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WAYS OF APPLICATION OF THE CIRCULAR BIOECONOMY IN THE WINE INDUSTRY

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Abstract. The article reviews the conventional (composting, landspreading, tartaric acid, and grapeseed oil production) and novel ways of winemaking by-products biomass conversion with the manufacturing of value-added products to solve the disposal problem and bring extra profit to producers. Winemaking waste may be used to make biopolymers - bacterial polymers that work as a plastic alternative, and can also be utilized to make biocomposites or serve as natural fillers. It showed to be a good substrate for microorganisms for the generation of biofuels from winery waste and is the most promising, economical, and ecologically friendly option. In biotechnological applications, it can be used for the production of microbial polysaccharides, alcohols, organic acids, and enzymes, as well as single-cell protein and protein-rich fungi. The available studies indicate that it is possible to create pharmaceuticals with multiple properties of preventing or treating obesity and multiple sclerosis, atherosclerosis, diabetes, allergies, and also benefit gut microbiota. The red grape marc can be used in manufacturing encapsulated natural pigments, applicable for baked products, dairy, soft drinks, and pasta making it a feasible alternative to synthetic colorants. Considering the available opportunities, it is advised the development of industrial technologies and quality standards for the available studies introduction.

Keywords: *winemaking by-products, extracts, sustainable development, waste recycling, circular approach.*

Rezumat. Articolul trece în revistă modalitățile convenționale de conversie a biomasei din subproduse de vinificație cu fabricarea de produse cu valoare adăugată pentru a rezolva problema eliminării gazului de seră și a aduce profit suplimentar producătorilor. Subprodusele de vinificație pot fi folosite pentru a obține biopolimeri - polimeri bacterieni care funcționează ca alternativă a plasticului și pot servi drept materiale de umplutură naturale. Tescovina prezintă un substrat bun pentru microorganisme în vederea generării de biocombustibili din deșeurile de vinărie și este cea mai promițătoare, economică și ecologică opțiune. În aplicații biotehnologice, tescovina de struguri poate fi utilizată pentru producerea de polizaharide, alcooli, acizi organici și enzime, precum și proteine unicelulare și ciuperci bogate în proteine. Studiile disponibile indică faptul că este posibil să se obțină produse farmaceutice cu proprietăți multiple de prevenire sau tratare a obezității și sclerozei multiple, arteriosclerozei, diabetului, alergiilor și pentru microbiota intestinală. Tescovina de struguri roșii poate fi folosită în fabricarea pigmenților naturali încapsulați, aplicabili pentru produse de copt, lactate, băuturi răcoritoare și paste, fiind o alternativă fezabilă pentru coloranții sintetici. Având în vedere oportunitățile disponibile, se recomandă dezvoltarea tehnologiilor industriale și a standardelor de calitate pentru implementarea studiilor disponibile.

Cuvinte cheie: *subproduse de vinificație, extracte, dezvoltare durabilă, reciclare a deșeurilor, abordare circulară.*

1. Introduction

Nowadays, in the Republic of Moldova it is manufactured about 14 mln dal of wine yearly [1]. Winemaking is a secularly-rooted economic activity in the Republic of Moldova that contributes 9% of the country's gross domestic product, making it one of the most significant sectors of the economy there. Wine production is a very sophisticated and costly technological process, as only 70% of the raw material is used to make this product, with the other 30% resulting as waste (around 100 000 to 200 000 t each year) [2]. Inappropriate handling of these materials may cause both ecological and food safety problems. Recycling is one of the viable solutions to solve this problem and avoid waste accumulation. Winemaking by-products have a high potential as raw material for various value-added products, including fertilizers, biopolymers, pharmaceuticals, functional foods, etc. This article reviews various possibilities of winemaking by-products treatment methods and valorification options, in terms of industry evolvement towards more sustainable approaches and circular bioeconomy principles application.

According to Law no. 57 on Vine and Wine of the Republic of Moldova, waste resulting from the production of wines and processing of secondary products of winemaking is subject to mandatory processing only at permitted enterprises in accordance with the requirements for environmental protection, transfer of waste to specialized enterprises for energy conservation and processing of industrial waste, as well as requirements for waste storage, not subject to processing, at specially equipped landfills [3]. Categories of secondary products of winemaking, provided by the current legislation of the Republic of Moldova are grape pomace, wine stillage, yeast stillage, diffusion juice, piquette, wine stone, stem must, and wine yeast. From mentioned by-products on the territory of the Republic of Moldova, it is legal to produce such categories of value-added products as enocolorant (a natural food coloring obtained from strongly colored red grapes), enotanine (a product obtained by the extraction of phenolic substances from grape seeds), calcium tartrate (sediment obtained from secondary products of winemaking, containing salts of tartaric acid), grape seed oil [4].

2. Basic principles of the circular bioeconomy

The word "sustainability" was adopted to close the gap between development and the environment. Sustainable development is defined as development that "meets the demands of the present without compromising the ability of future generations to satisfy their own needs" in the World Commission on Environment and Development's 1987 report [5]. Sustainability is also associated with enhancing long-term prosperity and well-being. Three strategies exist for sustainable development: ecological (preservation of the robustness and resilience of biological and physical systems), economic (maximization of income while maintaining a constant or rising stock of capital), social-cultural (preservation of the stability of social and cultural systems) [6].

The growing scarcity of resources used in agriculture, such as water, is projected to impede the expansion of agricultural output. Greater agricultural productivity came at a significant environmental cost and the expense of some non-renewable agricultural resources. The developing world is now where the environmental consequences of agricultural development are most noticeable. This may be seen, for instance, in the nations' increasing per-hectare use of synthetic fertilizers and pesticides. The beginning of climate change is another significant obstacle to the sustainability of agricultural production [7]. Climate change, environmental degradation, and biodiversity loss have driven Europe to transition from a fossil-based and linear economy to a bio-based circular economy model. The bioeconomy is the production of renewable biological resources and the conversion of waste streams into value-added products [8].

