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Acquisition of value-added products from plant-based wastes

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Abstract

Plant-based waste generation occurs on a large scale in agriculture, processing, as well as distribution and retailing processes. In such cases, a large part of the waste is not used properly and also it can cause serious environmental problems if it is not managed in a rational way. Thus, plant-based wastes are rich in sugars, fats and phytochemicals, and a number of valuable compounds, including protein and lignocellulose. The assessment of rich compounds in food industry waste minimizes environmental problems and also increases the economic competitiveness of products in the agro-food industry. This research paper mainly discusses the different types of phases of biorefinery systems and the applications associated with these systems, and then presents the recent positive results in the food industry of plant-based wastes for the production of various value-added products. As a result, techno-economic, ecological and social evaluations are conducted around these prospective issues.

From a statistical point of view, in the last ten years, research works directed to the general use of plant-based wastes in order to produce different types of products have increased. For the assessment of waste from the food industry, the complex processing of food waste through the combination of high technologies to produce products in mass form based on the principle of bioprocessing has the necessary advantages. In particular, it should be noted that plant-based wastes can be considered valuable resources for the regular production of biofuels and also chemicals. As a result, there is a great need for diversified economic, social and environmental analyzes for the biorefinery process in the future.

Keywords: plant-based wastes, biorefinery concept, disposal, value-added products, innovative technology.

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1. Introduction

Waste from the food industry remains the most urgent issue in developing countries and even in developed countries. Food waste is considered as the end products of various food processing industries. So, these wastes are considered as non-recyclable or non-useable wastes. From the point of view of economic value, these products have a lower value compared with recovery cost. For this reason, those products are disposed of in appropriate areas as waste. So, if we approach the mentioned waste from a statistical point of view, we will see that they are 1.2 billion tons on average. This statistical indicator is on average 1/3 of the edible parts of food produced for human consumption. Among the reasons for disposal of those wastes are the following issues [1, 2]:

1. Mechanical damage occurring in the production processes of agro-industrial products;

2. Sorting and washing, as well as shelling, extrusion and canning processes in food processing;

3. Occurrence of spoilage of products during the storage and transportation process;

Waste from the food industry ultimately leads to disposal problems. This, in turn, causes damage to the environment. In addition to the mentioned problems, it also leads to significant loss of valuable nutrients.In particular, it should be emphasized that the generated food waste is usually recycled to feed animals and also as fertilizer that can benefit the growth of plants. In other cases, it is thrown into the landfill together with the waste [3].

In recent years, research studies aimed at the complex use of plant-based waste generated during the production process in the food industry to produce various consumer products have been increasing.

Thus, the overall objective of this study is to analyze the latest integrated treatment technologies and applicable processes applied to the various types of plant-based wastes or by-products generated.

2. Experiments

In order to develop the efficient operation of the food industry and also to find a solution to the issues of creating no-waste technology, it is necessary to clarify several main tasks:

1. Show forms of development of low-waste and no-waste technology;
2. To investigate the acquisition of protein substances by rational methods;
3. To analyze the aspect of production carried out by modern methods;

A number of economic changes taking place in the global world have a great impact on the necessity of researching secondary raw materials in production enterprises. In many countries of the world, works on the use of raw materials and waste-free processing technology are widely implemented. For example, in the United States of America, in the production of food products, melon skin, almond skin, jmyx (residue of defatted seeds of oily plants), as well as the remains of dough and bread, and cheese whey are widely used [4]. To give another example, cocoa and bean husks obtained from food production in Great Britain, including beet pulp, are rationally widely used in the industry.

It should be noted that during the process of technological processing of raw materials, waste and also main and additional products are obtained. Here the question arises: What are the factors that cause waste? It includes factors that contribute to the generation of waste, regardless of the type of product produced, the established technological scheme, as well as the type structure of the raw materials undergoing the processing process, and it should be emphasized that they are based on the characteristics of the processing object from a biological point of view [5, 6].

