Scire Salutis

Ago a Out 2022 - v.12 - n.4

ISSN: **2236-9600**

This article is also available online at:
www.sustenere.co

Environmental sustainability in the context of circular economy in waste treatment

The world's population is growing at an exponential rate, and for that, agricultural industry plays an important role to produce food for all these people. Agricultural output will increase by 60% due to food demand in 2050. This situation puts enormous pressure on natural resources, and due to this, the environment is in crisis. At the same time, the waste generation is increasing, and if not properly treated, it can harm the ecosystem on land, rivers, and oceans. The circular economy concept came to solve this problem, with the idea of repurposing waste into new valuable products. This strategy assists in minimizing waste disposal that is not suitable, hence reducing water, air, and soil pollution, biodiversity loss, and health issues such as disease spread. In this context, the present review aims to present the most common waste generated along the food production chain, and the interesting processes for converting them into valuable products. This review brings an overview of possibilities to apply the circular economy concept to reach sustainable goals.

Keywords: Sustainability; Circular economy; Environment; Waste economy.

Sustentabilidade ambiental no contexto da economia circular no tratamento de resíduos

A população mundial cresce exponencialmente e, para isso, a agroindústria tem um papel importante na produção de alimentos para essa população. A produção agrícola aumentará 60% até 2050 devido à demanda de alimentos. Esta situação coloca uma enorme pressão sobre os recursos naturais e, por isso, o meio ambiente está em crise. Ao mesmo tempo, a geração de resíduos está aumentando e, se não forem devidamente tratados, pode prejudicar o ecossistema terrestre, fluvial e oceânico. O conceito de economia circular veio para resolver esse problema, com a ideia de reaproveitar resíduos em novos produtos. Essa estratégia ajuda a minimizar o descarte inadequado de resíduos, reduzindo assim a poluição da água, do ar e do solo, a perda de biodiversidade e problemas de saúde, como a disseminação de doenças. Nesse contexto, a presente revisão visa apresentar os resíduos mais comuns gerados ao longo da cadeia produtiva de alimentos e os processos interessantes para convertê-los em produtos valiosos. Esta revisão traz uma visão geral das possibilidades de aplicação do conceito de economia circular para atingir metas sustentáveis.

Palavras-chave: Sustentabilidade; Economia circular; Meio ambiente; Economia de lixo.

Topic: **Microbiologia**

Reviewed anonymously in the process of blind peer.

Received: **10/08/2022**
Approved: **08/10/2022**

William Michelon
Universidade do Contestado, Brasil
http://lattes.cnpq.br/1915524637784633
http://orcid.org/0000-0003-0713-0150
william@unc.br

Paula Roberta Silveira Málaga
Universidade do Contestado, Brasil
http://lattes.cnpq.br/4646385227640920
http://orcid.org/0000-0001-9788-4962
paula_rsilveira@hotmail.com

Aline Viancelli
Universidade do Contestado, Brasil
http://lattes.cnpq.br/1177756678285550
http://orcid.org/0000-0003-1654-6510
alinevbortoli@gmail.com

DOI: 10.6008/CBPC2236-9600.2022.004.0001

Referencing this:
MICHELON, W.; MÁLAGA, P. R. S.; VIANCELLI, A.. Environmental sustainability in the context of circular economy in waste treatment. **Scire Salutis**, v.12, n.4, p.1-10, 2022. DOI: http://doi.org/10.6008/CBPC2236-9600.2022.004.0001

INTRODUCTION

The world's population is growing at an exponential rate, as are consumption rates, and in this scenario the agricultural industry plays an important role in the economic growth. Overall agricultural output, including crops and animals, will increase by 60% due to food demand in 2050 (TIMSINA, 2018). Notably, this is driven by increased demand for animal protein, with some predictions indicating that milk output will need to expand by 63 % and meat production by 76 % to supply the demand (ALEXANDRATOS et al., 2012). Livestock production and aquaculture have been increasing around 2.5 and 5.8 % per year, respectively; and both, production and demand for animal source of foods are expected to rise further (HILBORN et al., 2018).

This situation puts enormous pressure on natural resources, and due to this, the environment is in crisis. The degradation of ecosystems, the loss of biodiversity, the climate changes, are examples supporting the Earth's inability to sustain life, putting ecological services at risk. Recognizing the environmental crisis is urgent and necessary (TREGIDGA et al., 2022). At the same time, the waste generation is increasing, and if not properly treated, it can harm the ecosystem on land, rivers, and oceans (HOFFMAN et al., 2022). According to FAO, approximately $^{1}/_{3}$ of all food produced became residues, such as by-products and waste, amounting to over 1.3 billion tons globally each year[1]. Simultaneously, cities around the world produce more than 2.0 billion tons of waste each year, with 3.40 billion tons estimated by 2050, half of which is organic waste[2].

The United Nations, in its report on the Sustainable Development Goals (SDGs) for 2030, declares and defines 17 priority goals to end poverty, protect the planet, and ensure all people have peace and prosperity (SACHS, 2012). These global goals offer up potential approaches for innovation, and the need of rethinking the traditional scientific methodologies in order to accept a more holistic view of all society sectors. Actually, the inspiration for innovation might come from a variety of sources. Innovation might be gradual, such as incrementally optimizing a transformation chain, or result from scientific breakthroughs generating new technologies for market. Scientists' responsibility in organic waste and wastewater management is no longer only to decrease and reduce waste and by-products, but to optimize resource recovery in a safe and sustainable manner (BAKAN et al., 2022).

In this context, connect the prospect of encouraging environmental benefits, sustainable economic growth, and production with added value, all while creating jobs, could reach all three sustainability pillars (social, economic, and environment) simultaneously (SCHÖGGL et al., 2020). Recognizing this, scientists, policymakers, and managers have attempted to discover ways to manage these wastes, such as converting them into reusable resources or valuable products (BHUVANESHWARI et al., 2019). Likewise, the shift to a more circular economy is expected to contribute to multiple SDGs, most notably SDG 12 on sustainable production and consumption patterns, but also SDGs 6, 7, 8, and 13 on water, energy, economic development, and climate change, respectively (GENG et al., 2019; SCHROEDER et al., 2019).

---

[1] *Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. Https://Www.Fao.Org/3/I3901e/I3901e.Pdf.
[2] The World Bank. *What a waste 2.0: global snapshot of solid waste management to 2050*. https://Datatopics.Worldbank.Org/What-a-Waste/

METHODOLOGY

What is a circular economy concept?