Biowaste is defined by the European Commission as “biodegradable garden and park waste, food and kitchen trash from residences, offices, restaurants, wholesale, canteens, caterers, and retail locations, as well as equivalent waste from food processing plants”. Unmanaged biowaste endangers public and environmental health. Furthermore, when biowaste is disposed of in an unmanaged manner, it contributes significantly to methane emissions, which contribute to climate change [9].

Agriculture, forestry, fishing, food, pulp, and paper manufacturing, as well as portions of the chemical, biotechnological, and energy industries, are all included. Its sectors have a high potential for innovation because they use a diverse set of sciences, enabling industrial technologies and local and tacit knowledge [10].

The circular approach causes three times less environmental impact than the linear system for global warming, freshwater eutrophication and mineral resource depletion [11].

The fundamental obstacles to the implementation of the concept of sustainable development consist in the awareness of the phenomenon of global warming, the lack of financial resources and advanced technologies, as well as the diversity of political and economic objectives on a global and local scale. [12]. Food by-products and waste valorization techniques have lately come to light as methods of sustainable management that may also boost local economies' revenues. To achieve the goal of a zero-waste society, stakeholders need to be more aware of the technologies for by-product recovery produced by academic institutions and research centers as part of the transition to a circular economy [13].

2.1 Combating food waste from production to consumption

Food loss (food spoilage) is defined as “the unintended reduction in edible food quantity or quality before consumption, which includes postharvest losses” [13]. It refers to a decrease in the mass of food that was originally meant for human consumption at all stages of a food chain before the consumer level. Food loss is the least desirable scenario among the others because there is no other option than to reject it.

Food waste is defined as “food that was created for human consumption but was discarded or was not consumed by people, including still edible food that is discarded on purpose” [14]. Food waste is less harmful to the environment than food loss. Depending on the type of food waste, it becomes the raw material for a biorefinery, which can provide material recycling, animal feed, nutrient recovery, or energy recovery.

Surplus food is edible food that has been produced, retailed, or served but has not been consumed by humans. It is the least harmful of all because it is easy to avoid and the surplus produced is still good for human use [14,15].

Differences in food waste between areas and countries are determined, in general, by economic, organizational, and behavioral conditions, and, in particular, by the number of resources in the region and regional behavioral patterns. In some regions, household food waste can be prevented up to 34% [16].

In the food chain there are multiple factors that contribute to the generation of food waste. In the case of agricultural enterprises, these are non-compliant products, resulting from their sorting due to rigorous quality standards regarding mass, size, appearance and shape; prices, which do not always justify the expenses; overproduction due to failure to fulfill supply agreements with retail chains and damage to the crop during harvest. In the manufacturing stage there are such factors as products of irregular sizes, inconsistency of manufacturing processes, contamination in the manufacturing process, food spoilage due to packaging problems, surplus production of supermarket own brands, and canceled commands.

The following factors contribute to food waste during product distribution: a lack of cold storage, packaging defects, overstocking, the requirement for retailers to order a diverse range of products and brands from the same producer, failure to comply with minimum food safety standards, and marketing strategies [17]. In general, a large amount of food waste is generated before the households, and this occurs as a result of a lack of communication and collaboration among food chain members, policies requiring manufacturers to discard non-compliant products, and poor management of all stages of food production and distribution [18].

The following aspects that are required for a successful corporate social entrepreneurship initiative aimed at reducing food waste: clear articulation of the problem and solution; mobilization of civil society actors; continuous investment; and alignment of the initiative's scaling-up strategy with the retailer's resources [19]. Simple things like making lists before going grocery shopping and buying less food can help you reduce your carbon footprint. At this point, money can be saved by purchasing only what is required and avoiding disposal fees. Food waste should be addressed not just through the use of existing and new technologies, but also through education and raising awareness [20]. In theory, the potential for preventing needless food waste is infinite. Apart from physical human requirements, various additional reasons impact consumer behavior, such as self-affirmation and the intrinsic value of buying in itself. Unexpected circumstances, such as storage failure, mite infections, and so on, will also put the theoretical potential to the test. However, the rationale for discarding avoidable food waste is immaterial from an environmental standpoint, as the zero-burden assumption is never applied to avoidable food waste [21]. In different member countries, there were elaborated different prevention initiatives, such as informing the population on food waste reduction in different ways (guidance on food labels, food storage tips printed on carrier bags, revised marketing for promoting perishable goods) or encouraging the retailers to donate the surplus food (exclude the VAT and deduct a part of the donated amount from the taxable income) [15]. Food waste awareness campaigns may have a positive impact on consumer efforts to reduce the amount of wasted food [22]. Environmental awareness is relatively high in industrialized countries, and recycling efforts are commonplace. However, in a developing country, the urgency of trying to safeguard the environment is still regarded as a low priority due to the belief that "we still have plenty of land" [20].

According to the legal analysis, existing legislation lacks the guiding impact needed to dramatically minimize food waste [23]. On the other hand, adopting new regulations and policies was viewed as ineffective, although no consensus was established among the various types of stakeholders [24].

Under a set of market assumptions, the home food waste reduction might lead to a rise in home savings, a decrease in agri-food production, and a slight negative macroeconomic impact [25]. Some attempts to decrease food waste include collecting undamaged healthy food and distributing it to neighbors or those in need [20]. Italy recently modified its food waste policy by instituting novel measures such as the ability to donate food after the best-before date (BBD) and a major reduction in donation bureaucracy. Food waste experts advocate for these procedures, which are considered to increase donations practically automatically. Furthermore, despite legal measures encouraging food donation, the analysis finds substantial reputational hazards that limit both the supply and demand for food beyond the BBD [26]. Also, anyone, with proper and safe treatment, can contribute food scraps to animals. Farmers have been doing this for a long time, and there are several options to feed these animals. This approach preserves the environment, saves money on disposal fees, and is already prevalent in rural regions [20]. Food waste recycling in animal nutrition may help to reduce the environmental effect and improve the environmental footprint of livestock production [27].

