without negatively affecting the production costs and the product quality. Figure 2 makes this implementation gap between large-scale bioprocesses and agro-industrial wastes (fruit pomace/sugar beet vinasse) visible. This in turn requires a mature technology, considerable changes in the infrastructure involved in bioprocesses as well, mentality, company's philosophy and marketing strategies [81]. The collaboration between academic teams and industrial partners plays an important role for the transition from research to industrial innovation and the efficient coordination between actors from different sectors with different backgrounds and interests. We believe that interdisciplinary academic actors are in charge of this task and their effort should focus on leading transdisciplinary research activities that embrace differences and generate global solution considering environmental, economic and ethical aspects.

At this stage, it seems necessary to discuss the lack of sustainability of both, primary and secondary production as the main problem in the framework of the implementation of the EGD. Due to the release of large amounts of vinasse, bioethanol and baker's yeast productions are currently quite problematic. The utilization of sugar beet vinasse requires the addition of co-substrates for the efficient production biogas production by means of anaerobic digestion [93]. It is common practice to concentrate vinasse, as a source of potassium and nitrogen, to generate a fertilizer of appreciable quality but requiring careful and precise dosage to avoid soil contamination [94]. This is usually achieved in energy demanding processes involving evaporation and centrifugation. The reuse of such condensates within the production process is limited and the produced wastewater is usually directed to a dedicated treatment station and finally released into the ecosystem.

4. Centralized Valorization Platforms as Well as a Close Collaboration between Academia and Industry Are Crucial to Bridge the Gap between Agro-Industrial Wastes and Large-Scale Bio-Industries

We now turn our attention to two distinguished recent works exploring the valorization of apple and grape pomace to generate alternative substrates for baker's yeast production [10,25]. In the mentioned research, apple pomace (obtained after extraction of apple juice) and grape pomace (by-product in wine production) were further processed in order to gain valuable by-products such as solid biofuels and sugar extracts as feedstocks for large-scale bioprocesses. The corresponding characteristics of the solid biofuels (heat release and mechanical stability) were very comparable to values reported for conventional wood pellets. Especially, the grape pomace fractionation process is characterized by a strong energy output that allow for covering the energy demand of the process and create an additional renewable energy surplus of 3 MJ/kg of processed grapes (dry mass). The efficiency of the mechanical dewatering of the treated pomace plays a key role in this technology by reducing the energy demand for drying.

Following a circular economy approach, this aspect makes this valorization process particularly interesting because it may supply other processes or citizens with heat. The feedstocks gained from these processes are the most interesting product, which were subsequently assessed for the production of baker's yeast under real industrial conditions. For this purpose, molasses was partly substituted with these extracts and the baker's yeast cultivations were performed in pilot bioreactor. The production procedure was optimized to reproduce the large-scale production conditions occurring in bubble columns. The results of the produced baker's yeast analyses indicate that the high quality yeast was produced by mixing molasses and sugar extract originating from pomace processing. It is worth mentioning that the particularity of these works relies in the close collaboration between academic teams and an industrial partner, who has a real technical, scientific and economic interest in the outcomes of the engaged research activities.

As a major outcome, this review combines these recent advances and proposes a way to transform largescale bioprocess by integrating them into a circular economy approach and gaining valuable feedstock from the processing of fruit pomace to achieve zero liquid discharge. In other works, the applicability of comparable sugar extracts originating from grape pomace transformation for the production of bioethanol was also reported in the literature [95]. Such feedstocks might also be appropriate as potential substrates for other large-scale bio-productions such as citric acid or amino acids but this has to be assessed and confirmed since these processes involve different microorganisms and fermentation conditions. Figure 3 shows a model to connect three fundamental sectors of the European economy namely, land/agriculture, post-harvest transformation and industrial biotechnology. During apple juice and winemaking transformations, the waste is converted into a valuable feedstock for the baker's yeast production or other large-scale bioprocesses. Renewable energy (solid biofuel) can be used in the energy balance of these transformations and heat surplus can used by other industries or citizens [10,25]. We believe that centralized valorization platforms are key enablers to bridge such implementation gaps by overwhelming the valorization chain and ensuring the efficient zero liquid discharge production of high value product such as feedstock for large-scale bioprocesses, renewable energy (solid biofuel) and pectin from apple pomace. Pectin is a polysaccharide originating from the cell wall of plants with excellent gelling properties. It is widely used in the food industry and in the pharmaceutical industry as well.

