

# Agro-Waste Management

Subjects: **Agriculture, Dairy & Animal Science**

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It is urgent that we increase global food production to support population growth. Food production requires significant resources, amongst them water and energy. Therefore, any losses of food or other agricultural products also means a waste of water and energy resources. A significant amount of these losses occurs during the postharvest stage, primarily during processing and storage. This is considered avoidable food waste. The water-energy-waste nexus (WEW), and its relationship to food production, needs to be investigated from a circular bioeconomy lens. Furthermore, alternative uses of the wastes should be investigated.

agroecology

bioenergy

biorefinery

compost

food security

## 1. Introduction

Agricultural wastes (agro-wastes) are defined as the residues that result from growing cultivated crops and/or during the first processing of raw agricultural products including vegetables, fruits, dairy products, meat, poultry, and other products [1]. Agro-wastes are produced during farming activities including horticultural, seed growing, dairy farming, livestock breeding, grazing, nursery plots, market gardens, and forestry or woodland production [2]. Agro-wastes can be classified into liquid, solid, or slurry forms [1]. Nearly 30% of the agricultural goods produced worldwide end up as agro-wastes. The residues of raw agricultural products may include animal and plant residues (e.g., manure, different crop residues, wastes from activities like pruning, harvesting, growing, fertilization) and applied pesticides (as hazardous and toxic agricultural wastes). Several studies have quantified agro-wastes generation and the environmental consequences of these wastes such as global nutritional and environmental losses due to food wastes [3], using digital agricultural technologies [4] and sustainable management with a focus on reducing food wastes as a more eco-friendly and economical option than treatment [5].

Utilization and management of agro-wastes have also been discussed from different points of view, such as production of pharmaceutical ingredients [6], biochar [7][8], nanomaterials like nano-silica and nanocellulose [9][10], agro-composites for packaging purposes [11], asphalt binder or natural aggregate in concrete [12][13], nano-adsorbents [14], composts [15], bioenergy production or biorefining approaches [16][17][18], and bioactive compounds [19][20][21][22]. The sustainable management of agro-wastes should be adapted under the food-energy-water (FEW) nexus, as agro-wastes are critical resources that, if properly used, can underpin human livelihoods and wellbeing. In this research the researchers will argue that how people treat agro-wastes will impact their ability to achieve the *Sustainable Development Goals* of the United Nations [23]. The FEW nexus includes natural resources (e.g.,

energy, land, and water) and wastes. The global demand on the FEW nexus constantly increasing, as reported by many researchers (e.g., [\[24\]](#)[\[25\]](#)[\[26\]](#)).

The researchers believe that simple illustrations may help in understanding complex situations. Based on the concept that “*one photo is worth one thousand words*”, the researchers recently published pictorial studies on soil and humans [\[27\]](#), the soil-water-plant-human nexus [\[28\]](#), management of salt-affected soils [\[29\]](#), global soil science education [\[30\]](#), soil restoration and macro-fungi [\[31\]](#), and plant nutrition for human health [\[32\]](#). Other photographic reviews/mini-reviews were published on agro-practices and activities such as nano-grafting of vegetables [\[33\]](#), sustainable applications of mushrooms [\[34\]](#), nano-farming [\[35\]](#), smart farming [\[36\]](#), smart irrigation [\[37\]](#), and smart-fertilizers [\[38\]](#).

## 2. Management of Agro-Wastes

The best approach to waste management is to avoid creating waste. The second-best approach is to recycle and re-use agro-wastes to produce compost, organic fertilizers, and other products. Food wastes can be sustainably managed through the 4 R rule: “reduce, reuse, recovery, and recycle” [\[39\]](#). The sustainable management of agroforestry wastes can be achieved using the sustainable biorefinery by collecting wastes and valorization, or recycling those wastes into valuable products such as organic fertilizers, biofuel, biochar, and industrial chemicals rather than engaging in traditional approaches, which include thermal management, landfilling, and decomposition [\[40\]](#)[\[41\]](#). Other sustainable utilizations of agro-wastes include producing biodegradable polymers [\[42\]](#)[\[43\]](#), or in wastewater treatment as adsorbents such as agro-waste based materials made from potato, tomato, apple, banana, citrus, grape, and mango [\[44\]](#). The management of agro-industrial wastes using solid state fermentation to produce bioactive compounds has been reported in multiple studies (e.g., [\[45\]](#)[\[46\]](#)). Agro-industrial by-products are considered a sustainable source for producing a wide array of bioactive compounds [\[47\]](#). A survey of selected crop wastes and the bioactive compounds extracted from them is given in **Table 1**.