Before describing the circular economy concept, it is important to know that the traditional linear system uses resources, converts them into products, and disposes of wastes elsewhere, with little regard for the natural organic and inorganic matter breakdown cycles (BAKAN et al., 2022). The linear manufacturing concept, often known as linear economy, is one of the causes of huge waste disposal (BHUVANESHWARI et al., 2019), mostly attributed to the fragmentation of the production chain in different areas, which makes life-cycle methods and circular economy implementation more challenging (MASI et al., 2017).

The circular economy concept dates back to 1966 and has gained popularity in recent years (REIKE et al., 2018). The idea of repurposing waste into new valuable products has generated growing interest in the circular economy. This strategy assists in minimizing waste disposal that is not suitable, hence reducing water, air, and soil pollution, biodiversity loss, and health issues such as disease spread (RAJEEV, 2021). Korhonen et al. (2018) expose us to the pillars of sustainability that characterize a circular economy: society, environment, and economy. Synergy among these pillars would help us to identify a solution for transitioning to a circular economy. In certain cases, just one or two of the pillars are addressed; nonetheless, a balance must be established between all three pillars within the concept of circular economy (KORHONEN et al., 2018). Thus, when it comes to establishing circular economies and the business models that go along with them, the pillars of sustainability are recognized as the golden thread (HOFFMAN et al., 2022).

The purpose of the circular economy is to maintain materials in use for as long as possible, while preventing waste dissipation and pollution emissions to the environment. Circular economy initiatives look for more sustainable processes by making better use of resources, resulting in lower emissions of pollutants and waste generation. It also intends to advance the products' life by postponing the end-of-life phase (reuse, repair, or remanufacture), reduce the usage of virgin resources and the amount of exploitation (LONDOÑO et al., 2021). Waste generation that cannot be avoided should be repurposed through recycling, reuse, conversion, and other approaches. Thus, a circular economy concept primarily is: waste streams are converted into value-added products such as food, feed, bio-based products, and biofuel (GHERGHEL et al., 2019).

In this context, the present review aims to present the most common waste generated along the food production chain, and the interesting processes for converting them into valuable products. This review brings an overview of possibilities to apply the circular economy concept to reach sustainable goals.

THEORETICAL DISCUSSION

Type of wastes and transformation into valuable products

Table 1 presents the most used biomass transformed into valuable products. A variety of organic compounds are originated from plants and animals that feed on plants, such as wood wastes, animal manure (cattle, poultry, swine), food waste, aquatic plants and algae biomass (macro- and microalgae), and municipal organic waste (DESSIE et al., 2020). Waste from biomasses are recognized as an excellent alternative for cleaner and sustainable reuses, due to their lack of competition with food.

Table 1: Variety and estimated amount of wastes with potential to be reused for the generation of valuable products.

Biomass	**Estimation (million t year^{-1})**	**Reference**
Rice straw	731.3	Sarkar et al. (2012)
Wheat straw	354.3	
Corn straw	203.6	
Bagasse	174.2	
Lignocellulose	200	Bhowmick et al. (2018)
Industrial waste	9176.7	Song et al. (2015)
Food waste	931	United Nations Environment Programme, (2021)[3]
Algae	32.6	Araújo et al. (2021)
Industrial wood production waste	715	Tripathi et al. (2019)
Animal waste	3120	Berendes et al. (2018)

Lignocellulose

Plant biomass waste is composed mainly of cellulose, hemicellulose and lignin (CHANDRA et al., 2012). Lignocellulosic biomass is composed of crop residues such stalks, straw and husk, originating from maize, wheat, rice and sugarcane (CHANDRA et al., 2012). This biomass has abundant availability and applicability, can be used as a raw material for biofuels production, or animal feed, composting, production of bio-energy, mushroom cultivation (MONFORTI et al., 2013), microcapsules to pharmaceuticals, biosensors and biopolymers (GARLAPATI et al., 2020).

The most difficult barrier in the use of this biomass is that lignin is resistant to degradation by fermentation (PÉREZ et al., 2002). To solve this problem, researchers have worked on pretreatment techniques based on mechanical, chemical, physico-chemical and biological processes, aiming to increase the surface contact area and porosity of materials (BRUNI et al., 2010). Wan et al. (2011), reported the pretreatment of corn over by the fungi *Ceriporiopsis subvermispora* during an 18-days process, where the lignin content was degraded up to 31.59%, and the glucose yield was 56.50%. Fungal pretreatment, using *Cyathus stercoreus*, was also used to enzymatic degradation of rice straw (YAMAGISHI et al., 2011). The authors reported that a 25-day pretreatment process led to a fivefold increase in enzymatic saccharification yield, compared to untreated control samples. *Pleurotus ostreatus,* a white-root mushroom, was cultivated on lignocellulosic material (rice straw) as a pretreatment step, followed by lignocellulosic biomass use for biogas production. The results showed that rice straw pretreated with these fungi produced 263 L kg^{-1} volatile solids of methane, compared to 120 L kg^{-1} produced by the untreated biomass (MUSTAFA et al., 2017).

Different microorganisms could perform the conversion of monomeric sugars, from pretreated biomass, into biofuels (ethanol) and bioproducts. The fermentation to ethanol production, using lignocellulosic biomass, is frequent reported as a consequence of metabolic activity of bacteria such as *Escherichia coli*, *Zymomonas mobilis* and *Clostridium phytofermentans*; yeasts such as *Saccharomyces cerevisiae* and *Pichia stipitis* (AMORE et al., 2012; TODHANAKASEM et al., 2020; VERMA et al., 2010). The degradation of cellulose by fungi and bacteria occurs by the production of cellulase enzymes. These enzymes

---

[3] United Nations Environment Programm. *Food Waste Index Report 2021*. https://Wedocs.Unep.Org/20.500.11822/35280

comprise about 20% of the global enzyme market (SARSAIYA et al., 2019), being useful in paper recycling and cotton processing, for example. However, the main barrier nowadays is the manufacturing price, impulsing the research for new organisms to produce cellulase with greater efficiency (SARSAIYA et al., 2019).

Among the cellulosic materials that could be reused in the circular economy context, the pineapple waste has been the focus of research. During the fruit processing, the waste generated corresponds to 60% of the original weight (SARANGI et al., 2022). This waste is composed of peel, core, crown end and pomace, which can be transformed into bioethanol, butanol, hydrogen and methane (SARANGI et al., 2022).