In the US Environmental Protection Agency's (EPA) food recovery hierarchy, landfilling and incineration are regarded as the least recommended and last-resort methods. Incineration technology provides energy by burning garbage; this procedure is not only costly, but it also pollutes the environment due to the chemical emissions it emits. However, landfilling is the most typical waste management solution [20].

The most desirable strategic goal is to manage food waste across the supply chain. Each link in the food value chain can help to reduce or even prevent food waste. To address this issue, supply chain solutions aimed at reducing food waste must be implemented through the integration and synchronization of activities by all involved parties and stakeholders [28]. Systemic waste creation processes are essential to preventing food waste. They must target the identified system processes that contribute to the blockage of the food chain. Transparent monitoring and disclosure of surplus food is necessary to prevent systemic food waste throughout the supply chain [29]. Based on the treatment of a functional unit of 1 ton of food waste, the results show that the bioconversion scenario is the most preferable solution, incineration and bioconversion scenarios exhibit the greatest environmental advantages [30].

2.2 Creating added value with bio-waste and co-products

The recovery of food waste opens up new economic opportunities by using garbage as fuel for bioprocesses. Advanced technologies such as microwave-assisted extraction, ultrasound-assisted extraction, bioreactors, and enzyme immobilization-assisted extraction, as well as their combination, contribute to food waste processing [31].

Biorefining is the use of biotechnology to convert various types of biomass into marketable goods and energy. Currently, the majority of existing biofuels and biochemicals are generated in single production chains. Advanced biorefineries are being designed to process a broader range of biological resources into a variety of platform chemicals that may then be processed into biocomposites, bioplastics, energy, or food [9].

2.2.1 Biobased polymers

Biopolymers are bacterial polymers that are built as natural storage polyester by a diverse range of microbes, typically in unstructured growth conditions. Carbon source contributes around 70–80 % of the raw material cost as a substrate for both microorganism growth and biopolymer synthesis. This has influenced the manufacture and use of biopolymer because the technique is economically unfavorable overall. As a result, it is critical to minimize the cost of biopolymer manufacturing by utilizing less expensive carbon and nutrient sources [31]. Biopolymers that are derived from raw biomass may occasionally be made directly, but they may also be employed to create biocomposites by being reinforced, acting as natural fillers, or even both. They are frequently used as a bacterial fermentation substrate to produce natural polyesters like polylactic acid and polyhydroxyalkanoate [32].

Pseudomonas bacteria may produce *mcl*-polyhydroxyalkanoates from grape pomaces when used in combination with waste frying oil (*Pseudomonas putida* KT2440 and *Pseudomonas resinovorans*). For the Solaris grape, the production of *mcl*-polyhydroxyalkanoates was 21.3 g/L [33].

Utilizing the strain *Cupriavidus necator* DSM 7237, poly 3-hydroxybutyric acid can be produced in batch and fed-batch fermentation using wine lees and crude glycerol as carbon and nutrient sources. About 30.1 g/L of yield has been produced [33].

Investigated were the wine lees and seed extracts combined with polyhydroxybutyrate. The resulting eco-friendly and affordable biocomposites can be employed in large-scale disposable applications when simultaneous requirements for heat resistance and quick biodegradability are significant. Another study suggested making disposable cutlery out of three different flours (grape, millet, and wheat) combined with xanthan and palm oil as potential alternatives to plastic materials [34].

Grape pomace is known to be used as a substitute for chemical preservatives and natural antioxidants in edible wrapping to preserve the organoleptic properties and increase the shelf life of food products such as burgers and pork, as well as edible films [35].

Red grape seed extract, chitosan, gelatin, and *Ziziphora clinopodioides* essential oil can be used to create a biodegradable edible film with enhanced antioxidant, antibacterial, and phenolic content, as well as improved optical and water barrier qualities [35].

The effect of grape seed extract mixed into chitosan film on extended shelf life for vacuum-packed food under refrigerated settings was studied by taking into account its physicomechanical characteristics, antioxidant, and antibacterial activities. Films were more effective than chitosan films alone at inhibiting certain types of pathogenic microorganisms [36].

Extracted grape skins were demonstrated to be a promising raw material for the manufacture of low-density boards for insulation purposes. Over a wide temperature range, the boards made from grape skins and bound with 8% urea-formaldehyde resin had reasonable tensile strength and moderate thermal conductivity [37].

2.2.2 Biofuels

The production of biofuels from food waste is the most promising, cost-effective and ecological alternative to sustainable development and a circular bioeconomy. Food waste has been described as a substrate for biofuel synthesis. Food waste provides microorganisms with a complex of nutritious organic components to produce a variety of biofuels.

Hydrochar is a promising alternative to solid fuels. Technological parameters have a significant effect on the final quality of hydrochar. Increasing the processing temperature up to 260 °C resulted in an increased removal rate of N, S, and Cl, and combustion of hydrochar resulted in a significant reduction in NO, SO_2, and HCl emission [31].

2.2.3 Biogas

A possible method for generating energy from alternative renewable sources is the creation of biogas from leftover agro-food biomasses produced through anaerobic digestion. The use of advanced anaerobic digestion plant technologies, such as the combination of anaerobic membrane technology with particular systems, is currently the most promising factor to take into account to improve the anaerobic digestion process for the production of biogas. Additionally, real-time process monitoring should be carried out to regulate the primary process variables and enable effective biogas generation.

The following factors should be considered in future efforts to increase biogas generation from the anaerobic digestion of agro-food waste. A better and more precise characterization is required to mix agro-food waste in the right proportion to increase biogas production and process stability because of the variety in the origin and content of agro-food waste, which gives it special features. Small farms tend to be located in locations with seasonal availability of agro-food waste, which might lead to input unpredictability. This problem can be resolved through collaboration among farms producing various products [38,39].

2.2.4 Bioactive compounds

Bioactive chemicals are health-promoting elements found in small amounts in fruits, vegetables, cereals, and animal sources that provide extra-nutritious and health advantages in addition to the fundamental nutritional value of the meal. As medicinal medications, bioactive substances have antioxidant, cardioprotective, anti-inflammatory, anti-cancerous, immunomodulatory, and antimicrobial activities.