**Table 1.** The main bioactive compounds extracted from selected horticultural crops.

Plant	Family	Agro-Waste	Bioactive Compounds	Refs.
Almond: <i>Prunus dulcis</i> (Mill.) D. A. Webb	Rosaceae	Seed coat	Catechin, kaempferol, isorhamnetin, naringenin, quercetin	<a href="#">[48]</a>
Apple: <i>Malus domestica</i> (Suckow) Borkh.	Rosaceae	Pomace, seed, peel	Anthocyanins, catechin, caffeic acid, phloretin glycosides, quercetin glycosides	<a href="#">[49]</a>
Banana: <i>Musa</i> sp.	Musaceae	Peel, stalk, pulp	Anthocyanins, auroxanthin, cyanidin, catecholamine, delphinidin, flavonoids, hydroxycinnamic, lutein, neoxanthin, α-and β-carotene, β-cryptoxanthin	<a href="#">[50]</a>

Plant	Family	Agro-Waste	Bioactive Compounds	Refs.
Date palm: <i>Phoenix dactylifera</i> L.	Arecaceae	Pulp, seed	Phenolic acids, fatty acids, flavonols, sphingolipids, steroids	[51]
Durian: <i>Durio zibethinus</i> L.	Malvaceae	Peel, pulp, rind, seed	Glutathione, $\gamma$ -glutamyl cysteine, pyridoxamine, cysteine, leucine	[52]
Grapefruit: <i>Citrus × paradisi</i> Macfad.	Rutaceae	Peel, pulp, seed	Neohesperidosides, naringenin	[53]
Lemon: <i>Citrus limon</i> (L.) Osbeck	Rutaceae	Seed, peel, pulp	Apigenin-6, caffeic acid, coumarate, ferulate	[54]
Mango: <i>Mangifera indica</i> L.	Anacardiaceae	Exocarp, pulp, seed	Flavonoids, gallates, hydrolysable tannins, methyl gallate, phenolics	[55]
Pineapple: <i>Ananas comosus</i> L. Merr.	Bromeliaceae	Stem, pulp, peel	Catechin, epicatechin, ferulate, gallic acid, phenolics	[56]
Pomegranate: <i>Punica granatum</i> L.	Lythraceae	Pulp, seed, peel	Anthocyanins, flavonoids, gallic acid, punicalagin	[57]
Strawberry: <i>Fragaria × ananassa</i>	Rosaceae	Sepals and peduncles	Phenolic compounds and antioxidant capacity	[58]
Carrot: <i>Daucus carota</i> L.	Apiaceae	Peel	Anthocyanidin, $\alpha$ -carotene, carotenoids, $\beta$ -carotene	[59]
Potato: <i>Solanum tuberosum</i> L.	Solanaceae	Peel, tuber, leaf	Anthocyanin, caffeic acid, carotenoid, lutein, caffeoylquinic acid	[60]
Rice: <i>Oryza sativa</i> L.	Poaceae	Husk, straw, bran	Anthocyanins, caffeic acid, phytosterols, pantothenic, niacin, pyridoxine, tricin	[61]
Soybean: <i>Glycine max</i> L. Merr.	Fabaceae	Husk	Chlorogenic acid, ferulate, gallic acid	[62]
Tomato: <i>Solanum lycopersicum</i> L.	Solanaceae	Peel, pulp, seed	Caffeic acid, chlorogenic acid, lycopene $\beta$ -carotene,	[63]
Wheat: <i>Triticum aestivum</i> L.	Poaceae	Bran	Caffeic acid, ferulate, gallic acid, p-coumaric acid	[64]