Another good example of lignocellulosic waste reuse is the production of mushrooms that are saprophytic fungi, with cosmopolitan distribution and easily cultivated on lignocellulosic biomass. Mushroom species are cultivated for commercial purposes related to culinary and medicinal use (BALAN et al., 2022). Shankar et al. (2022) reported the use of multiple agriculture biomass for the cultivation of *Ganoderma lucidum,* a basidiomycetous fungus, aiming enzymes production, biomass degradation and ethanol generation. The fungi produced an average of 5087.48 ± 81.44 U g^{-1} of laccase, while degraded 49.16% of the lignin from the biomass. The degraded biomass was saccharified by *Aspergillus flavus* and *Trichoderma citrinoviride,* and then fermented using *Saccharomyces cerevisiae*, that generated 6.24 ± 0.14 g L^{-1} ethanol with an average yield of 89.11%. The studies highlight the positive association between biological processes and the production of enzymes, which represent an important market field.

Animal manure for bioenergy and byproduct

Based on the water content and material handling characteristics, the diverse range of organic wastes generated by animal processing is often classed as either liquid waste (wastewater) or solid waste. These characteristics frequently influence the choice of waste management and alternative treatments. Wastewater can present high organic content and, in certain cases, a high nutrient content. The wastewater is generated during the cleaning procedures of animal building, pens, processing areas, and equipment, and is frequently directed to wastewater treatment facilities. Several activities and processes in the livestock industry cannot be eliminated without having a major impact on production and/or animal health. Manure production, for example, is an inevitable result of animal production. However, waste minimization has been widely practiced (RAMIREZ et al., 2021).

A variety of processes has been established to convert animal waste manure into electrical energy in order to mitigate pollution and gain value from all that animal waste (SORATHIYA et al., 2014). Using microorganisms (anaerobic digestion), animal manure can be digested and converted to biogas such as methane, which is used to power turbine boilers that generate both electricity and heat (O'CONNOR et al., 2021). Furthermore, value-added bioproducts such as volatile fatty acids can be produced during the anaerobic digestion process (SEKOAI et al., 2021).

Brazilian energy potential using animal manure and sewage from cattle, chicken, sheep, swine, buffalo and horse, was estimated in different regions. As a result, the Midwest, North, South, Southeast, and Northeast areas presented a potential of 20.582; 13.731; 11.327; 10.296; and 8.793 TWh $year^{-1}$, respectively

(OLIVEIRA et al., 2020). In China, the energy potential from swine, dairy, beef, layer, and broiler manures was investigated. The annual potential of thermal energy, syngas, and methane production from the five varieties of animal manures, were estimated to be 4400.63 TJ, 983.40 109 m^3, and 188.89 109 m^3, respectively (SHEN et al., 2015). In 2030, the European Union's energy potential from manure, grass, and straw was estimated to range from 1.2×10^3 to 2.3×10^3 PJ y^{-1}. France, Germany, and the United Kingdom were estimated to have the biggest energy potential, amounting to 300 - 540 PJ y^{-1}, 250 - 400 PJ y^{-1}, and 90-220 PJ y^{-1}, respectively (MEYER et al., 2018). There are an estimated 8,113 dairy farms and swine operations in the United States with a total energy-generating capacity of 15,838,413 MWh $year^{-1}$ (USEPA, 2018).

In anaerobic co-digestion with poultry manure, lignocellulosic biomasses (rice straw, maize cob, peanut shell, sawdust, coffee husk, and sugarcane bagasse) were investigated for methane generation. The results indicated that maize cob and poultry manure produced the highest volume of methane (126.02 Nm^3 CH_4 ton $residue^{-1}$) and the total amount of volatile fatty acids produced varied from 80 to 1391. 16 mg L^{-1} (PARANHOS et al., 2020). Anaerobic co-digestion of sweet sorghum stalks, cheese whey, and cow manure resulted in approximately 0.52 mol H_2 mol^{-1} of biogas and 3250 N mL of biogas, as well as the major fermentation volatile fatty acids acetic (7.8 g L^{-1}), propionic (2.2 g L^{-1}), and butyric (10.1 g L^{-1}) (DAREIOTI et al., 2021).

In recent years, the Arabian Peninsula has converted animal manure into a valuable resource. Camel manure has been used to produce energy for cement factories. In 2018, 6,000 camels produced more than 90,718 tons of manure, which were transformed into fuel, reducing the amount of fuel required by the cement factory (CAMPRA et al., 2021). Furthermore, 1.68 Mtpa of crop residues and 25.52 Mtpa of animal manure could be utilized for bioenergy in these nations (WELFLE et al., 2021). Besides, biomethane production of dromedary manure ranged between 129 and 160 mL CH_4 gVS^{-1}, and the observed calorific values of dromedary manure were between 12.18 and 13.60 MJ kg^{-1} (SHANABLEH et al., 2021). All these studies show the huge potential of reuse of animal manure to decrease the pressure of natural energy sources.

Using insects and annelids as animal feed

Insects are progressively playing a part in a process known as bioconversion. Bioconversion is the process of transforming previously devalued organic materials, such as animal manure, harvest waste, food processing wastes, and other byproducts, into valuable resources that may be reused. In instance, the black soldier fly (*Diptera: Stratiomyidae*) can effectively convert a variety of organic materials into insect biomass (SIDDIQUI et al., 2022). They are pest-free and may be grown and harvested without the use of special facilities (LOPES et al., 2022). Furthermore, the frass produced by black soldier fly larvae is one of the process's key outputs, which may substitute traditional N fertilizers, reducing the global warming potential associated with the usage of conventional N fertilizer (SALOMONE et al., 2017).

Black soldier flies larvae have been reported to feed on a wide range of organic materials such as food waste (FISCHER et al., 2021; LALANDER et al., 2019), rice straw (LIU et al., 2021), distillers' grains

(WEBSTER et al., 2016), animal offal (ST-HILAIRE et al., 2007), animal manure (AWASTHI et al., 2020). Furthermore, black soldier flies are well-known for their ability to lower the mass and nutrient of swine and poultry manure, consequently promoting farm sanitation, pest fly population reduction, and nutrient pollution during runoff episodes (MAZZA et al., 2020; PARODI et al., 2021).

The biochemical content of black soldier fly larvae changes depending on the substrate used. Despite this, values generally indicate the black soldier fly larvae as a rich source of proteins and lipids, with 40.8 ± 3.8 % protein and 28.6 ± 8.6 % lipids (WANG et al., 2017). The black soldier fly biomass could be converted into valuable ingredients, as well as be a sustainable animal feed. Thus, feed produced from black soldier fly biomass are already considered to be an alternative to feed animals, including fish, swine, poultry and alligator (FONSECA et al., 2017; BODRI et al., 2007; MAURER et al., 2016). Protein replacement in fish diets by black soldier fly larvae and prepupae has been reported and is a promising alternative in the production of a range of fish species (channel catfish, blue tilapia, hybrid tilapia, rainbow trout, atlantic salmon, turbot, and yellow catfish) (FONSECA et al., 2017). For poultry feed black soldier flies have been utilized as a partial substitute for maize or soy-based diets. In instance, addition (50%) or entire replacement of soybean meal in the diets for egg production, showed no influence on hen health or performance, and had minimal or no effect on the eggs (MAURER et al., 2016). Black soldier fly supplementation in dietary broiler quails (*Coturnix coturnix japonica*) had no effect on breast meat sensory characteristics, oxidative level, or cholesterol profile; and it increased the meat's amino acid content, resulting in higher nutritional value (CULLERE et al., 2018).