Nutraceuticals have numerous therapeutic benefits with no significant evidence of negative effects. The skin of grapes is left unused and is produced in mass as a by-product from vineyards. It is high in resveratrol (3,5,4′-trihydroxystilbene). Resveratrol is a multifaceted antioxidant that improves the anti-inflammatory response of NF-cells to reduce inflammatory responses, free radical scavenging action, and cytochromes P-450 enzyme activity, which aids in hepatic detoxification [31]. Some nutraceuticals can be utilized to supplement important nutrients for co-adjuvant cancer treatment (breast, lung, and pancreatic) [8].

Nutraceuticals, or functional compounds, have been recovered via membrane methods from novel sources, specifically agro-food by-products. Specific phenolic compounds may be recovered, separated, and fractionated using techniques like ultrafiltration and nanofiltration. These compounds, depending on their biological activity, may find value in the food and pharmaceutical sectors. These separation techniques are also more cost-effective than conventional ones, both in terms of recovery and because they don't call for the use of destructive reagents or added agents. Therefore, the recovery of high-value solutes from agro-food wastes is both ecologically conscientious and industrially viable [40].

The pulsed electric field (PEF) pre-treatment has a significant impact on recovering grape polyphenols. PEF was therefore determined to be the best non-thermal method for extracting certain bioactive chemicals from grape residues. It has been observed that increasing pulse width increased polyphenol yield with higher energy efficiency. Published studies claim that there is a rise in anthocyanin recovery of between 22 to 200 % as compared to the ultrasound and high-voltage electric discharge methods. Also, pre-treatment with PEF is more advantageous for recovery with low turbidity of the extract. As a result, the treated juice wouldn't need to be filtered with harmful filter aids such as diatomite [41,42].

2.2.5 Separation and drying of grape seeds

The seed oil content (recalculated on dry matter) varies from 9.5% to 20.0% depending on the grape variety and the place of cultivation. Approximately 190 - 512 t of grape seed oil can be generated annually. The efficient management of agro-industrial waste can be ensured by modernizing existing technological processes and by developing new processing methods based on high efficiency. The long duration of heat treatment of seeds leads to a decrease in the quality of the oil [43].

2.2.6 Landspreading the grape pomace

It has been established that the vine shoots produced during pruning include phenolic, volatile, and mineral components that are used as foliar fertilizer and a biostimulant for the grapevine [44].

The grapevine draws huge amounts of nutrients from the soil each year and persists in the same location for many years (30-40 and even more). Within a year, the vine absorbs 100-150 kg/ha of nitrogen, 20-50 kg/ha of phosphorus, and 75-250 kg/ha of potassium from the soil. In addition to nitrogen, phosphorus, and potassium, the vine requires the following mineral nutrients on an annual basis: calcium, magnesium, iron, boron, manganese, copper, zinc, molybdenum etc. It is suggested that grape pomace be used as a fertilizer to replenish the soil with nutrients.

Fertilization with fresh pomace - spreading in a thin layer directly on the soil after the grapes have been harvested. Fresh pomace should only be used sparingly and in small quantities in viticulture to avoid erosion.

Composted grape marc fertilization - most composting is done in piles, and the compost is used in the platform after composting. The advantage is that the compost has already been adequately matured by the time it is applied. As a result, the soil structure will increase (pore volume, water retention capacity, aeration, and heating), and nutrients will be more broadly available to plants [43].

The addition of composts made from agro-food sources to vineyard soil boosted the soil's salinity, nitrogen and oxidizable organic carbon contents, and biological activity. Similar to the treatment using compost pellets made from sheep manure, the waste-based compost treatments considerably boosted grape production when compared to the control treatment [45]. Vermicomposting is a viable solution for managing winery waste [46].

2.2.7 Tartaric acid

Tartaric acid is a well-known organic acid found within many fruits, most notably grapes. The most frequent form of acid found in nature is L(+)-tartaric acid, while D(-)-tartaric acid sources are scarce [47]. L(+)-tartaric acid is historically produced as a solid by-product of wine fermentation, and this method is significantly influenced by the grape development stage and climatic circumstances. Chemical production of L(+)-tartaric acid using maleic acid is also possible, but this produces a substantially less soluble racemic product (DL-form) that is unsuitable for inclusion in foods due to the presence of D(-)-tartaric acid, which is harmful to human health. The chemical process's commercialization is hampered by both the product form and the high production cost. Microbial approaches are currently believed to be substantially simpler and more cost-effective for the production of L(+)-tartaric acid and D(-)-tartaric acid [47]. L(+)-tartaric acid is used in the culinary, wine, pharmaceutical, chemical, and polyester industries. D(-)-tartaric acid is also vital in the pharmaceutical business. Both are well-known chiral chemical building blocks with several industrial and scientific applications [47]. Tartaric acid is preferred in dishes containing cranberries or grapes, such as wines, jellies, and confectioneries [48].

Tartaric acid esters/ethers were evaluated as polyvinyl chloride plasticizers. These compounds have good plasticizing action, a low migration potential, and have no effect on the thermal stability of the polymers [49]. Chitosan and tartaric acid were employed to form the stable double chelating network in magnesium oxychloride cement [50].

2.2.8 Obtaining sorbents from winemaking waste

The transformation of grape pomace into sorbents capable of reducing the concentration of heavy metals in wastewater is a new approach to the processing of agri-food waste. There is also the possibility of producing activated carbon or biochar. Microporous activated carbon obtained from winery waste had a higher capacity to adsorb Mn(VII) than other commercial adsorbents [51] and could be used to successfully remove Pb^{2+} from polluted water [52]. Biochar is less expensive to obtain than activated carbon and has a comparable adsorption capacity [43]. Biochar has the potential to be exploited as a source of bioenergy [53].

