

Agro-industrial residues: a link in the circular economy chain

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ABSTRACT

Objective: to compile, through documentary research, the potential of agro-industrial residues in different agriculture sectors, through their use as raw material towards generating other economically viable products.

Design/Methodology/Approach: documentary research in different primary and secondary sources of current consultation and databases of Mexico's Government Secretariats (Agriculture-SADER, Economy, and Natural Resources-SEMARNAT), to analyze the importance of agro-industrial waste as a source of raw material in processes that generate value-added products. The analysis of the information focused on highlighting the importance of the current use and transformation of residues and waste generated in various sectors of the agri-food industry. Also, in the identification of the challenges faced by this industry to achieve a circular economy. Emphasis was placed on innovative strategies and research aimed at converting these residues into value-added products.

Results: according to the sources consulted, about 35% on average of the raw materials used in food production end up as waste. Many of these residues have bioactive, nutritional or functional properties that make them suitable for alternative applications. In recent years, agro-industrial by-products and residual fluxes have attracted the attention of the scientific community due to their potential for valorization. A synthesis of information on current food products was obtained that give a guideline to generate usable waste and with easily extracted active compounds. Certain components of residues, nowadays wasted, can be reintegrated into the production cycle as raw materials for new processes, thus reducing environmental impact and promoting a circular economy.

Limitations/Implications of the study: only databases with official information were consulted; without discrimination for specific or extensive documentary sources by subsector or product. However, innovation was identified and emphasized in those by-products identified with the greatest potential for transformation.

Conclusions: despite the interest in sustainability and minimizing environmental damage, the environmental problem and non-sustainability of the food industry that often affects the country occurs because the industry continues to be aligned with a linear economic model of extraction, production and disposal that generates a considerable amount of waste. Limited infrastructure for waste recovery in new value chains is a barrier to the large-scale implementation of circular economics principles, which is another crucial step in achieving long-term sustainability.

Keywords: food industry, valorization, zero waste, sustainability.

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INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO, 2020) defines agribusiness as the set of economic activities that favor the transformation of products from agriculture, livestock, fishing and forestry into more valuable final goods. That is, the production of raw materials and intermediate products derived from the primary sector, which creates employment opportunities and contributes to global economic development.

On the other hand, according to the Secretariat of Agriculture and Rural Development (SADER, 2016), there are five types of agribusiness: food, non-food, supplier of raw materials, consumer of raw materials and artisanal. Food agribusiness comprises raw materials from the agricultural, livestock, aquaculture and forestry sectors, and is aimed exclusively at obtaining food. Meanwhile, non-food agribusiness is responsible for the transformation of agricultural products into non-food products such as wood, flowers, tobacco, fibers, dyes, among other very diverse products.

In a similar and complementary way, the raw material supplier industry is engaged in the initial processing of agricultural products such as milling, tanning, pressing, sawing and canning. While the raw material consuming industry is responsible for the manufacture of articles based on intermediate products derived from agricultural materials, such as the manufacture of paper, fabrics, clothing, footwear or rubber manufactures. In each of the aforementioned agro-industries, residues and waste materials are generated, biomass that is not fully used. These agro-industrial residues can constitute a real pollution problem in some parts of the world due to the increase in the demand for food consumption, which forces a constant increase in food production.

The main negative impacts on agribusiness are related to the contamination of soils and aquifers, as well as the emission of gases that contribute to the greenhouse effect. This is due to the elimination of solid, liquid and semi-liquid waste with a high concentration of organic load, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) that require adequate sanitation to minimize their environmental impact and excessive expenses that this industry sometimes fails to cover. However, agro-industrial waste can be an important and rapidly developing source of accessible raw material with low cost of production. Because they are derived from a main process, the industry accounts for expenses in the production of that main product and not the by-product. In addition, any agro-industrial residue can be converted into various by-products, which generates added value and less environmental pollution.

To explore various options, the objective of this review was to compile, through documentary research, the potential of agro-industrial residues in different agriculture sectors, through their use as raw material towards generating other economically viable products.

MATERIALS AND METHODS

A database search and documentary review of recent scientific articles was done on official websites of the Secretariat of Agriculture and Rural Development (SADER), Secretariat of Economy (SE), and Secretariat of Environment and Natural Resources

(SEMARNAT), among others. The keywords considered important information related to food production and waste generation from the food industry.

The criterion for determining the objects of analysis comes from Mexico's General Law for the Prevention and Comprehensive Management of Waste (PROFEPA, 2023); according to which, waste is "those materials or products whose owner or possessor discards and which are in a solid or semi-solid, liquid or gaseous state, are contained in containers or deposits and may be susceptible to recovery or require treatment or final disposal in accordance with the provisions of the same Law". Although their disposal is intended to avoid health or environmental problems, the scarcity of some raw materials or the depletion of their sources means that residues can be reused or included as a constituent part of other processes.