A large amount of industrial waste generated in the food industry is used as secondary raw materials. Secondary raw materials in the food industry are divided into 3 groups according to their sources of formation [7]:

1. Herbal
2. Animal origin
3. Mineral origin

3. Results and discussion

Wastes of plant origin play the role of optimal substrate in the diversification of the raw material base in the fields of microbiology industry. Thus, by means of mineral acids, the polysaccharides contained in the plant wastes have been hydrolyzed and turned into monosaccharides. In short, insoluble sugars are converted into soluble sugars. The resulting mixture of monosaccharides is used as a substrate for microorganisms.

Plant waste is extremely rich in proteins, carbohydrates, as well as minerals and a number of phytochemicals. Since it consists of valuable substances, we must restore the generated waste or, in other words, turn it into valuable products with the help of technological processes. So, since food waste has a mixed composition, evaluating food waste in an optimal form is a matter that should be approached comprehensively.

Therefore, 1 technology is not enough to solve a complex problem. For this reason, products based on the biorefinery system have been mass-produced by combining different types of innovative technologies to achieve the recovery of those wastes. The concept of biorefinery is defined as the ongoing integrated processing of biomass into various marketable fuels, energy and also chemicals. Thus, the essence of the system in the concept of biorefinery is the application of hybrid-based technologies from different industries to an integrated process to divide biomass into blocks such as proteins, carbohydrates and also fats [8, 9, 10].

We can divide the biorefinery concept into 3 rational cycles:

Thus, it uses one type of biomass, one process and also one intended product (target product). An example of this is the dry grinded ethanol process. In this process, the corn crop is grinded, then saccharified, and finally fermented into ethanol (Figure 1). There is very little flexibility in this process.

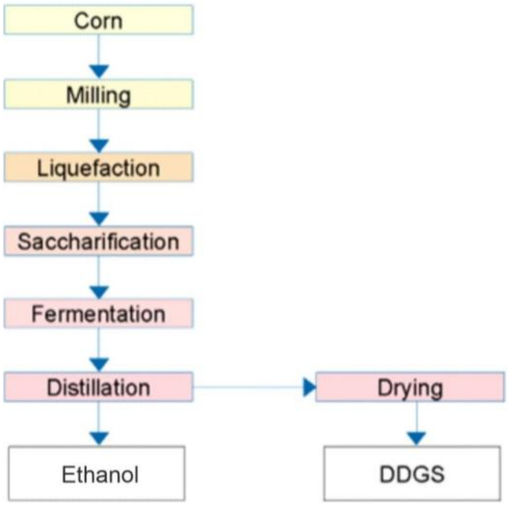

Figure 1. Dry grinded ethanol process

Phase II of the biorefinery has the potential to produce a large amount of product during the process. As an example of phase II biorefinery, we can show corn wet grinding process. By carrying out this process, we can obtain a number of products (such as starch, lactic acid, ethanol, corn syrup and corn oil). (Figure 2). The specificity of the mentioned products can improve the indicators of the biorefinery process from the economic point of view at the necessary level.

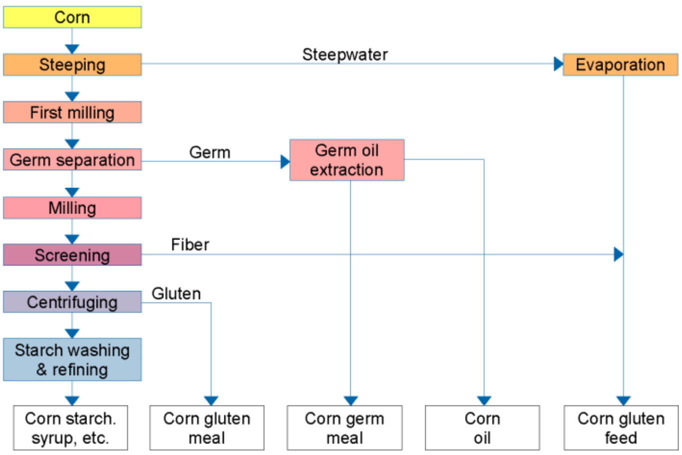

Figure 2. Corn wet grinding process

Phase III biorefinery is very flexible compared to the previously mentioned phases (Figure 3). The flexibility of a phase III biorefinery can be exemplified by its potential to produce value-added products and, in addition, to use different types of feedstocks and processing methods. It should be noted that the potential of using different types of raw materials provides a great basis for ensuring a stable supply of the realized process. This, in turn, can create a basis for increasing the economic expediency of evaluating food industry waste in a rational form [11,12].