Vermicomposting, which comes from the Latin term *vermis* for earthworm (EDWARDS et al., 1988), is a bioconversion process that incorporates the collaborative action of earthworms and mesophilic microorganisms to convert organic wastes into valuable products known as vermicompost. These associations have been studied for straw, husk, leaves, stalks, weeds, animal manure, dairy wastes, food processing wastes, organic fraction of municipal solid waste, bagasse, digestate from biogas plants (KAUR, 2020; ZHOU et al., 2022), where earthworms assimilate organic waste, reducing its volume by 40-60%.

Each earthworm weighs 0.5 - 0.6 g, consumes waste proportional to its weight, and generates a cast that is approximately 50 % of the waste it consumes in a day (YATOO et al., 2020). Earthworms are classified into two types: burrowing and non-burrowing and there are around 3,600 different species. Red earthworm species, such as *Eisenia foetida*, are the most efficient in composting (PATWA et al., 2020). Vermicompost is the result of the complete bioconversion. Vermicompost is high in micro- and macronutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, zinc, boron and others. As well as, beneficial soil microorganisms, including nitrogen-fixing and phosphate-solubilizing bacterial, plant growth promoters and hormones (auxins, gibberellins, and cytokinins), and can thus be used as an organic fertilizer for plants (YATOO et al., 2020).

Non-traditional protein sources, such as earthworm, have received attention as an alternative protein source due to nutritional characteristics similar to fish meal. Several earthworm species have been investigated for use in fish feed production. For example, *Eisenia fetida* has significant quantities of lipids and protein that are comparable to those found in fish meals and fit the nutritional demands of various fish species (MUSYOKA et al., 2019). Protein derived from *Eisenia fetida is shown* to be more economically feasible than chicken gut and soybean waste in the production of fish. The results demonstrated that the earthworm powder-based fish feed composition has a high protein content and could be a viable option in the catfish aquaculture industry (ZAKARIA et al., 2012).

Additionally, earthworms are a natural protein source for hens, and currently there is no conflict between human and animal consumption (GUNYA et al., 2019; SOLOMON et al., 2019). Thus, earthworm meal has the potential to serve as a significant protein source in broiler chicken diets (ZANG et al., 2018). For example, earthworm meal from *Eudrilus eugeniae* is an excellent alternative for fish meal in the diet of broiler chickens due to it improves carcass features, digestive organs, and overall meat quality. Also, increasing the amount of earthworm meal in the diet enhanced the meat and sensory ratings (NALUNGA et al., 2021).

Food wastes and value-added materials

Food waste represents social and economic problems, and nowadays, an environmental disaster. The pressure for food production strongly increases, while 1.3 billion tons of food produced for human consumption are wasted; and it is estimated that the food waste generation will increase one-third each year by 2030 (RIOS et al., 2020; SKAGGS et al., 2018). Food waste management is also part of the 17 Sustainable Development Goals, aiming to reduce the losses of food along the production and supply chains.

Conrad et al. (2018) reported that in the USA, each person wasted 26% of daily food during the 2007-2014 period, representing 422 g person/day. The majority (39%) of waste was composed of fruits and vegetables, followed by dairy products (17%), meat (14%), and grains (12%). The authors highlighted that, contrary to the traditional thought that higher quality diets (composed of fruits and vegetables) are better for the environment due to the fact that vegetable production requires less land use, this production chain uses higher volumes of pesticides, and the vegetables are the most discharged food type. In this sense, the authors highlight that diet quality improvement and decrease in food waste generation are actions that need to occur simultaneously, where the consumption of fruits and vegetables should increase, but with less waste (CONRAD et al., 2018).

Considering this, food waste has been studied as valuable biomass for energy (biogas, biofuels) and resource (biofertilizers) recovery through biological processes such as anaerobic digestion, composting and fermentation (MA et al., 2019). Food waste has been studied for the production of enzymes such as glucoamylase, cellulase, protease, xylanase and lipase (MA et al., 2019).

Another food waste of special concern is the fish manufacturing waste. This waste is a rich material, composed of proteins and oil (CALDEIRA et al., 2020). These compounds can be reused in the fish production chain, once that the fish diet needs protein and oil, which is normally supplemented by other fishes of lower interest (RACIOPPO et al., 2021). The fish waste has been studied as an alternative to bioplastic production, due to special characteristics such as elasticity, plasticity, and an efficient oxygen barrier (URANGA et al., 2018). Enzymes can be extracted from fish waste to be applied on food processing, cosmetic, textiles industries, being a cheaper alternative to obtain these substances (OLIVEIRA et al., 2019).

The meat industry generates huge amounts of meat waste, which can vary depending on the animal species (JAYATHILAKAN et al., 2012). Beef lung, pork lung, deboned chicken meat can be used for protein production, while poultry feathers and swine hair can be used for keratin production (MALDONADO et al., 2022; PRECZESKI et al., 2020). Collagen can be obtained from the tissue of bovines, and applied to the food and cosmetic industry (NOORZAI et al., 2020).

The main waste generated in the dairy industry is whey protein, where studies have been conducted aiming to obtain a valuable source of oligosaccharides and production of kefiran, a water-soluble exopolysaccharide (BARILE et al., 2009; CHEIRSILP et al., 2011). Eggshell waste is a considerable residue that has been studied as soil additive to improve the agronomic properties of soil, as biochar for the removal of pollutants from water, fertilizer, animal food, and production of calcium oxide used in biodiesel fabrication (OLIVEIRA et al., 2013; WEI et al., 2009).

Aquatic plants and algae

Microalgae, which include eukaryotic algae and cyanobacteria (photosynthetic bacteria), have shown to be an environmentally beneficial and sustainable alternative to the energy-intensive and traditional biological treatment techniques that are often used currently (MOHSENPOUR et al., 2021). Apart from being a renewable resource of biomass, the use of micro-algae in wastewater treatment is a cost-effective and viable way of CO_2 biofixation (ALMOMANI et al., 2019). Microalgae use nitrogen and phosphorus, among other compounds present in wastewater, for their growth, resulting in reduced concentrations of these compounds in the water (PAW et al., 2019).