The analysis was emphasized on agro-industrial waste, which is waste, by-products, or leftover solid or liquid materials of organic origin that are generated during the processes of reception, production and processing, packaging, and even storage of agricultural, livestock, and food products (Romero-Sáez, 2022). The by-products identified by the analysis come from the livestock, poultry, and cattle and sheep breeding sectors; from the food industry (production of dairy, meat, fruits, vegetables, bakery, or additives); from the beverage industry (juices, wines, beers); from the sugar sector (bagasse, molasses, and blackstrap molasses); as well as from the confectionery industry and oil industry.

RESULTS AND DISCUSSION

Agro-industries that generate waste

Food agro-industries includes the production, processing and marketing of products for consumption as human food. This industrial sector includes sugar production; the non-alcoholic beverage industry, and the beer or table wine industry; the dairy industry, with the production of cheese, yogurt, and packaged liquid milk; the meat industry, which produces cuttings of meat and sausages; the bakery industry (bread, pasta); the canning industry (such as dressings, sauces and dips); as well as the confectionery industry.

Each of the agro-industries described above generates between 35-40% of residues throughout the production chain, due to the natural or induced deterioration of food, or as part of its preparation. Residues from the food agro-industry can be classified into agri-waste (agriculture debris, such as stems, leaves, or roots discarded in the harvesting process) or by-products. Agriculture debris are also known as waste, because in most cases they are only discarded and disposed, because they are not recognized as valuable to be used in other production processes. Although there are some examples reported of agricultural residues used in composting, energy generation (Razia *et al.*, 2024); construction materials (Vieira *et al.*, 2025); fertilizer production (Mahish *et al.*, 2025) and in the extraction of bioactive compounds (Panda *et al.*, 2025).

On the other hand, there are processing residues or by-products (pulp, bagasse, seeds, fibers, bones, serums, wastewater, among others). Also known as discarded products, which are materials that are generated during processing, but are not the main products. These are disposed as well because they are not considered valuable to be used in other production processes. As by-products are included, the harvest remains of fruits and vegetables, peels

or husks, and seeds from agriculture use; and from livestock, blood, bones, skin, fat, as well as those products that do not meet quality standards for sale to the consumer.

Food industries must implement good waste management, separating residues, classifying them not to be mixed with other stuff or chemicals, to avoid the risk of turning them into hazardous waste that cannot be used again, such is the case of some chemical waste derived from transformation processes. The consumer also discards packaging that is a mixture of plastic, metal and paper which are difficult to separate, among others. Each food industry has specific process residues or by-products that depend on the type of main product that is generated. Some have the potential to be used, through being reprocessed to become raw materials for other products. So, those can generate other forms of marketing that minimize pollution; examples are described in the next section.

Sugar industry

The sugar industry is engaged in the production, processing and marketing of sugar or sucrose from sugarcane (*Saccharum officinarum*). In Mexico, 55 589 515 tons (Megrams, Mg) of sugar approximately are produced per year, which position this country in the eighth place as sugar producer worldwide (SADER, 2024). The general flow chart for obtaining sugar shows the most important stages of the process; and it is worth mentioning that each mill or industry has clear specifications for its individual or peripheral processes (Figure 1).

In general, once the sugar cane is harvested, it is transferred to the mill to wash it and obtain the juice by crushing and squeezing the cane. In this part of the process, the first residue, called bagasse, is obtained. Later, the juice goes through a process of evaporation of water by heating and in this way the sugar is concentrated.

This results in a denser and darker syrup due to enzymatic browning, and the obtained residues are the molasses, which are the most important fraction in the process to obtain sugar. Finally, the sugar crystals are separated from the remaining liquid by centrifugation;