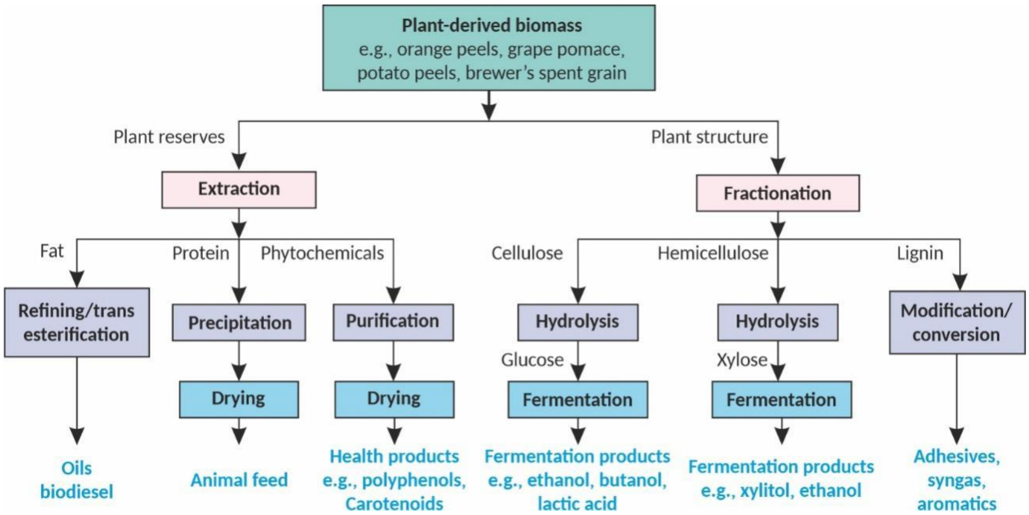

Figure 3. The process of producing value-added products

Plant biomass contains many important substances (for example, proteins, fats, carbohydrates, lignin, vitamins, as well as aromatic compounds). Each type of biomass has physical properties as well as important chemical properties. These properties, in turn, make it possible to largely determine the possible end products used during the biorefining process, as well as the necessary technologies. In a word, it can be concluded that for the progressiveness of the biorefinery of food industry waste, the preparation of a database of physical properties and chemical composition of biomass is an important issue. From another aspect, it is also possible to combine different types of biomass for the production of biomaterials and even biofuels. It should be taken into account that when we carry out the fermentation process, nitrogen, vitamins, carbon and a number of other trace elements should be present in that environment. If we do not combine different biomasses, that is, if we consider one type of biomass, it is very likely that we will not provide them all. For this reason, combining different types of raw materials that contain the necessary compounds is a more appropriate approach.

One of the issues to consider is the processes used to change the chemical structures of biomass. Transesterification, basic hydrolysis, oxidation, and hydrogenation can be examples of processes applied at this time. For example, if we apply the transesterification process in order to change the chemical structures of biomass, it will be possible to convert vegetable oils into biodiesel [13-15].

The non-grain portion of products such as rice straw and also wheat straw is the largest portion of plant-based waste generated during production. The high availability and compositional stability of these agro-industrial products make them suitable feedstocks for large-scale industrial biorefineries. İf we look at the second largest food waste, it is clear that it is the beverage industry, which produces a large volume of pomace, such as grape puree and applesauce. Thus, the composition of grape and apple pomace formed during production in the beverage industry is rich in essential oils, polyphenols, and high-value functional compounds that are considered important, such as vitamins.

We have summarized the composition of various plant-based wastes in figure IV with a percentage indicator. In particular, it should be emphasized that there are certain wastes whose composition may vary depending on regions or processing methods. An example of this is grape harvest. Thus, the composition of polyphenols inside the grapes is directly related to the climate and soil. We can observe this composition difference in the polyphenol content of the waste produced in the wine production process.