3. Wine enterprises - the production structure and possibilities for capitalization of by-products and waste

Wine production is one of the world's most important agricultural enterprises. Wine production necessitates the use of numerous valuable resources, including water, fertilizers, and other organic items. The precise vinification techniques alter the physicochemical qualities of the residual material formed, whose features define its further usage and even condition the subsequent specialized recovery circuit in which it might be integrated. The growing amount of lignocellulosic products generated by the development of agro-industrial activities over the last 100 years has been one of the key environmental challenges in producing countries. To contribute to a healthy environment, wastes are recycled mechanically, chemically, or biologically and repurposed as raw materials for new products and applications. It is the so-called circular economy, which seeks to achieve a "zero waste" society. Vine cultivation and winemaking in cellars generate a large amount of trash and by-products, with only a small portion of these materials being reutilized. Furthermore, wine by-products can be used to value functional components or bioactive phytochemicals for the production of medicinal, culinary, and cosmetic constituents [54].

Grapes are one of the most valuable traditional fruits in the world. It can be eaten raw or used to make wine, juice, jam, jelly, raisins, vinegar, and seed oil. According to the entire grape harvest, around 75% of the grapes have been used for wine production. Wine consumption has increased over time, and the concurrent increase in grape pomace output has drawn attention. The primary organic solid waste created by the winery business is grape pomace. It is produced in vast numbers throughout the world as a by-product of the processing and fermentation processes. Grape pomace is mostly made up of seeds and skin [35]. Several investigations have demonstrated the potential to recover phenolic and antioxidant fibers from the skin, as well as seed oil. Grape pomace is high in cellulose, lignin, hemicellulose, phenolic compounds and tannins [35].

3.1 Characteristic of wine by-products

Winemaking produces a variety of residues that are rich in biodegradable chemicals. Although winemaking is considered an environmentally friendly operation, between 1.3 and 1.5 kg of waste is generated for every liter of wine produced [36].

Winery and distillery waste has a low pH (3.8-6.8), electrical conductivity (1.62-6.15 Ds/m), and a high organic matter concentration (669-920 g/L). They contain a high concentration of macronutrients, particularly potassium (11.9-72.8 g/kg), as well as a high concentration of polyphenols (1.2-19.0 g/L) and a low concentration of micronutrients and heavy metals. Because these features are incompatible with agricultural standards, the waste must be conditioned before use [54]. The chemical composition of grape stalks (leaves and shoots), grape seeds, wine lees, and grape pomace differs depending on the source [55].

Leaves of *Vitis vinifera* L. are a less studied and less valorized by-product of grape crops and the winery business. According to the minimal information available, it contains phenolic acids, organic acids, flavonols, tannins, procyanidins, anthocyanins, vitamins, enzymes, carotenoids, lipids, terpenes, and reducing or non-reducing sugars [56].

Grape pomace is a solid waste product generated during the early stages of grape juice manufacturing that contains both water-soluble and water-insoluble components. It has a high moisture content of 40-81% and contains a substantial number of insoluble residues as well as protein, cellulose, and pectin components [55]. Table 1 shows the estimated composition of grape pomace [57].

Table 1

Estimated chemical composition of grape marc

Compounds, %	Raw grape marc	Dried grape marc
Crude protein	12.4	13.6
Crude cellulose	22.5	24.7
Crude lipids	5.4	6
Mineral	6.7	7.4
Insoluble ash	1.3	1.5
Fibers - hemicellulose, cellulose and lignin	55.4	60.8
Fibers - lignocellulose	48	52.6
Lignin	30.8	33.7
Cell membrane	54.6	59.9
Starch	1	1.1
Total sugars,	2	2.2
Energy, MJ//kg	17.4	19.1

Insoluble residues contain a lignin percentage ranging from 16.8 to 24.2% and a protein level of less than 4%. Peptic compounds are the primary polymer-type constituent of the cell walls present in grape pomace, accounting for 37 to 54% of the cell wall polysaccharides, while cellulose concentration ranges between 27 and 37% [58].

Water-soluble substances include polysaccharides, oligosaccharides and monosaccharides, whereas cell wall participating polysaccharides do not demonstrate solubility in water [55]. When we look at its composition, grape pomace is distinguished by its appropriateness for usage in a variety of industrial processes, including the extraction of grapeseed oil and polyphenols, the fermentation of citric acid, methanol, ethanol, and xanthan, and the generation of energy by methanisation. Grape pomace contains phenolic acids, flavan-3-ols, flavonols, anthocyanins, and proanthocyanidins as the primary polyphenols [59].

Wine lees are the remnants that form at the bottom of wine production tanks after fermentation, storage, or further treatment. The lees' usual composition includes yeast, tartaric acid, phenolic chemicals, and other inorganic elements [60]. The sediment that forms when the must ferments must be eliminated. In extreme cases, this can result in waste levels of up to 20% of the harvested grape mass. In some cases, separation procedures can reduce the amount of sediment that forms during fermentation. Yeast sediment is mostly composed of yeast cells and tartar. Their quantities differ depending on the type of wine produced [61]. Wine lees contain both liquid and solid components. The solid parts of wine lees contain cellulose, hemicellulose, lignin, seeds, grains, and organic and inorganic salts.

Vinasse is the liquid part of wine lees generated from residual fermentation broth. It is the principal source of polyphenol compounds and contains around 58% water by weight, with a pH of 3.5 [55]. Vinasse should be used shortly after distillation and clarifying of wine.

Today's society is particularly concerned with the sustainable management of agricultural soils and the water supplies that support them. This setting includes agricultural properties dedicated to wine production. In quantitative terms, each tone of grapes processed produces approximately 3000–4000 L of effluent. The use of wastewater for farm irrigation is being implemented throughout the country, and for it to be acceptable, it must be pre-processed at various levels [54].

3.2 Analysis of the experience of applying the circular bioeconomy to wine enterprises

The concept of circular economy is not yet claimed as incorporated in a lot of studies while being mentioned as a vital topic for future research. In some cases, it was confirmed that, even though the plant did not include in policies a definition of circular economy, the concepts are, in some way, present, particularly with the concern about reducing waste disposal through treatment and recovery, making the best use of resources at all stages of the chain process, and the need to rethink and redesign current practices with sustainability in mind [62].