The utilization of microalgae presents an innovative step for wastewater treatment since it provides tertiary treatment while also producing potentially valuable biomass that can be utilized for a variety of applications, including bioenergy, nutraceuticals, aqua-feed and fertilizer. Different microalgae species on a variety of wastewater types, including municipal, agricultural, animal manure, and industrial effluents, with different treatment efficacy and microalgae growth efficiencies (SALAMA et al., 2017). When cultivated with dairy effluent as a nutrient medium, *Chlamydomonas* biomass was used for simultaneous wastewater treatment and biofuel generation, yielding lipid productivity of 87.5 mg L^{-1} day^{-1}. The C14:0, C16:0, C16:1, C18:0, C18:2, and C18:3 fatty acid chains reported were promising for biofuel synthesis (ARORA et al., 2016).

Microalgae biomass also serves as a potential source of biomethane. Since microalgae biomass has little lignin and cellulose, it can be rapidly converted into biogas by digestion (HARUN et al., 2011). *Scenedesmus* spp. biomass cultivated in swine wastewater under different conditions, generated biomethane yields ranging from 44 L_N CH_4 (kg biomass)$^{-1}$ to 103.5 L_N CH_N (kg biomass)$^{-1}$ (PERAZZOLI et al., 2016). A comparative evaluation of biogas generation from algal wastes (residues after oil extraction from *Chlorella minutissima*) and algal wastes (*Ulva lactuca* from coastal regions) was conducted. As a result, *U. lactuca* waste generated 342.59 cm^3 CH_4 g^{-1} VS biogas, almost the same obtained from waste from oil extraction, that was 341.43 cm^3 CH_4 g^{-1}VS (KOÇER et al., 2018).

Microalgae can synthesize essential and non-essential amino acids, which can then be processed for human and animal nutrition (KOYANDE et al., 2019). In a recent study, microalgae were efficient to remove ammonia-N and P (100%) from swine wastewaters and presented high amino acids content (up to 59.6 % dry weight); from the 11 essential amino acids identified, the most abundant were lysine, leucine, threonine, methionine, and tryptophan (MICHELON et al., 2022). Besides, 25 bioactive peptides were found in the microalgae biomass, with possible multiple bio functionalities including anticancer, antioxidant, anti-amnestic, antithrombotic, immunomodulating, neuropeptide, hypolipidemic, anti-inflammatory and hypotensive (MICHELON et al., 2022).

Similarly to microalgae, the aquatic plants' use (phytoremediation), also is considered an eco-friendly process and advantageous technique for substances contaminants (CAMPOS et al., 2019). This approximately 300-year-old process is used effectively in wastewater treatment (CAROLIN et al., 2017), and different plant species were evaluated and identified for their ability to remove contaminants from wastewaters (PRASAD, 2007). Plants grow during the treatment phase, as a result of nutrition intake to eliminate contaminants (KADIR et al., 2020). There have been studies on the use of plant biomass as a substitute or supplemental animal feed, such as broiler chicken (JOYSOWAL et al., 2018), goat (SAMANTA et al., 1995), cattle (INDULEKHA et al., 2019), and buffalo (SINGH et al., 2017) production.

Biofuel produced from macrophytes biomass such as bioethanol, biohydrogen, biogas, and biodiesel have been studied. The conversion from *Eichhornia crassipes* and *Pistia stratiotes* (free-floating aquatic plant) produced 0.14-0.17 g ethanol g^{-1} biomass (SODA et al., 2013). The biohydrogen production from macrophyte biomass wastes (*Azolla* sp.) was 2.2 mol hydrogen mol $glucose^{-1}$, indicating that this is a viable alternative feedstock (MIRANDA et al., 2016). Aquatic plant biomass was also converted into biogas via anaerobic digestion and presented yields ranging from 0.89 to 2.33 mL biogas g $biomass^{-1}$ (MOELLER et al., 2018). *Eichhornia crassipes* biomass was applied to produce biodiesel and resulted in a maximum yield of 63.6 mg biodiesel g $biomass^{-1}$ via transesterification (SHANAB et al., 2018). Also, biochar can be produced from aquatic plant biomass; several aquatic plants were reported to produce biochar with yields ranging from 120 to 420 mg biochar g $biomass^{-1}$ (KURNIAWAN et al., 2021).

CONCLUSIONS

This review showed a variety of possibilities to reuse wastes, from different sources, and transform them into valuable products. These processes are in accordance with the circular economy concept, and can be applied all around the world to promote sustainable practices. For the future, the researcher will help to fill the gaps existent, and permit the successful implementation of real scale systems.

In this sense, it is important to highlight that under the umbrella of sustainability there are thousands of actions to preserve the environment, to increase the economy creating financial opportunities, to improve life quality and human development. The 17 SDGs are interlinked, and their implementation are the key points to achieve a better future for the next generations. However, the efforts need to be integrated among the scientists, politicians and population. Sustainability just will be a reality if all of us work together.

REFERENCES

ALEXANDRATOS, N.; BRUINSMA, J.. **World agriculture towards 2030/2050:** the 2012 revision. Rome: FAO, 2012.

ALMOMANI, F.; JUDD, S.; BHOSALE, R. R.; SHURAIR, M.; ALJAML, K.; KHRAISHEH, M.. Intergraded wastewater treatment and carbon bio-fixation from flue gases using Spirulina platensis and mixed algal culture. **Process Safety and Environmental Protection**, v.124, p.240-250, 2019. **DOI:** http://doi.org.10.1016/j.psep.2019.02.009

AMORE, A.; FARACO, V.. Potential of fungi as category I Consolidated BioProcessing organisms for cellulosic ethanol production. **Renewable and Sustainable Energy Reviews**, v.16, n.5, p.3286-3301, 2012. **DOI:** http://doi.org.10.1016/j.rser.2012.02.050

ARAÚJO, R.; VÁZQUEZ CALDERÓN, F.; SÁNCHEZ LÓPEZ, J.; AZEVEDO, I. C.; BRUHN, A.; FLUCH, S.; GARCIA TASENDE, M.; GHADERIARDAKANI, F.; ILMJÄRV, T.; LAURANS, M.; MAC MONAGAIL, M.; MANGINI, S.; PETEIRO, C.; REBOURS, C.; STEFANSSON, T.; ULLMANN, J.. Current Status of the Algae Production Industry in Europe: An Emerging Sector of the Blue Bioeconomy. **Frontiers in Marine Science**, v.7, 2011. **DOI:** http://doi.org.10.3389/fmars.2020.626389