Cellulose, hemicellulose and lignin contained in plant-based wastes enable the production of value-added products. For example, we can use cellulose to produce biofuel and also nanocellulose materials. Hemicellulose can be broken down into xylose and then xylitol, which are valuable chemical products. According to its chemical properties, xylitol is a typical representative of polyatomic alcohols. Xylitol is used as a plasticizer and moisture stabilizer in the production of cellophane, and in the paper and perfume industries. Lignin is usually used as a natural binder and adhesive. In addition, with the help of lignin, we can obtain phenols, which are considered valuable compounds. Potentials such as these prove that plant-based food waste is worthy of recovery. This, in turn, leads to directing research work to the production of important chemicals and biofuels from plant-based waste [16-18].

Most of the fruit and vegetable waste is widely used as animal feed. According to statistics, 121 million tons of citrus fruits are produced annually in the world. So, these fruits are on the list of the most abundantly produced products in the world. Azerbaijan has very favorable natural climate conditions for the cultivation of citrus fruit plants. It is planned to increase the production of citrus fruits to 100 thousand tons by 2025. Thus, the use of citrus fruits in the process of juice production results in the generation of large volumes of waste in industrial areas. Pulps, peels, and also its seeds, which make up an average of 50% of the fruit mass, are the waste generated during the production process of citrus fruits. The presence of oils, enzymes, polyphenols, as well as vitamins and minerals in the composition of these wastes provides the basis for mass production of high-value products. Based on these, we conducted such an experiment to obtain ethanol and galacturonic acid:

So, first of all, we applied the steam-explosion method to lemon peels, which were accepted as industrial waste, to obtain essential oils. After this process, we obtained ethanol and galacturonic acid by applying sequential and simultaneous hydrolysis and fermentation methods. The result of the conducted experiment shows that if we conduct the experiment with an average of 1000 kg of fresh lemon peel, then we can achieve more than 60 L of ethanol production.

Chemical compositions in plant-derived waste.								
Plant structure (% of dry matter)				Plant reserves (% of dry matter)				
Plant - derived vaste	Cellulose	Hemicellulose	Lignin	Pectin	Protein	Fat	Sugar	Other valuable compounds
Mandarin peel	22.5	6	8.6	16	7.5	1.6	10.1	
Orange peel	37.08	11.04	7.52	23.02	9.06	4	9.57	4.5 (Flavonoid)
Citrus pulp	20.9	0.4	0.31		6.7		79	1.56 (Phenolics)
Grapefruit peel	26.57	5.6	11.6	8.5	12.5	0.5	8.1	
Grape pomace	9.2 - 14.5	4 - 10.3	11.6 - 17.2	5.4 - 5.7	7 - 14.5			
Apple pomace	43.6	24.4	20.4	11.7				
Pear pomace	34.5	18.6	59.3	13.4				
Carrot pomace	51.6	12.3	32.2	3.88	0.9	0.2		
Wheat straw	32 - 49	23 - 39	5 - 19		2 - 6			
Wheat bran	13	35.5	2.84		17.3		70.3	6.51 (Phenolics)
Brewer's spent grain	21.73	19.27	19.40		24.69			0.65 (Phenolics)
Corn stover	31 - 41	20 - 34	16 - 23		4 - 9			
Soybean hull	51.2	15.9	1.48		10.1		81	4.19 (Phenolics)
Beet pulp	29.7	12.9	3.35		8.77		76.2	4.87 (Phenolics)

Figure 4. Chemical compounds in plant-based waste

As a note we would like to add: We can even get 4 important products called pectin, bio-oil, cellulose and sugar from orange peel which is considered as waste by microwave oven [19, 20].

Every year, the world grape harvest is on average more than 60 million tons. According to statistics, the grape crop is considered the second largest fruit crop in the world. In 2022, 212.6 thousand tons of grapes were produced in Azerbaijan. This means an increase of 1.3% compared to the grapes produced in 2021. Grape products are used in the production of wine, which is considered the main alcoholic beverage. Thus, an average of 80% of the world's grape production is widely used in the production of wine. It should be emphasized that a large amount of waste is generated in the production of wine. Thus, it is possible to divide the waste produced in the field of winemaking into four main categories:

1. Grape puree
2. Waste water
3. Wine juice
4. Grape stalk

Note that 1000 kg of grape pomace consists of 425 kg of grape skins, 225 kg of grape seeds and 249 kg of stalks (Figure 5).