remove them from the field after harvesting [65]. Crop residues can have both positive and negative impacts on an agroecosystem, depending on the chemical composition of the residue. If the crop grew in polluted soil the residues may contain hazardous materials and/or harmful microbial species that threaten human health [66]. However, several positive outcomes can arise from leaving residues in a field, including mineralization, or release of nutrients, into soils and increased nutrient uptake efficiency [67]. In developing countries, landfilling and/or burning agro-residues after harvest is a common practice [68]. About 35, 85 and 45% of N, P, and K, respectively, taken up by rice plants remain in vegetative parts and may be re-used to feed soil and nourish cultivated plants [69].

Composting is a microbial process, by which the decomposition, biodegradation and bioconversion of agro-residues can be accelerated from complex materials into simpler organic and/or inorganic soluble forms [70]. This process mainly depends on factors including the kind of agro-wastes, their C:N ratio, and environmental conditions such as pH, aeration, moisture content, temperature, etc. (Figure 1, Figure 2 and Figure 3). In general, some essential chemical fertilizers (NPK) need to be applied to start the composting process along with the addition of plant growth-promoting bacteria (PGPB) [69]. The PGPR help decompose and process the compost (i.e., organic matter), forming a bioorganic fertilizer with many bioactive compounds or enzymes that stimulate biological processes that enhance the bioavailability of nutrients to cultivated plants [71]. The role of PGPR may also include enhancing the germination of seeds, growth of plants, soil rehabilitation, and biological suppression of diseases in soil [69]. Furthermore, PGPB can produce phytohormones that mediate nutrient and water uptake and improve plant growth and yield due to high root proliferation [72]. Agro-wastes from horticultural crops are used to extract many bioactive compounds, as reported by Khaksar et al. [73] and in Table 1. The main challenges that face food waste composting include odorous substances and leachate production, which should be collected and treated for pollutants [74].



**Figure 1.** Horticulture and field crops are primary sources for agro-wastes such as date palms. The upper left photo shows waste in a horticultural nursery. The upper right photo shows the same wastes after crushing. The lower photos show maize (left) and citrus (right) residues. Photos courtesy of El-Mahrouk and El-Baily.



**Figure 2.** Crushed wastes can be used to prepare compost to improve the properties of sandy soil and be used in growing media in horticultural nurseries. Banana compost (A); banana compost and sand (1:1) (B); date palm compost (C); date palm compost and sand (1:1) (D). Photos courtesy of El-Mahrouk.



**Figure 3.** Different kinds of banana wastes, including leaf wastes (A), peduncle wastes (B) (upper photos), pseudo-stem wastes (C,D) (middle photos), and wastes belong in vitro seedlings, which harvested this year (photo E) and last year (photo F). Photos courtesy of El-Mahrouk and El-Baily.