One enterprise established in 1969 in France to protect the survival of the region's wine cooperatives demanded winemakers to provide their waste from production for distillation in 1970. Since 1994, the company has been diversifying its new products and ingredients into new markets, the food and pet food industries, and nutraceutical enterprises, transforming itself into a small 'biorefinery' with the incorporation of modern bio- and extraction technologies. In 2007, a regional expansion was planned to reach a critical mass of waste, significantly altering logistic supply and demand networks [63].

The Italian wine business can serve as a perfect model for the use of bioeconomy principles, such as the valorization of agricultural and food waste, in the problem of transforming waste into valuable products that can be re-used cyclically. To valorize winery leftovers and enhance overall environmental performance, two side production chains (grapeseed oil and tartrate production) were integrated, and circular patterns were devised and implemented in the traditional production chain [64, 65]. The holistic use of all winery by-products, such as grape stalks, grape pomace, and wine lees, could lead to the establishment of integrated biorefineries for the production of a wide range of goods with diverse market outlets [66].

A performance measurement system can play in tracking the contribution of circular economy partnerships to the sustainability of an agro-waste valorization wine value chain. Furthermore, analyzing the progress of the circular economy concept helps to analyze the responsible production of sustainable development targets at the supply chain level [67].

4. Biotechnologies applied for the capitalization of wine by-products

It is proposed bioconversion as one of convenient ways of winemaking waste valorization. A comparative analysis of bioconversion of various forms of waste demonstrates that cellulose microbial enzymatic degradation is the most effective for grape pomace in waste, allowing us to acquire valuable feed additives while lowering the environmental risk level [68]. Fermenting grape pomace using *Aureobasidium pullulans, Scelorotium glucanium* and *Xanthomonas spp*. strains is used for obtaining microbial polysaccharides [69]. Also, vine shoots might be a suitable feedstock for the manufacture of xylooligosaccharides and galactooligosaccharides [70].

Grape stalk hydrolysis methods produced liquors with varying concentrations of fermentable sugars, which were utilized by *Debaryomyces nepalensis* to produce industrial metabolites. The predominant product of *Debaryomyces nepalensis* growth was ethanol, followed by lactic acid and xylitol in the presence of xylose, which was produced mostly when glucose was exhausted [71].

Fructose and glucose are abundant in white grape pomace, which can be used as a carbon source throughout the fermentation process. *Lactobacillus casei* produced lactic acid, which was used to valorize this waste. 33.3 g/L of lactic acid was produced by adding white grape pomace directly or as a water extract to the growth medium at a solid dosage of 10%. White grape pomace is a viable plant-based feedstock that *Lactobacillus casei* can use to produce lactic acid [72]. Lactic acid can be also produced by fermenting grape vine lees with *Lactobacillus rhamnosus* and *Lactobacillus pentosus* strains [69].

Vinegar has several uses in the food industry, including use as an acidifier, flavor enhancer, pH control agent, flavoring agent, and pickling agent. Because of their high sugar content, grapes and their residues are suitable raw materials for vinegar manufacture by anaerobic and aerobic fermentation [69].

The possibility of using grape pomace as a substrate for the generation of citric acid has also been looked into using solid-state fermentation methods. When *Aspergillus niger* NRRL 567 species fermented grape pomace, the yield was around 600 kg/m^3, whereas *Aspergillus niger* NRRL 2001 species produced a yield of 413 kg/m^3 [73]. Using grape must as a nutrient source, research established the growth and citric acid production characteristics of two *Yarrowia lipolytica* strains. This natural source was shown to be a promising substrate for the citric acid manufacturing process [74].

Agro-food waste can be utilized by microorganisms to make industrially useful enzymes. There are a few studies in the literature on the use of grape pomace for the synthesis of the enzymes pectinase, cellulase, and xylanase by various *Aspergillus* species [73]. For industrial manufacturing of the pectinases, cellulases and xylanases enzymes, *Aspergillus awamori* strain is utilized as well as grape pomace as a substrate [69]. Cellulolytic enzymes can also be produced using grape stalks [75].

Grape waste demonstrated potential as a substrate for the generation of single-cell protein and protein-rich fungi by a variety of microorganisms [73].

Compared to typical chemical catalysts, microbial enzymes are crucial in the valorization of agro-industrial crops and food wastes. It holds enormous potential for effective waste utilization and adequate biocatalytic systems with high conversion efficiencies, allowing the realization of the goals of sustainable development [76].

5. Use of products obtained from wine waste in the food, pharmaceutical and cosmetics industries.

5.1 Pharmaceuticals

Agro-industrial by-products contain a high concentration of bioactive chemicals. It is suggested that combining agro-industrial by-product extracts with a traditional technique could constitute a new strategy for preventing or treating obesity and multiple sclerosis [77].

Employing an atherosclerotic environment model, pressurized liquid extraction enabled the development of stem and seed extracts with significant anti-inflammatory activity. These extracts have a high potential for application as natural components in the creation of anti-atherogenic products. Furthermore, these findings raised the usefulness of winemaking by-products as a source of natural anti-atherogenic chemicals [78].

Studies show that regarding affecting glucose metabolism, it is important to mention, that a single dose of grape juice does not significantly alter glucose metabolism; regular ingestion remains to be investigated [79]. Nevertheless, according to another research, taking two capsules of grape pomace extract twice a day for three weeks reduced blood fasting glucose levels significantly. The *in vivo* regulation of targeted miRNAs linked to glucose metabolism found after grape pomace extract consumption implies a possible role for grape pomace in glucose metabolism, which would lead to a lower risk of type 2 diabetes. Despite this, significant increases in the production of certain short-chain fatty acids and significant decreases in medium-chain fatty acids were seen with grape pomace administration [80]. Grape shoot extracts inhibited α-amylase and acetylcholinesterase enzymes, indicating their potential for application in the treatment of Alzheimer's and diabetes. According to high-performance liquid chromatography analyses of the phenolic profile was the significant contributors to the antioxidant and biological activities of the vine shoot extracts [81].