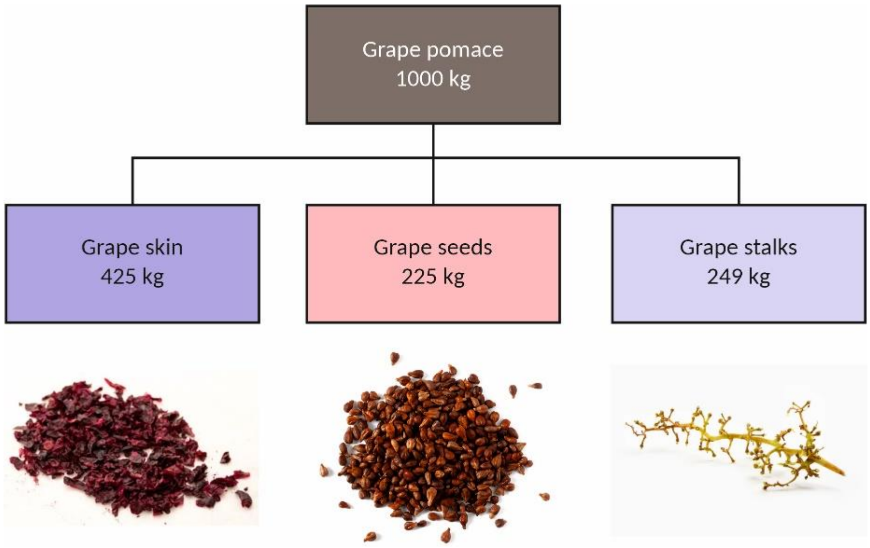

Figure 5. Components of grape puree

It is possible to separate many components from the processed winemaking waste. Examples include grape seed oil, polyphenols, and dietary fiber. Grape stalks are waste from vineyards. They contain cellulose, lignin and also hemicellulose. It should be noted that ethanol was used to precipitate hemicellulose in autohydrolysis solution. Acid was used to precipitate lignin from the autohydrolysis solution. Grape mash is produced during production in the winery. This resulting mixture is considered solid waste. Thus, about 50% of the resulting grape mash consists of the skin, 25% of the seed and the remaining 25% of the stem. It should be emphasized that grape pomace contains a large number of proteins, fibers, polyphenols, minerals and lipids. Let's look at one of the visual experiences: Martinez et al showed the recovery of polyphenols (2.7 g/100 g dry biomass) by applying supercritical CO_2 extraction in red grape pomace. After this process, the extracted residue was sent to anaerobic digestion in the next step, producing a liquid stream rich in volatile fatty acids (20 g/L). This fluid stream was used as a substrate. The goal here was to produce polyhydroxyalkanoates. It should be noted that polyhydroxyalkanoate is biodegradable, non-toxic and environmentally clean. In short, all solid residues have undergone anaerobic digestion to achieve methane-rich biogas [7 ,21, 22].

In particular, it should be emphasized that the anaerobic digestion process generates renewable energy through food waste. Thus, with the help of the anaerobic digestion process, soil nutrients are recycled. Through these processes, the way to the development of the circular economy is opened. Anaerobic digestion uses certain microorganisms. The reason for this is to ensure the breakdown of food waste when there is no oxygen inside the closed system. When food waste is decomposed in this method, it releases methane gas, which is used to transport electricity, as well as heat (Figure 6).