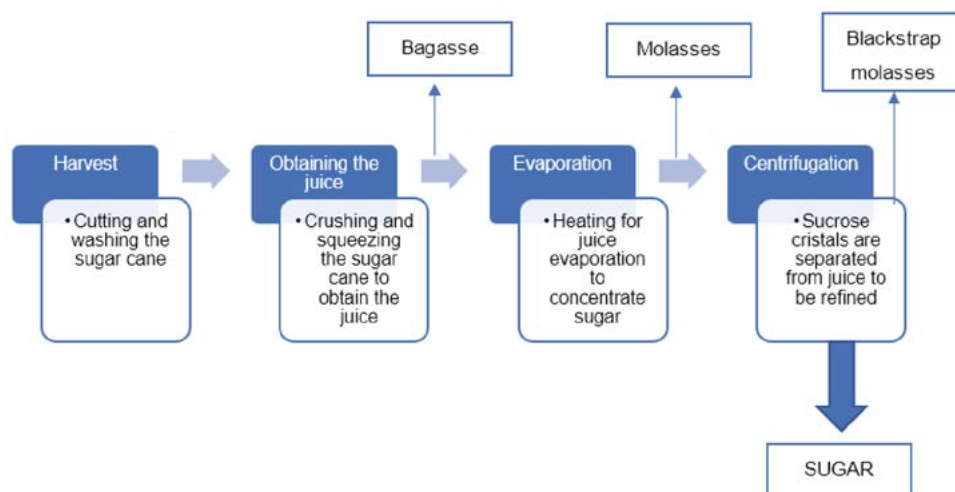


Figure 1. General diagram of sugar production, as obtained from sugar cane (*Saccharum officinarum*). Source: original prepared by the authors.

and they are refined to obtain brown or white sugar. The darkest and densest waste obtained here is another by-product called blackstrap molasses.

Sugarcane bagasse is a fibrous waste composite of cellulose, hemicellulose and lignin, and is used as a material for construction, energy production, and bioplastics production (Phiri *et al.*, 2024). Whereas, molasses are dense and dark liquids that contains non-crystallized carbohydrates, minerals and vitamins, whose uses are mainly as a sweetener (Camelo-Rangel *et al.*, 2025) and for citric acid production (Dementev *et al.*, 2024). Blackstrap is a jellified and dark by-product formed from the sediments of tanks that contain water, impurities, waxes, soil particles; hydrocarbons and residual dissolved sugars from the sugar cane. Blackstrap molasses is used as fertilizer (Singh *et al.*, 2025).

Currently, waste derived from the sugar industry is part of an area of opportunity to produce other viable compounds of economic interest that could even be reused by the sugar industry itself. Such is the case of biogas production (as fuel in the mills), or the return of some residues to be used as fertilizers in sugarcane cultivation.

Beverage industry

In Mexico, according to unofficial sources, more than 35 billion liters (L) of sugar beverages were produced to be consumed in 2024. This figure corresponds only to the non-alcoholic beverage industry, which includes soft drinks, juices, nectars, functional drinks, among others. On the other hand, alcoholic beverages are represented by the beer industry and the wine industry. In Mexico, the beer industry is paramount because of a great recent growth; just in 2023, 13.64 billion L were produced, representing an economic contribution to the country equivalent to 1.6% of the national Gross Domestic Product (GDP) (SADER, 2024).

Then there is the wine industry, Mexico produces around 39.6 million L of grape wine per year, some of which are of world quality, which makes the country to have an impact and to be characterized by the flavor and texture of its wines. Both the non-alcoholic beverage industry and the industries that produce beer and table wines generate residues with opportunities to be used as raw materials that can be transformed into other important products. Examples are, in the brewing industry, beer bagasse, residual brewer yeast and filtration residues (diatomaceous earth) which are considered as waste, but can be mainly used in bio-digesters for biogas production (Lozano-Tever, 2024).

Dairy industry

Mexico is in fourteenth place in milk production worldwide (CANILEC, 2024). The dairy industry in this country produced 13.3 billion L of milk, with Durango, Coahuila and Jalisco as the states with the highest production in 2023. Among the main products, cheeses, cream and yogurt were obtained; 1.4 billion L of milk were needed to produce them in that year, and 617 726 Mg of cheeses were produced, among which fresh cheese, double cream cheese, and Panela, Chihuahua, Manchego and Oaxaca are the most important types. These processes in turn originated around 984 million L of whey, the main waste generated by the dairy industry, which represents a danger of contamination if

it is thrown directly into streams or other bodies of water, due to the high concentrations of organic matter it contains.

Among the main evidence of whey use is the extraction of enzymes, such as lipases and peptidases (Sumny & Kempka, 2025); the extraction of organic acids, such as gluconic acid and lactic acid (Mukherjee *et al.*, 2023); and the generation of biofuels, as a bio-digestion substrate for bioethanol and bioenergy production (Kumar *et al.*, 2023).

Meat industry

The meat industry produces chicken, beef, and pork, which represent the most consumed animal species in Mexico, with a production of around 7.8 million Mg in 2023; in this production, about 40% of the inputs are waste (SADER, 2024). The main waste generated by the meat industry during the slaughter, processing and packaging of meat includes organic waste such as skin, blood, feathers, bones, fat, gastrointestinal contents and other inedible materials. But packaging materials, including paper, plastic and metal, are also discarded in processing and consumption. This, not to mention the waste that is generated by rearing and breeding these animals.