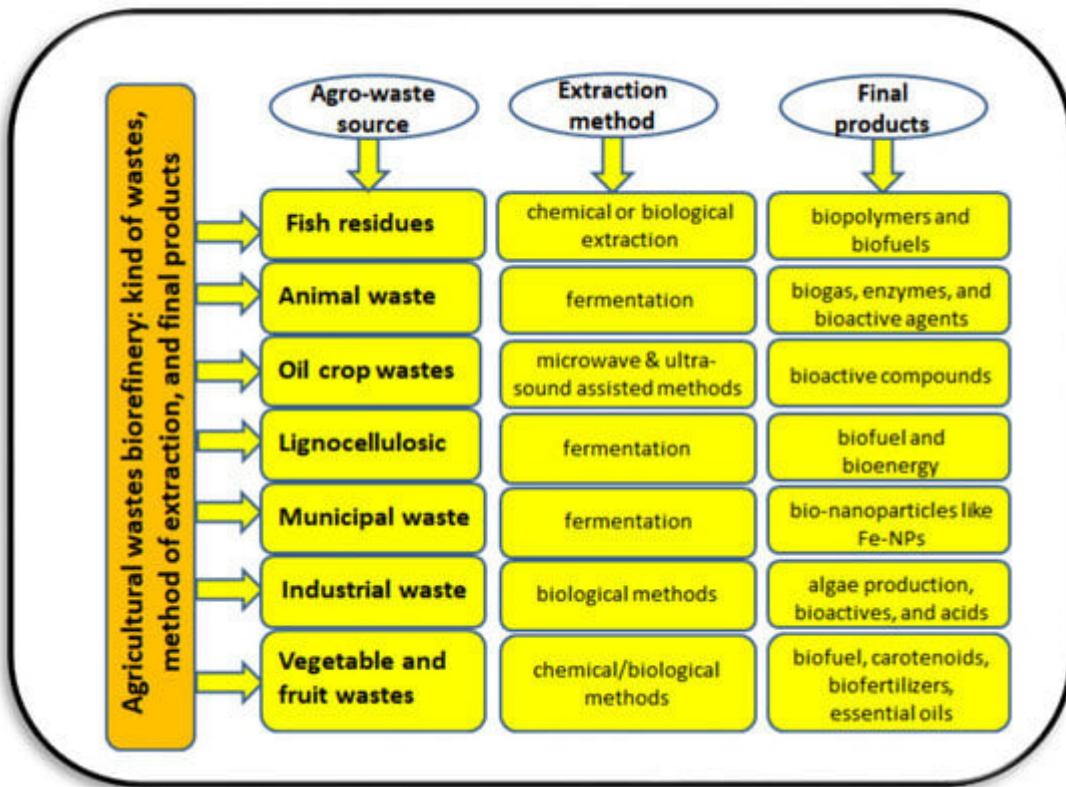
The accumulation of by-products (wastes) produced from the vegetable and fruit processing industries are a potential pollution hazard, as these wastes contain many bioactive molecules (e.g., coloring pigments, phenolic compounds, essential fatty acid, flavonoids, pectin, proteins, dietary fibers, and vitamins). Instead of releasing these into the environment through landfilling, these bioactives could be utilized in industries including food, cosmetics, pharmaceuticals, and textiles [75]. The extraction of the bioactive compounds mainly depends on the extraction technology, the type of by-products (wastes) and their characteristics, and water and energy inputs. In general, the most common by-products that result from the fruit processing industry are seeds, peels/skin, leaves, roots, tubers, and pomace [22]. These by-products are considered an excellent source of bioactive compounds, which include the phenolic compounds (e.g., carotenoids, phenolic acid, and flavonoids), bioactive proteins (e.g., amino acids and peptide isolate), fibers, fatty acids, etc. The seeds of fruits have high phytochemical, essential oils, and phytosterols content, whereas fruit peels contain valuable fibers, pectin, and minerals [75]. The uses of enzymes and fermentation are considered biological approaches that can be used in the extraction of bioactive compounds from agro-industrial wastes [22].

## 2.2. Nano-Management of Agro-Wastes

Management of agro-wastes is considered a major challenge. This management may include many processes, starting with the production and collection, transportation, and disposal of wastes. The management of agro-wastes has become a global issue, which may include options from composting to forming biochar. Some agro-wastes, such as oil crop wastes, cannot be composted because of their low economic value [75], although there can be benefits to applying oil crop wastes to soil [76]. Agro-wastes can be left in the field after harvest, which may protect soil from erosion and/or provide nutrients. Other common practices involving agro-wastes include burning or dumping in landfills, which may cause pollution of soil, water, and air [77]. Nanotechnology is one of the most promising new applications for the management of agro-wastes [78].