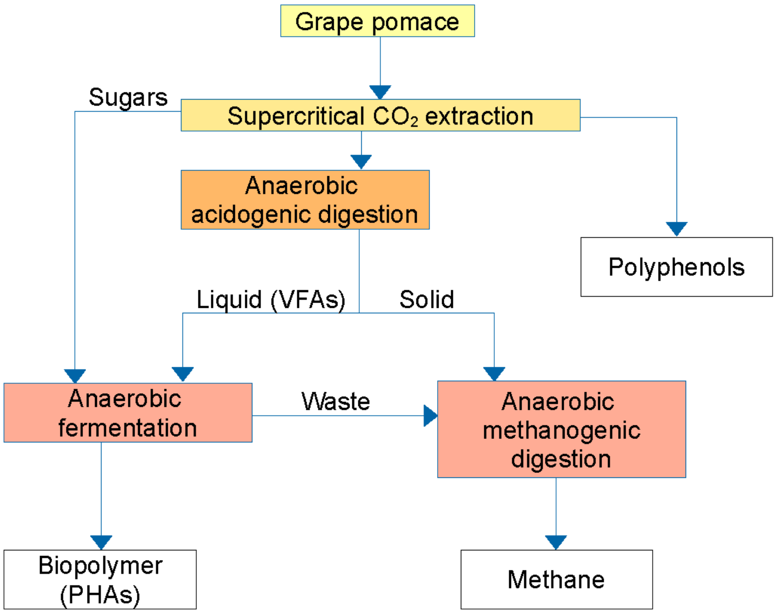

Figure 6. Supercritical CO_2 extraction on red grape pomace

According to statistics, during the last 20 years, apple production worldwide has increased by an average of 66.8%. Currently, the production of apple products worldwide is approximately 69-70 million tons. China is the world leader in apple production. Thus, this country realizes about 48% of apple production. Compared to economic regions in Azerbaijan, Guba-Khachmaz region accounts for 72.2% of apple production on average. On average, 25-30% of the produced apples are used to produce juice. The residue of juice extraction from production is called apple pomace. Apple pomace is usually used to feed animals or as compost. So, since apple puree contains valuable substances such as pectins, polyphenols and carbohydrates, there is a trend of increasing development day by day in the direction of optimal use of apple pomace [21].

China ranks first in the list of tomato production in the world with a share of 31%. This country produces an average of 57 million tons of tomatoes in a year. If we look at the volume of tomato production in greenhouses in Azerbaijan in January-June 2022, we will see that it is 220.1 thousand tons on average. This indicator is 3.3% more compared to the same period last year. Tomato peels contain protein, sugar, polyphenols and a large number of organic acids. The cascade process of biorefinery, newly applied in industrial enterprises of European countries, can be shown to prepare added value products from tomato peels. So, in this process, supercritical CO_2 technology is used to extract carotenoids from the oil fraction of tomato skins and seeds. [14]. Carotenoids are chemical compounds present in food. Carotenoids are a large group that includes different types of molecules. Carotenoids are divided into 2 groups:

1. Carotenes
2. Xanthophylls

Each contains many compounds called lutein and beta-carotene. These compounds are vital in the human body. The reason for this is that it helps to improve important functions such as vision. As a continuation of the process, the residue obtained after the supercritical

CO_2 extraction is used to extract protein by alkaline solution and acid precipitation. In the next step, the resulting protein-free residue is processed with hot water to hydrolyze the cellulose and hemicellulose into oligomeric and monomeric sugars.

Grain is another product that we can use to produce value-added products from the waste generated in the food production process and has promising properties. Grain is considered a product with a high demand flow in the world. It should be emphasized that the products obtained from grain are the basis of the world's food ration. Therefore, the development of grain farming is of great importance. The most cultivated type of grain in the world is wheat. For example, in the Republic of Azerbaijan, during 2022, the main grain products were collected from the area covering 964 thousand hectares. On average, 97% of the harvested grain products, in other words, 933.5 thousand hectares, were made up of wheat and barley fields. It should be taken into account that for every kg of grain harvested from the fields, about 1-1.5 kg of straw and other residues are produced, which in turn leads to the generation of a large amount of grain waste.

If we consider, it is clear that an average of 21% of the global food supply depends on wheat. Day by day increasing demand creates a basis for increasing the production of wheat. When the harvesting process takes place in the fields, waste like wheat straw remains. A number of by-products such as wheat bran and also parts of the endosperm are created during the wheat milling process. Wheat straw contains a number of important substances (cellulose, hemicellulose and lignin). In some industrial enterprises of European countries, extensive experiments were conducted using wheat straw in order to produce bioethanol, biohydrogen and methane. Let's consider the extensive experience with wheat straw.