Among the alternative uses reported for this waste, in recent years its use is worth noticing for composting and its application as fertilizer; also, to generate biogas via anaerobic digestion (Samuel & Oluwoye, 2024); bones and viscera used for animal feed (Ogava *et al.*, 2024); leather for bags and footwear; and gelatin production (Demaman *et al.*, 2025).

As can be seen in the previous options, most of the viable alternative uses for processing waste or by-products are in composting and fertilization. But also, in the generation of energy (biogas or biofuel); and in the extraction of bioactive compounds such as phenols, for food or pharmaceutical applications. This reflects the great potential that waste processing has, for promoting the generation of alternative sources of commercialization; which are necessary, in many cases, to support the approach of circular economy.

CIRCULAR ECONOMY

The circular economy is an economic system designed to eliminate waste and keep resources in use for as long as possible. According to the definition of the FAO (2020), it is an economic approach “that aims to reduce the use of raw materials in the production chain, as well as the waste generated in it”. The circular economy is based on the principles of sustainable production, through the reuse of waste to create new products; and with the reduction of pollution or the environmental impact of production, to allow the regeneration of natural systems.

The implementation of a circular economy that makes use of agro-industrial waste directly connects the environmental, economic and social parts of the principles of sustainable management. For example, in the environmental field, it minimizes waste and garbage generation, as well as pollution; fewer greenhouse gases are generated and less dependence on non-renewable resources such as oil or agrochemicals is generated. Likewise, alternative energies such as the generation of biofuels are used; or biological

fertilizers are produced that have the same characteristics of a chemical or synthetic fertilizer, with the difference of less damage to the soil microbiome (Shieh *et al.*, 2025).

In the economic sphere, new products are developed that generate new sources of employment, open new markets, and savings in production costs due to the alternative use of the by-products generated. In addition to favoring the local reuse of resources that improve sustainability and self-sufficiency, to achieve resilience in the supply chain.

In the social sphere, the formation of development, research and innovation pathways with a circular approach and zero waste are promoted, where everything is taken care of and progress is made towards the sustainability dictated several decades ago. The circular economy can be put into practice in all agribusinesses, but its application depends on the type of agro-industry, the nature of the waste it generates, and the technology and infrastructure available.

The key principle of the circular economy is to close resource cycles, which is particularly compatible with bio-based sectors such as agriculture. Some examples of circular economic generation, not cited among the examples already mentioned, were added in Table 1.

Challenges and limitations of the circular economy

This section discusses some implications and challenges in the exercise of the circular economy.

Economic viability. Some waste recovery processes require a high initial investment or complex technology that may be unaffordable for smallholder farmers or developing regions.

Lack of infrastructure. Collection, processing and distribution systems for waste recycling may be non-existent or underdeveloped, especially in rural areas.

Gaps in policies and regulations. Inconsistent waste management policies, lack of incentives, or regulatory issues can impede the implementation of circular economy practices.

Technical restrictions. Some types of agricultural waste are more difficult to process, or less suitable for current reuse technologies, for example, mixed or contaminated waste. In other words, the circular economy also implies a correct and efficient separation and classification of waste.

Market demand. Even if products such as compost, bio-charcoal or bioplastics are produced, there must be a market willing to pay for them. Current markets, however, often

Table 1. Examples of agrifood industries that apply the circular economy approach.

Agrifood industry	Type of waste	Circular economy-based solution	Source
Milling of cereals and grains	Peel, bran and powder	Biomass to generate biofuel; dietary fiber; Packaging Material	Gari <i>et al.</i> , 2024
Coffee/cocoa	Peels, pulp	Composting; cosmetics; substrate for fungal growth	Kongor <i>et al.</i> , 2024
Palm oil	Clusters of empty fruits; husks	Bio-charcoal; composting; biogas production	Singh <i>et al.</i> , 2025

do not take risks, because consumers prefer to buy what they know, without recognizing the environmental or economic implications of obtaining the products that are the most commercialized.

CONCLUSIONS

Creating a circular economy with agro-industrial waste is not just about reducing environmental damage, but about a strategic opportunity to add value, drive innovation, and build more sustainable food systems. It is a move from a linear model of “extract-make-dispose” to a closed-loop system where waste becomes a resource.

The circular economy approach is adaptable to all agribusinesses and agro-industries, but its success depends on adapting solutions to local conditions. As well as investment in enabling economic systems, and the promotion of a change in mentality, which starts from the elimination of waste to the optimization of resources.

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