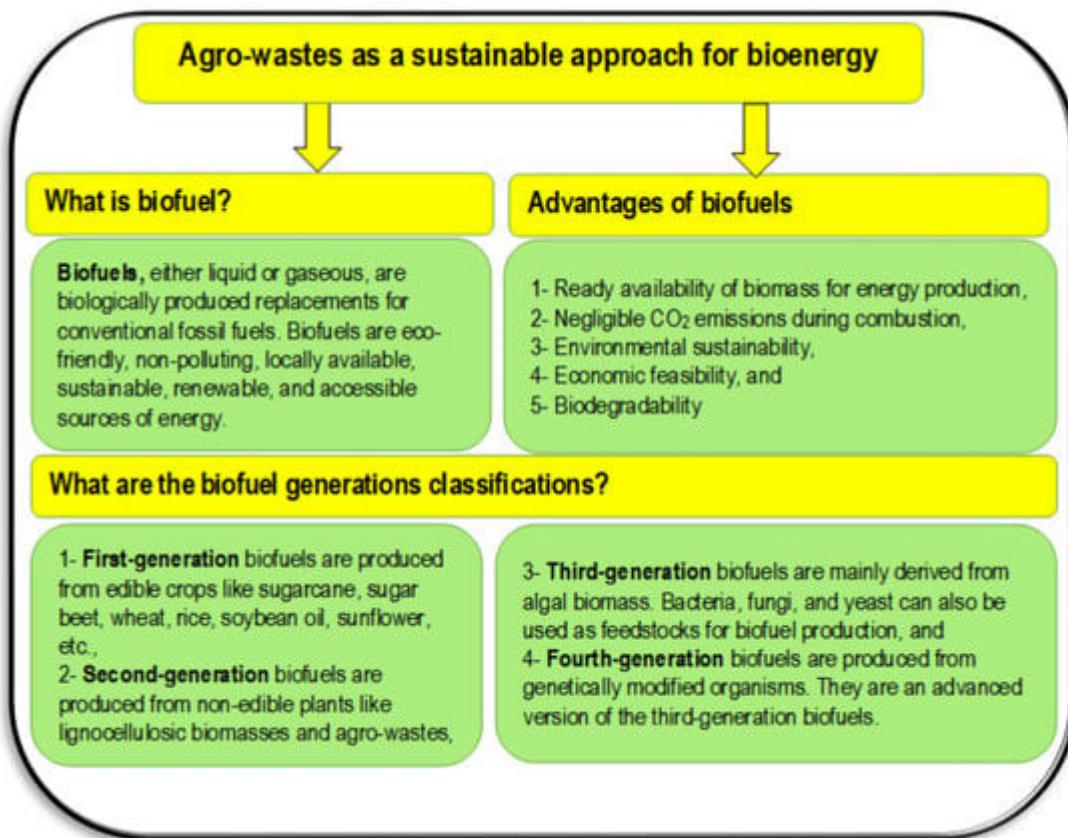
## 2.3. Agro-Wastes to Produce Bioenergy and Biorefinery

Energy demand is expected to increase worldwide due to rapid population growth and urbanization. To avoid continued and increased use of fossil fuels, new sources of energy need to be utilized. Renewable energy resources are considered the best options to alleviate environmental pollution and climate change risks while fulfilling future energy demands. Bio-based energy (e.g., biodiesel, bioethanol, etc.) is considered a sustainable, safe, cost effective, and eco-friendly source. Converting agro-wastes to energy is a promising alternative to fossil fuels [79]. Many studies have discussed the positive and negative aspects of converting agro-wastes and/or agro-industrial wastes into products such as chemicals, fuels, and by-products (e.g., [80][81][82][83]). Agro-wastes are considered an important resource for the generation of renewable energy through new methodologies [84]. The extraction methods used depend on the type of agro-wastes being processed (Figure 4).