ARORA, N.; PATEL, A.; SARTAJ, K.; PRUTHI, P. A.; PRUTHI, V.. Bioremediation of domestic and industrial wastewaters integrated with enhanced biodiesel production using novel oleaginous microalgae. **Environmental Science and Pollution Research**, v.23, n.20, p.20997-21007, 2016. **DOI:** http://doi.org.10.1007/s11356-016-7320-y

AWASTHI, M. K.; LIU, T.; AWASTHI, S. K.; DUAN, Y.; PANDEY, A.; ZHANG, Z.. Manure pretreatments with black soldier fly Hermetia illucens L. (Diptera: Stratiomyidae): A study to reduce pathogen content. **Science of the Total Environment**, v.737, p.139842, 2020. **DOI:** http://doi.org.10.1016/j.scitotenv.2020.139842

BAKAN, B.; BERNET, N.; BOUCHEZ, T.; BOUTROU, R.; CHOUBERT, J. M.; DABERT, P.; DUQUENNOI, C.; FERRARO, V.; GARCÍA-BERNET, D.; GILLOT, S.; MERY, J.; RÉMOND, C.; STEYER, J.-P.; TRABLY, E.; TREMIER, A.. Circular Economy Applied to Organic Residues and Wastewater: Research Challenges. **Waste and Biomass Valorization**, v.13, n.2, p.1267-1276, 2022. **DOI:** http://doi.org.10.1007/s12649-021-01549-0

BALAN, V.; ZHU, W.; KRISHNAMOORTHY, H.; BENHADDOU, D.; MOWRER, J.; HUSAIN, H.; ESKANDARI, A.. Challenges and opportunities in producing high-quality edible mushrooms from lignocellulosic biomass in a small scale. **Applied Microbiology and Biotechnology,** v.106, n.4, p.1355-1374, 2022. **DOI:** http://doi.org.10.1007/s00253-021-11749-2

BARILE, D.; TAO, N.; LEBRILLA, C. B.; COISSON, J.-D.; ARLORIO, M.; GERMAN, J. B.. Permeate from cheese whey ultrafiltration is a source of milk oligosaccharides. **International Dairy Journal**, v.19, n.9, p.524-530, 2009. **DOI:** http://doi.org.10.1016/j.idairyj.2009.03.008

BERENDES, D. M.; YANG, P. J.; LAI, A.; HU, D.; BROWN, J.. Estimation of global recoverable human and animal faecal biomass. **Nature Sustainability**, v.1, n.11, p.679-685, 2018. **DOI:** http://doi.org.10.1038/s41893-018-0167-0

BHOWMICK, G.; SARMAH, A. K.; SEN, R.. Lignocellulosic biorefinery as a model for sustainable development of biofuels and value added products. **Bioresource Technology**, v.247, p.1144-1154, 2018. **DOI:** http://doi.org.10.1016/j.biortech.2017.09.163

BHUVANESHWARI, S.; HETTIARACHCHI, H.; MEEGODA, J.. Crop Residue Burning in India: Policy Challenges and Potential Solutions. **International Journal of Environmental Research and Public Health**, v.16, n.5, p.832, 2019. **DOI:** http://doi.org.10.3390/ijerph16050832

BODRI, M. S.; COLE, E. R.. Black soldier fly (Hermetia illucens Linnaeus) as feed for the American Alligator (Alligator mississippiensis Daudin). **Georgia Journal of Science**, v.65, n.2, p.82-89, 2007.

BRUNI, E.; JENSEN, A. P.; ANGELIDAKI, I.. Comparative study of mechanical, hydrothermal, chemical and enzymatic treatments of digested biofibers to improve biogas production. **Bioresource Technology**, v.101, n.22, p.8713-8717, 2010. **DOI:** http://doi.org.10.1016/j.biortech.2010.06.108

CALDEIRA, C.; VLYSIDIS, A.; FIORE, G.; LAURENTIIS, V.; VIGNALI, G.; SALA, S.. Sustainability of food waste biorefinery: A review on valorisation pathways, techno-economic constraints, and environmental assessment. **Bioresource Technology**, v.312, p.123575, 2020. **DOI:** http://doi.org.10.1016/j.biortech.2020.123575

CAMPOS, F. V.; OLIVEIRA, J. A.; SILVA, A. A.; RIBEIRO, C.; FARNESE, F. S.. Phytoremediation of arsenite-contaminated environments: is Pistia stratiotes L. a useful tool? **Ecological Indicators**, v.104, p.794-801, 2019. **DOI:** http://doi.org.10.1016/j.ecolind.2019.04.048

CAMPRA, M.; BRESCIA, V.; JAFARI-SADEGHI, V.; CALANDRA, D.. Islamic countries and Maqasid al-Shariah towards the circular economy. The Dubai case study. **European Journal of Islamic Finance,** v.17, 2021.

CAROLIN, C. F.; KUMAR, P. S.; SARAVANAN, A.; JOSHIBA, G. J.; NAUSHAD, M.. Efficient techniques for the removal of toxic heavy metals from aquatic environment: A review. **Journal of Environmental Chemical Engineering**, v.5, n.3, p.2782-2799, 2017. **DOI:** http://doi.org.10.1016/j.jece.2017.05.029

CHANDRA, R.; TAKEUCHI, H.; HASEGAWA, T.. Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production. **Renewable and Sustainable Energy Reviews**, v.16, n.3, p.1462-1476, 2012. **DOI:** http://doi.org.10.1016/j.rser.2011.11.035

CHEIRSILP, B.; RADCHABUT, S.. Use of whey lactose from dairy industry for economical kefiran production by Lactobacillus kefiranofaciens in mixed cultures with yeasts. **New Biotechnology**, v.28, n.6, p.574-580, 2011. **DOI:** http://doi.org.10.1016/j.nbt.2011.01.009

CONRAD, Z.; NILES, M. T.; NEHER, D. A.; ROY, E. D.; TICHENOR, N. E.; JAHNS, L.. Relationship between food waste, diet quality, and environmental sustainability. **PLOS ONE**, v.13, n.4, p.e0195405, 2018. **DOI:** http://doi.org.10.1371/journal.pone.0195405

CULLERE, M.; TASONIERO, G.; GIACCONE, V.; ACUTI, G.; MARANGON, A.; DALLE ZOTTE, A.. Black soldier fly as dietary protein source for broiler quails: meat proximate composition, fatty acid and amino acid profile, oxidative status and sensory traits. **Animal,** v.12, n.3, p.640-647, 2018. **DOI:** http://doi.org.10.1017/S1751731117001860