The first digestion of grape pomace extracts using a dynamic gastrointestinal digestion model was reported [82]. Simulator gastro-intestinal (SIMGI) was created to simulate the actual digestion and fermentation processes. The system consists of three-stage culture reactors designed to simulate the microbial conditions of various parts of the human large intestine *in vitro* [83]. The primary bioaccessible phenolic metabolites produced from grape pomace extract were discovered to be various benzoic, phenylacetic, and phenylpropionic acids. Furthermore, from the SIMGI stable microbiota, a bacteria strain capable of metabolizing (-)-epicatechin gallate, a phenolic molecule found in grapes and wine, was recovered and identified as *Raoultella ornithinolytica* or *Raoultella planticola*. In conclusion, feeding the SIMGI with grape pomace extract increased the metabolic activity of colonic microbiota, particularly during chronic feeding, resulting in a large number of bioaccessible phenolic metabolites. Concurrently, grape pomace extract feeding caused microbial alterations, particularly in the *Lactobacillus* and *Bacteroides* species. Grape pomace extracts are promising candidates for the creation of innovative products with gut microbiota-related beneficial qualities [82]. There is compelling evidence that phenolic compounds can influence the composition of the gut microbiota in humans, hence enhancing a range of biochemical indicators and risk factors for chronic diseases. According to the available literature, metabolites of phenolic compounds generated by gut bacteria, including probiotics, provide a variety of health benefits. These metabolites are more active than their parent food phenolic substances [84].

Microbiological valorization and reutilization of grape marc are based on the biomass synthesis and delivery of antioxidant chemicals by lactic acid bacteria and bifidobacteria [85]. The oligosaccharides found in grapes were examined as potential functional components with prebiotic activity [86].

Strained lees of wines made from crimson glory vine berries could be used effectively as auxiliary materials for the development of interesting sources of natural antioxidants and angiotensin-converting-enzyme and hyaluronidase inhibitors for the prevention and treatment of allergy and lifestyle-related diseases [87]. Anthocyanins have been proven to reduce creatine kinase, muscular pain, and strength loss, and improve power after exercise. Following anthocyanin consumption, there was less inflammation and an increase in antioxidant capacity/status, indicating a possible causative relationship. Subgroup analyses revealed that metabolically biased exercise and longer-term interventions have the most beneficial effect on biomarkers, whereas shorter duration interventions have the most benefit on physiological variables, which can help inform research designs and the application of anthocyanins in exercise recovery. These findings give additional evidence to support the use of anthocyanin-rich meals in boosting recovery after severe exercise, which can help exercisers and practitioners [88]. According to the literature, certain types of stress might change flavonoid metabolism and intracellular accumulation. To move away from the universal approach to dietary recommendations and toward science-based individualized nutrition, further mechanistic research on the impact of health status on flavonoid responses under physiologically relevant micro-environments is needed [89].

The polyphenol-based grape extract suppresses adenovirus Ad-5 replication irreversibly. These findings support the use of polyphenol-based grape extract and Resveratrol as possible sources of promising natural antiviral medicines against adenovirus Ad-5 infection [90]. Also, it was proven that polyphenols are a promising natural therapeutic for both preventing microbial-derived oral diseases and maintaining oral health [91].

A rising number of researchers are currently focused on the biological activities of grapes and grape derivatives as potential sources of useful nutraceuticals. Numerous studies have strongly shown that incorporating grapes and grape products as supplements into our daily diets may result in considerable health advantages. Most of these phytochemicals, however, must be utilized in a precise dose-dependent way to elicit favorable therapeutic effects. Bioavailability *in vivo* is a critical problem to address before determining the level of therapeutic blood concentrations of grape flavonoids. As a result, more research in this area is required. Future discovery of novel renewable sources, such as *in vitro* cell systems capable of continually producing highly pure grape flavonoids, is critical and potentially widespread [92]. Future research should and will include the validation of appropriate biomarkers of effect antioxidant, new cellular and molecular targets, the precise contribution to dietary profiles, and further clarification of *in vivo* biotransformation, including analyses of metabolite biological effects, and the formulation of pro-drugs [93].

5.2 Food industry - technologies and drawbacks

Inedible raw materials can be transformed into more useful, shelf-stable, and pleasant foods or drinkable liquids for human consumption by food processing. Some of the advantages of food processing for phytochemicals include increased bioaccessibility, shelf-life extension, improved sensory features, and functional properties. Phytochemicals may produce more beneficial molecules during food processing as a result of physical or chemical changes. Fermentation, for example, produces a variety of secondary metabolites, some of which have been linked to health benefits. During polyphenol fermentation, some small-molecule organic acids (e.g., citric, malic, lactic acid) are also formed, enhancing iron and zinc absorption via the creation of soluble ligands [94]. Food processing may improve phytochemical bioaccessibility in the following ways: increasing liberation from the food matrix, improving micellization of some hydrophobic phytochemicals, improving phytochemical synthesis, increasing absorption in the gastrointestinal tract, and improving phytochemical stability [94].

Depending on the dosage, the form of the by-product (powder or extract), and the dairy matrix in which it is integrated, the inclusion of fruit and vegetable by-products can have either good or negative impacts on the sensory qualities of the final product [95]. Regarding winemaking by-products, according to several studies, freezing fruits before jam production or adding benzoate do not affect anthocyanin concentration or color when compared to untreated fruits. Furthermore, other factors, such as the addition of ascorbic acid or other natural phytochemicals, did improve the color and sensory qualities of anthocyanin-rich goods [94]. The use of anthocyanins from natural sources is thus approved by European Food Safety Authority (EFSA) and Food and Drug Administration (FDA) [96,97]. Due to a lack of characterization and toxicity data, EFSA did not develop an average daily intake (ADI) for this colorant; hence, consumption as an additive should not exceed the typical intake of these substances. JECFA has not assigned ADI to anthocyanins derived from grape skin extract [98].