So, first of all, wheat straw was purified by hydrothermal method in order to obtain a liquid fraction rich in hemicellulose substance and also a solid fraction rich in cellulose substance [23, 24]. After this process, in order to produce bioethanol (0.41 g/g glucose), first of all, the liquefaction process was carried out in solid residues, and in the next stage, the fermentation process was carried out. Then, the process of dark fermentation of the hydrolyzate was carried out in order to obtain biohydrogen (178 mL/g of sugar). As a result, wastes obtained from both bioethanol and biohydrogen processes were combined in a joint form to produce biogas (0.32-0.38 m^3 /kg volatile solids) (Figure 7).

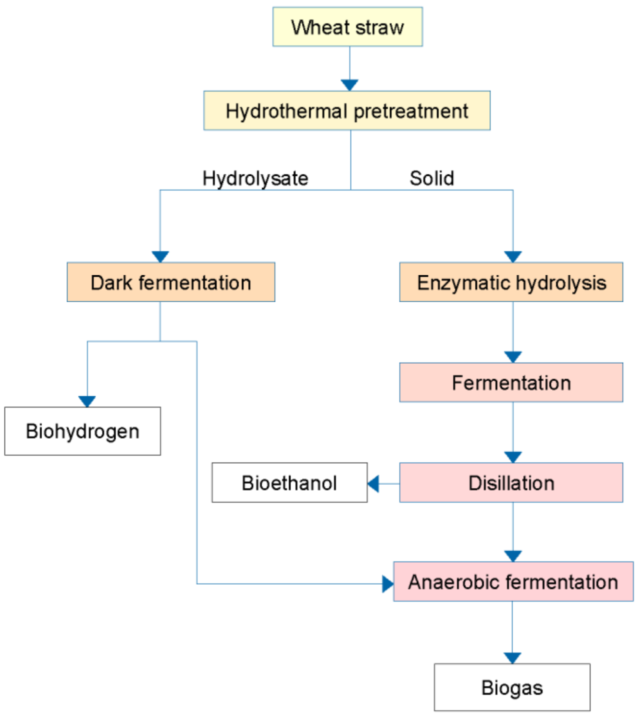

Figure 7. The process of obtaining biogas from wheat straw

Another important product with great potential for wide use of the waste generated in the production process is olive. According to the information provided by the International Olive Council, olive oil is produced annually in the amount of 1.6-2.6 million tons. About 75-80% of the produced olives are consumed by the producing countries. The remaining 20-25% is exported to global markets. The countries that account for 90% of world olive production are Spain, Italy, Greece, Turkey, Syria, France and Portugal. Among the economic regions in Azerbaijan, the Absheron economic zone accounts for 65% of olive production. During the production of large quantities of olives in our country, it is inevitable to generate a large amount of waste.

To obtain olive oil, olives are crushed and pressed, and then the black water is separated. Olive oil is obtained only by physical methods and no chemical methods are used here. Olive oil production produces on average 4 times more waste than commercial oil. This, in turn, is a heavy burden for industry and ecology. Among the wastes generated during the production of olive oil, the wastes that stand out are almost always olive mill wastes. It is possible to produce polyphenols and biofuels from olive mill wastes. By using olive mill waste, we can get fuel and biocoal. So, for the first time, this idea was proposed by Schievano and others. This idea is applied in several enterprises of European countries. This idea is called the olive biorefinery concept. With this concept, the disposal of olive mill waste is realized. The authors, separated polyphenols, polyunsaturated fatty acids and also monounsaturated fatty acids from olive mill waste with the help of supercritical CO_2 technology with ethanol acting as solvent. After this process, the dry solid residues were passed through the pyrolysis process and activated. By this means, fuel and also biochar was obtained. The implementation scheme of the intended process is reflected in the following graph (Figure 8).