On the one hand, the organic content of fruit pomace (e.g., sugar, fibers, and polymers) constitutes the high valorization potential of this agro-industrial waste; on the other hand, it is exactly the biodegradation of this fraction that makes fruit pomace becoming a problematic fertilizer leading to soil contamination. In this regard, the main role of the centralized valorization platforms relies in the extraction, fractionation and conditioning of the organic fraction from these wastes to generate high value products and intermediates. Such a platform could simply consist of unit operations (solid–liquid extraction, membrane-based separation processes, ion-exchangers, mechanical dewatering, drying/evaporation) that could be combined in a customized way depending on the type of agro-industrial feed.

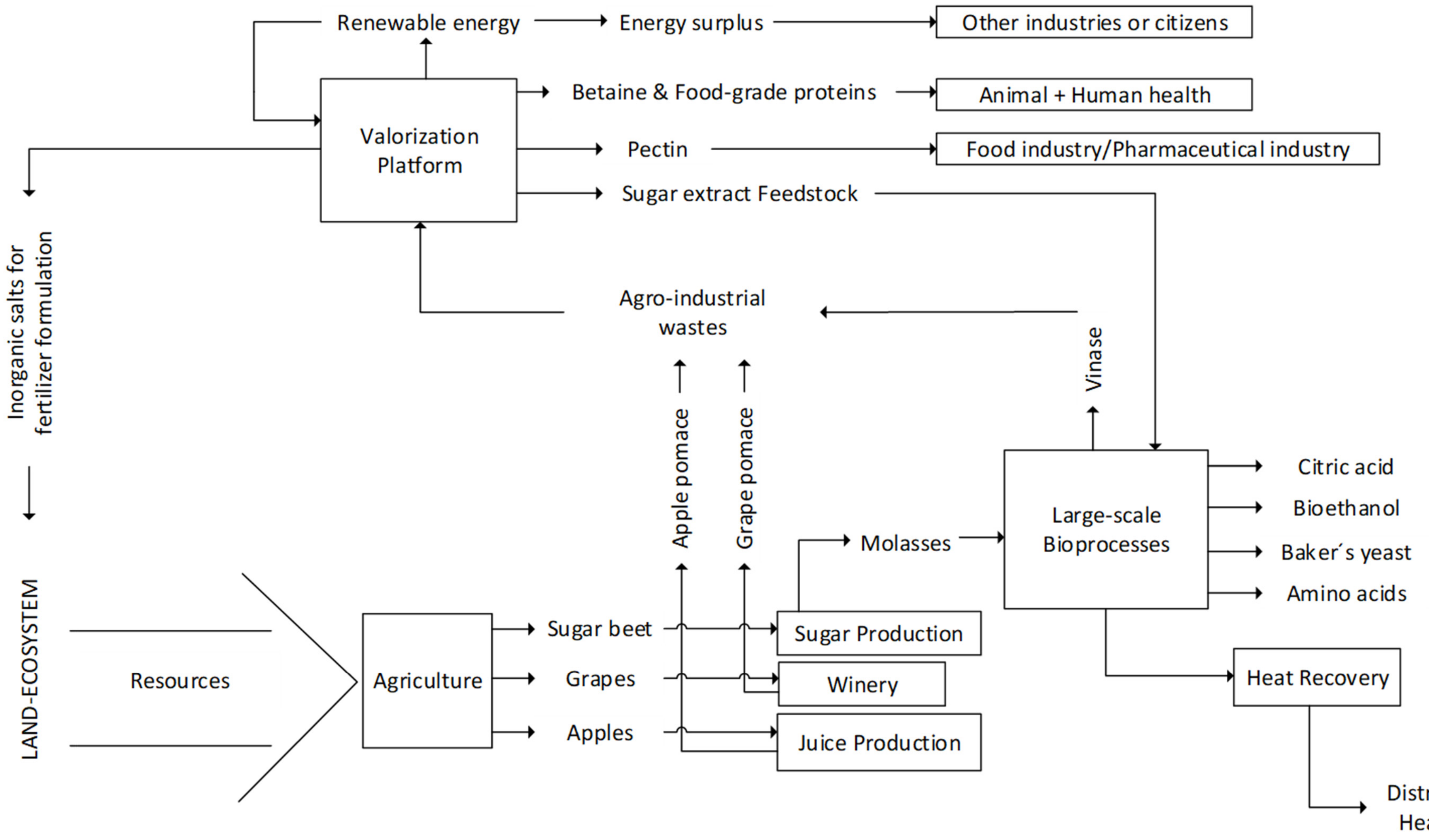

Figure 3. A circular flow diagram to bridge the implementation gap between agro-industrial wastes and large-scale bioprocesses. It connects agriculture and post-harvest transformation with the industrial biotechnology and other industries through the substantial valorization of vinasse, apple pomace and grape pomace into renewable energy (solid biofuels), betaine, food-grade proteins and sugar extracts as feedstock for large-scale bioproductions.

Aiming to integrate secondary product vinasse as an important member of the circular link with the valorization of grape and apple pomaces, we recently published interesting advances that demonstrate the enhanced valorization of sugar beet vinasse produced during baker's yeast production [23,96,97]. As presented in Table 1, the chemical composition of vinasse is quite simple when compared to molasses. It mainly contains minerals especially potassium and organic nitrogen (amino acids, peptides and proteins). In contrast to sugar cane vinasse, sugar beet vinasse contains an appreciable amount of betaine (approx. 22.4% *w*/*w* based on dry mass) [production [23]]. Natural betaine is a key osmolyte with applications in animal and human health [23]. In these works, we approached the valorization of sugar beet vinasse by separating the organic fraction from the inorganic fraction. Food grade proteins and betaine are recovered from the organic fraction and salts especially potassium are recovered from the inorganic fraction that can be used as formulation ingredient for fertilizers. Updating our circular workflow by implementing these advances within the above mentioned valorization platforms (Figure 3) allows for converting vinasse from a problematic waste to valuable products. Energy-efficient