DAREIOTI, M. A.; VAVOURAKI, A. I.; TSIGKOU, K.; ZAFIRI, C.; KORNAROS, M.. Dark Fermentation of Sweet Sorghum Stalks, Cheese Whey and Cow Manure Mixture: Effect of pH, Pretreatment and Organic Load. **Processes,** v.9, n.6, 1017, 2021. **DOI:** http://doi.org.10.3390/pr9061017

DESSIE, W.; LUO, X.; WANG, M.; FENG, L.; LIAO, Y.; WANG, Z.; YONG, Z.; QIN, Z.. Current advances on waste biomass transformation into value-added products. **Applied Microbiology and Biotechnology**, v.104, n.11, p.4757-4770, 2020. **DOI:** http://doi.org.10.1007/s00253-020-10567-2

EDWARDS, C.; BURROWS, I.. The potential of earthworm composts as plant growth media. **Earthworms in Waste and Environmental Management**, p.21-32, 1988.

FISCHER, H.; ROMANO, N.; SINHA, A. K.. Conversion of Spent Coffee and Donuts by Black Soldier Fly (Hermetia illucens) Larvae into Potential Resources for Animal and Plant Farming. **Insects,** v.12, n.4, p.332, 2021. **DOI:** http://doi.org.10.3390/insects12040332

FONSECA, K. B. B.; DICKE, M.; VAN LOON, J. J. A.. Nutritional value of the black soldier fly (Hermetia illucens L.) and its suitability as animal feed - a review. **Journal of Insects as Food and Feed,** v.3, n.2, p.105-120, 2017. **DOI:** http://doi.org.10.3920/JIFF2016.0055

GARLAPATI, V. K.; CHANDEL, A. K.; KUMAR, S. P. J.; SHARMA, S.; SEVDA, S.; INGLE, A. P.; PANT, D.. Circular economy aspects of lignin: Towards a lignocellulose biorefinery. **Renewable and Sustainable Energy Reviews**, v.130, p.109977, 2020. **DOI:** http://doi.org.10.1016/j.rser.2020.109977

GENG, Y.; SARKIS, J.; BLEISCHWITZ, R.. How to globalize the circular economy. **Nature**, v.565, n.7738, p.153-155, 2019. **DOI:** http://doi.org.10.1038/d41586-019-00017-z

GHERGHEL, A.; TEODOSIU, C.; GISI, S.. A review on wastewater sludge valorisation and its challenges in the context of circular economy. **Journal of Cleaner Production**, v.228, p.244-263, 2019. **DOI:** http://doi.org.10.1016/j.jclepro.2019.04.240

GUNYA, B.; MUCHENJE, V.; MASIKA, P. J.. The Effect of Earthworm Eisenia foetida Meal as a Protein Source on Carcass characteristics and Physico-Chemical Attributes of Broilers. **Pakistan Journal of Nutrition**, v.18, n.7, p.657-664, 2019. **DOI:** http://doi.org.10.3923/pjn.2019.657.664

HARUN, R.; DAVIDSON, M.; DOYLE, M.; GOPIRAJ, R.; DANQUAH, M.; FORDE, G.. Technoeconomic analysis of an integrated microalgae photobioreactor, biodiesel and biogas production facility. **Biomass and Bioenergy**, v.35, n.1, p.741-747, 2011. **DOI:** http://doi.org.10.1016/j.biombioe.2010.10.007

HILBORN, R.; BANOBI, J.; HALL, S. J.; PUCYLOWSKI, T.; WALSWORTH, T. E.. The environmental cost of animal source foods**. Frontiers in Ecology and the Environment**, v.16, n.6, p.329-335, 2018. **DOI:** http://doi.org.10.1002/fee.1822

HOFFMAN, M.; SCHENCK, C. J.; HERBST, F.. Exploring the Intersection Where Business Models, a Circular Economy and Sustainability Meet in the Waste Economy: A Scoping Review. **Sustainability**, v.14, n.6, p.3687, 2022. **DOI:** http://doi.org.10.3390/su14063687

INDULEKHA, V. P.; THOMAS, C. G.; ANIL, K. S.. Utilization of water hyacinth as livestock feed by ensiling with additives. **Indian Journal of Weed Science**, v.51, n.1, p.67, 2019. **DOI:** http://doi.org.10.5958/0974-8164.2019.00014.5

JAYATHILAKAN, K.; SULTANA, K.; RADHAKRISHNA, K.; BAWA, A. S.. Utilization of byproducts and waste materials from meat, poultry and fish processing industries: a review. **Journal of Food Science and Technology**, v.49, n.3, p.278-293, 2012. **DOI:** http://doi.org.10.1007/s13197-011-0290-7

JOYSOWAL, M.; AZIZ, A.; MONDAL, A.; MOHAN, S.. Effect of Azolla (Azolla pinnata) feed on the growth of broiler chicken. **Journal of Entomology and Zoology Studies**, v.6, n.3, p.391-393, 2018.

KADIR, A. A.; ABDULLAH, S. R. S.; OTHMAN, B. A.; HASAN, H. A.; OTHMAN, A. R.; IMRON, M. F.; ISMAIL, N; KURNIAWAN, S. B.. Dual function of Lemna minor and Azolla pinnata as phytoremediator for Palm Oil Mill Effluent and as feedstock. **Chemosphere**, v.259, p.127468, 2020. **DOI:** http://doi.org.10.1016/j.chemosphere.2020.127468

KAUR, T.. Vermicomposting: an effective option for recycling organic wastes. In: **Organic Agriculture.** IntechOpen, 2020. **DOI:** http://doi.org.10.5772/intechopen.91892

KOÇER, A. T.; ÖZÇIMEN, D.. Investigation of the biogas production potential from algal wastes. **Waste Management & Research: The Journal for a Sustainable Circular Economy**, v.36, n.11, p.1100-1105, 2018. **DOI:** http://doi.org.10.1177/0734242X18798447

KORHONEN, J.; HONKASALO, A.; SEPPÄLÄ, J.. Circular Economy: The Concept and its Limitations. **Ecological Economics**, v.143, p.37-46, 2018. **DOI:** http://doi.org.10.1016/j.ecolecon.2017.06.041

KOYANDE, A. K.; CHEW, K. W.; RAMBABU, K.; TAO, Y.; CHU, D.-T.; SHOW, P.-L.. Microalgae: A potential alternative to health supplementation for humans. **Food Science and Human Wellness**, v.8, n.1, p.16-24, 2019. **DOI:** http://doi.org.10.1016/j.fshw.2019.03.001