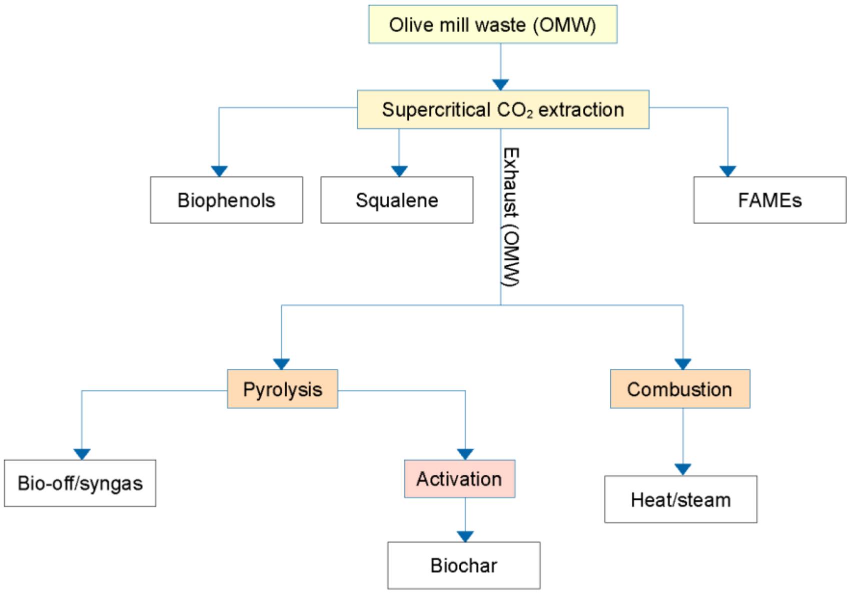

Figure 8. The process of obtaining fuel and biochar from olive mill waste

4. Conclusion

The number of rational studies used for the purpose of designing the biorefinery process to reduce the environmental impact of food industry waste has been increasing in the American and European countries in recent years. At the same time, some important issues, such as the selection of certain raw materials, which should be comprehensively reviewed in the future, important issues such as ecological, economic and also social assessment of those resources, still remain relevant. First of all, it should be noted that in almost the majority of the conducted studies, special attention is paid to the waste generated from cereals or oil crops, while in the remaining parts, the waste generated from fruits and vegetables is not paid attention to. It should be noted that in terms of geographical climate, development in the field of production of plant-based products is constantly increasing in Azerbaijan. In this case, the work that can be done in the direction of the production of value-added products in various fields from the large amount of waste generated during the production of plant-based waste, unfortunately, has not yet taken a priority position in a diversified manner. It should be noted that some fruit and vegetable waste contains a number of rich value-added compounds. In the list of these called value-added compounds, polyphenols and also essential oils have a special place. If we take the initiative seriously, we can use those value-added compounds extensively in the food and even cosmetic industries. It should be especially emphasized that there are a number of food wastes that are generated depending on the season. So, it is not an easy task to save those food wastes. This considered issue, in turn, causes a number of big problems in the process of stable raw material supply of the biorefinery during the year. In short, ensuring the economic feasibility of food industry waste assessment depends on the capacity of the process. In addition to these issues, the transportation problems of the generated food industry waste should also be solved rationally as soon as possible. The complexity of the formed plant-based food waste bioprocessing process requires rational evaluations from an economic as well as a social point of view. For this reason, there is a great need for fundamental empirical research and analysis in the areas under review. If we pay attention, we will see that in most of the rational studies carried out, too much attention is paid to the economic or environmental aspects of the biorefinery process. In such cases, a number of important social issues remain in the background. Over time, these actual issues become problems that are difficult to solve.

Complex processing processes for plant-based waste disposal meet the need to reduce food waste generation problems, minimize energy consumption and improve the sustainability of the food industry as a whole. With the help of modern innovative technologies, food industry waste is processed into valuable added products. However, when we choose a bioprocessing system, some problems such as finding the necessary products from biomass feed resources and also processing ways to achieve high efficiency and minimize the negative impact on ecology are still not solved. For this reason, a comprehensive evaluation of the plant-based food industry waste bioprocessing plant from an ecological and social point of view is necessary in the future. In particular, it should be noted that the concept of biorefinery comes from the field of the oil industry. Thus, an average of more than 150 years was needed for the development of the oil refinery at the required level. From this point of view, the newer plant-based food waste biorefinery concept needs some time to develop in a high form.

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