water reuse can be dramatically improved by substituting evaporation by state-of-the-art membrane processes such as ultrafiltration combined with electrodialysis and hybrid reverse osmosis leading to the energy-efficient dewatering of the different fractions and the generation of clean water, which can be further distributed to surrounding citizens [98–100]. Finally, the installation of state-of-the-art heat pumps allows for supplying residential neighborhood with 4th-generation district heat through the processing of the low-grade heat generated during aerobic fermentation operations [96].

5. Conclusions

In this work, we proposed a circular flow diagram that connects agriculture and post-harvest transformation with the industrial biotechnology and other industries through the substantial valorization of sugar beet vinasse as well as apple and grape pomaces into natural betaine, food-grade proteins, minerals, renewable energy (solid biofuels) and sugar extracts as feedstock for baker's yeast and bioethanol production. These feedstocks might also be appropriate for other large-scale bioprocesses such as citric acid or amino acid production but this has to be further assessed and confirmed. In this context, the transition from a linear to circular supply chain is feasible but requires:

- Openness and mentality changes, especially in companies involved in the bioproduction of one main product. New expertise and financial risks are often associated with the extension of a product portfolio. This move is often uncomfortable for small- and middle-sized companies, which then become new players in existing or novel markets. Centralized valorization platforms can play a crucial role in overwhelming the valorization chain and accelerating the transition towards a circular economy.
- Adequate policies to ensure the correct balance between the pressure to enforce, engage and consolidate the transition and the support to encourage companies to take risks and develop new market opportunities.
- Academic research plays a vital role for the establishment and the acceleration of transition towards a sustainable circular economy. However, the conversion of research outputs into innovation necessitates a close and trustful collaboration between academic and industrial partners. Prior to the project start, academic researchers should have a deep understanding of the workflow of the companies involved in the research with a special focus on the current constraints associated with the market dynamics, and the product quality standards.

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