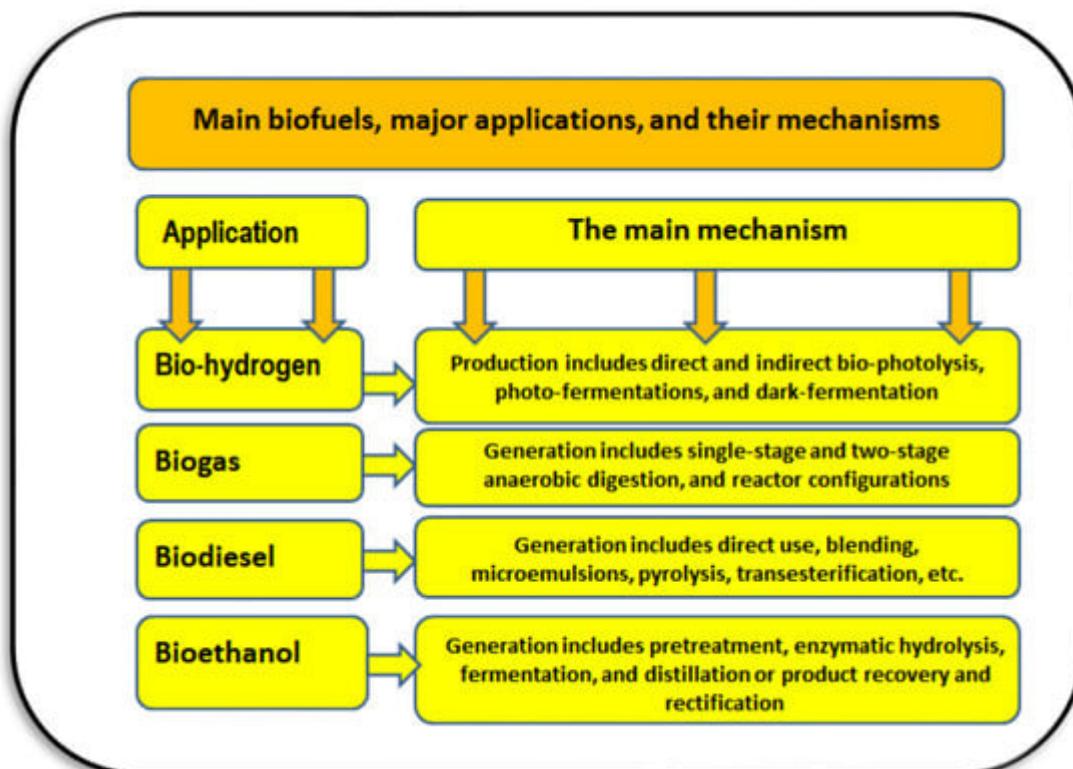


**Figure 4.** Common methods used in the processing and biorefinery of agro-wastes to produce bioproducts.

Water and energy security both have a close relationship with food security. Moreover, the ever-increasing global population puts more demand on water and energy resources. Bioenergy (e.g., biogas, biohydrogen, bioethanol, biodiesel, etc.) can be generated from several agricultural and related wastes. Biofuels produced from agro-wastes have many advantages over fossil fuels like lower pollution rates (**Figure 5** and **Figure 6**; [85]). Due to high efficiency, negligible CO<sub>2</sub> emissions during combustion, sustainability, economic feasibility, and biodegradability, additional research and development of biofuels should be undertaken [85].



**Figure 5.** A general classification of biofuels along with applications and mechanisms for generating these biofuels.



**Figure 6.** The main biofuels and the primary mechanisms for manufacturing them.

## 2.4. Agro-Wastes for Plant Tissue Culture Media

The agricultural industry has been fundamental for human survival for thousands of years [86]. However, modern agriculture generates tons of organic agricultural wastes such as inedible plant tissues (shells, peels, stalks, etc.) [87]. The rapid expansion of cities and human population has led to millions of tons of solid waste generation annually, which has serious implications for pollution of the global environment. Waste management systems that include storage, collection, transportation, segregation, processing and disposal of waste are very expensive and require technology that is not readily available in poor developing countries. Proper management of these wastes is essential to protect the environment and practice sustainable utilization of the available resources. This may include making compost for soil application or substitutional media for microorganisms. Agro-wastes can be used to prepare environmentally safe alternative plant tissue culture media that is less expensive than current commercial artificial media [88].

For example, cost-effective media for plant tissue culture have been formulated using the wastes of cabbage, beetroot, and onion. The agro-wastes were dried, then ground to powder. Coconut water was added as a source of natural hormone (cytokinin). This alternative medium could be used to grow plants because it contains micro and macronutrients within required ranges. It is useful for laboratory applications and at the industrial level for large scale production of plants [88]. It is a new strategy to produce the components of tissue culture media from farm wastes. This is a possible sustainable solution to protect the environment and preserve natural resources.

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