It has been established that new green technologies such as pulsed electric fields, ultrasounds, microwaves, high hydrostatic pressure, and supercritical fluid extraction may produce high-quality extracts. These extraction procedures, when combined with purifying operations with resins and membrane processes, result in anthocyanin-rich extracts with lower impurity levels [99]. Furthermore, in terms of anthocyanin recovery, it should be highlighted that encapsulation has been recognized as one of the most significant ways of stabilizing these molecules, particularly given the decrease in anthocyanin concentration in fortified products after thermal treatment and storage [99].

Encapsulating agents operate as a shield against harmful environmental factors such as light, humidity, and oxygen. Bioactive substances that have been encapsulated are easier to handle and have a higher degree of stability. Encapsulation techniques are already widely used to limit interactions between food and medical components and environmental elements like temperature, light, moisture, and oxygen. Microencapsulation of anthocyanins with a mix of maltodextrin and gum arabic resulted in the best encapsulation efficiencies. Spray-drying is a typical process for microencapsulating isolated plant phenolics like anthocyanins. Polysaccharides and other matrix materials such as glucose syrup and soy protein isolate are commonly employed [100].

Peanparkdee et al. had determined that in the case of baked products, the addition of anthocyanin-rich extracts can protect the food from damage caused by baking, while improving its antioxidant capacity. Anthocyanins have good stability during storage in products such as kefir, yogurt, and various beverages, making them suitable foods for anthocyanin fortification. The inclusion of anthocyanins improved the color of processed meals, indicating a feasible alternative to synthetic colorants [99].

It is important to mention that many phytochemicals are lost during food preparation. This process usually occurs in two ways, one of which results in the direct generation of by-products or waste. Some hydrophilic phytochemicals, for example, may be lost while soaking. During the juicing process, some insoluble phytochemicals may be discarded as waste. Others may be damaged or oxidized as a result of chemical changes (food processing frequently causes the breakdown of phenolic chemicals, lowering their concentration in processed meals). As a result, the canning process entails a significant loss of water-soluble and heat-sensitive components, resulting in a lower level of phenolic compounds when compared to the original fresh fruit and vegetable [94].

Unwanted food processing may result in the formation of substances that have a negative impact on the texture, flavor, or color of phytochemical-rich goods, or even cause human health risks. However, by utilizing proper technology, it is possible to optimize food formulations, processing technologies, and preparation processes to reduce or even eliminate their production [94].

The addition of natural substances may affect other qualities such as flavor and odor. Kaimainen et al. assessed the acceptability of natural colorants based on betalains from beetroot and anthocyanins from grapes in different concentrations in model juice. It was discovered that increasing the concentration of beetroot powder as a colorant reduced significantly the acceptability of the attributed flavor, making the product unpleasant and strange, which did not occur with the addition of anthocyanins. However, the same impact was observed when grape marc power was mixed into fettuccini pasta [98]. Natural pigments diffusion in real meals is influenced by a variety of parameters, including composition, pH, water activity, packaging material, and the presence of trace metals. The usage of natural pigments in meals at the concentration levels required to achieve the desired color intensity and hue may result in unacceptable alterations in the product's organoleptic quality [101].

Natural pigments' stability requirements limit their employment in food matrices, such as anthocyanins, which are more stable in foods with low pH. Anthocyanins from grape by-products were added to kefir (pH 4.5) and carbonated water. The authors concluded that the kefir product had better color stability because the half-life time of the total anthocyanins was 27 days, whereas the carbonated water half-life time was shorter (only 6 days), which could be influenced by the type of food matrix over the anthocyanins' stability [98].

Published literature data on the use of encapsulated natural pigments as coloring agents in food products is relatively limited. According to several recent studies, the bioaccessibility and stability of encapsulated plant polyphenols vary depending on not just the encapsulation process and carrier agent, but also the kind of polyphenol. Plant polyphenols encapsulated have the potential to be used in food products. It is also critical in the food business to examine the stability of encapsulated phenolic compounds during food processing [102].

6. Conclusions

The current technological level allows variable ways of winemaking waste treatment, creating different eco-sustainable and bio-based materials (biobased polymers, biofuels, bioactive compounds extracts, grapeseed oil, fertilizers, tartaric acid, and sorbents) with a broad range of application. Those value-added products not only solve the problem of waste disposal but also potentially bring profit to the wineries. Despite traditional methods of treatment being cost-effective or showing high yields, the modern industry should focus on more eco-friendly and sustainable technologies, which are currently proposed by scientific studies.

At the moment, the production of tartaric acid is the most priority for the processing of winemaking by-products for the Republic of Moldova, due to the availability of sufficient raw materials and the high need for use in wine production.

Biogas production takes place only in the case of complex bioprocessing enterprises in order to cover part of the energy costs since its transportation is not advisable.

Production of biobased polymers from winemaking waste opens up a vast opportunity in different practical applications of the final product, with the future possibility of its recycling and decomposition.

Manufacturing of sorbents (activated carbon and biochar) not only solves the issue of organic winery waste disposal but also will benefit in clearing the polluted wastewater, and preserving the freshwater basin, which is vital for the ecology and biosphere as a whole.

Grape pomace is considered to be a good substrate for production of industrial microbial metabolites, because of the high carbon content.

The grape pomace extracts, depending on the processing method, have a high potential in manufacturing profit-generating pharmaceuticals with anti-inflammatory properties or prebiotic formulations due to the polyphenol-rich composition of this raw material.

The incorporation of grape pomace powders or extracts have a high potential for creating functional foods, avoiding the utilization of synthetic antioxidants and colorants. Nevertheless, those technologies still have drawbacks to be solved. Encapsulation should ideally not only help to overcome any instability issues that may impair the efficacy of the coloring, but also make their integration into foods easier.

The Moldovan legislation in force considers the valorization and recycling of winemaking wastes. Nevertheless, the list of products that are allowed for production is limited and needs reconsideration. The elaboration of plant-scale technologies and state quality standards for new value-added products will allow producers to solve the waste disposal problem and attract investments, both national and international in this business domain.

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