KURNIAWAN, S. B.; AHMAD, A.; SAID, N. S. M.; IMRON, M. F.; ABDULLAH, S. R. S.; OTHMAN, A. R.; PURWANTI, I. F.; HASAN, H. A.. Macrophytes as wastewater treatment agents: Nutrient uptake and potential of produced biomass utilization toward circular economy initiatives. **Science of The Total Environment**, v.790, p.148219, 2021. **DOI:** http://doi.org.10.1016/j.scitotenv.2021.148219

LALANDER, C.; DIENER, S.; ZURBRÜGG, C.; VINNERÅS, B.. Effects of feedstock on larval development and process efficiency in waste treatment with black soldier fly (Hermetia illucens). **Journal of Cleaner Production**, v.208, p.211-219, 2019. **DOI:** http://doi.org.10.1016/j.jclepro.2018.10.017

LIU, C.; WANG, C.; YAO, H.; CHAPMAN, S. J.. Pretreatment is an important method for increasing the conversion efficiency of rice straw by black soldier fly larvae based on the function of gut microorganisms. **Science of The Total Environment**, v.762, p.144118, 2021. **DOI:** http://doi.org.10.1016/j.scitotenv.2020.144118

LONDOÑO, N. A. C.; CABEZAS, H.. Perspectives on circular economy in the context of chemical engineering and sustainable development. **Current Opinion in Chemical Engineering**, v.34, p.100738, 2021. **DOI:** http://doi.org.10.1016/j.coche.2021.100738

LOPES, I. G.; YONG, J. W.; LALANDER, C.. Frass derived from black soldier fly larvae treatment of biodegradable wastes. A critical review and future perspectives. **Waste Management**, v.142, p.65-76, 2022. **DOI:** http://doi.org.10.1016/j.wasman.2022.02.007

MA, Y.; LIU, Y.. Turning food waste to energy and resources towards a great environmental and economic sustainability: An innovative integrated biological approach. **Biotechnology Advances**, v.37, n.7, p.107414, 2019. **DOI:** http://doi.org.10.1016/j.biotechadv.2019.06.013

MALDONADO, R. R.; SOUZA, T. R. C.; KUBENECK, S.; AGUIAR-OLIVEIRA, E.; TREICHEL, H.. Isolation and Cultivation of Actinobacteria by Submerged Fermentation for the Production of Keratinase. In: DHARUMADURAI, D.. **Methods in Actinobacteriology**. Springer Protocols Handbooks. New York: Humana, 2022. p.513-520. **DOI:** http://doi.org.10.1007/978-1-0716-1728-1_76

MASI, D.; DAY, S.; GODSELL, J.. Supply Chain Configurations in the Circular Economy: A Systematic Literature Review. **Sustainability**, v.9, n.9, p.1602, 2017. **DOI:** http://doi.org.10.3390/su9091602

MAURER, V.; HOLINGER, M.; AMSLER, Z.; FRÜH, B.; WOHLFAHRT, J.; STAMER, A.; LEIBER, F.. Replacement of soybean cake by Hermetia illucens meal in diets for layers. **Journal of Insects as Food and Feed**, v.2, n.2, p.83-90, 2016. **DOI:** http://doi.org.10.3920/JIFF2015.0071

MAZZA, L.; XIAO, X.; UR REHMAN, K.; CAI, M.; ZHANG, D.; FASULO, S.; TOMBERLIN, J. K.; ZHENG, L.; SOOMRO, A. A.; YU, Z.; ZHANG, J.. Management of chicken manure using black soldier fly (Diptera: Stratiomyidae) larvae assisted by companion bacteria. **Waste Management**, v.102, p.312-318, 2020. **DOI:** http://doi.org.10.1016/j.wasman.2019.10.055

MEYER, A. K. P.; EHIMEN, E. A.; HOLM-NIELSEN, J. B.. Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production. **Biomass and Bioenergy**, v.111, p.154-164, 2018. **DOI:** http://doi.org.10.1016/j.biombioe.2017.05.013

MICHELON, W.; SILVA, M. L. B.; MATTHIENSEN, A.; ANDRADE, C. J.; ANDRADE, L. M.; SOARES, H. M.. Amino acids, fatty acids, and peptides in microalgae biomass harvested from phycoremediation of swine wastewaters. **Biomass Conversion and Biorefinery**, v.12, n.3, 869-880, 2022. **DOI:** http://doi.org.10.1007/s13399-020-01263-2

MIRANDA, A. F.; BISWAS, B.; RAMKUMAR, N.; SINGH, R.; KUMAR, J.; JAMES, A.; RODDICK, F.; LAL, B.; SUBUDHI, S.; BHASKAR, T.; MOURADOV, A.. Aquatic plant Azolla as the universal feedstock for biofuel production. **Biotechnology for Biofuels**, v.9, n.1, p.221, 2016. **DOI:** http://doi.org.10.1186/s13068-016-0628-5

MOELLER, L.; BAUER, A.; WEDWITSCHKA, H.; STINNER, W.; ZEHNSDORF, A.. Crop characteristics of aquatic macrophytes for use as a substrate in anaerobic digestion plants: a study from Germany. **Energies**, v.11, n.11, p.3016, 2018. **DOI:** http://doi.org.10.3390/en11113016

MOHSENPOUR, S. F.; HENNIGE, S.; WILLOUGHBY, N.; ADELOYE, A.; GUTIERREZ, T.. Integrating micro-algae into wastewater treatment: a review. **Science of The Total Environment**, v.752, p.142168, 2021. **DOI:** http://doi.org.10.1016/j.scitotenv.2020.142168

MONFORTI, F.; BÓDIS, K.; SCARLAT, N.; DALLEMAND, J.-F.. The possible contribution of agricultural crop residues to renewable energy targets in Europe: A spatially explicit study. **Renewable and Sustainable Energy Reviews**, v.19, p.666-677, 2013. **DOI:** http://doi.org.10.1016/j.rser.2012.11.060

MUSTAFA, A. M.; POULSEN, T. G.; XIA, Y.; SHENG, K.. Combinations of fungal and milling pretreatments for enhancing rice straw biogas production during solid-state anaerobic digestion. **Bioresource Technology**, v.224, p.174-182, 2017. **DOI:** http://doi.org.10.1016/j.biortech.2016.11.028

MUSYOKA, S. N.; LITI, D. M.; OGELLO, E.; WAIDBACHER, H.. Utilization of the earthworm, Eisenia fetida (Savigny, 1826) as an alternative protein source in fish feeds processing: A review. **Aquaculture Research,** v.50, n.9, p.2301-2315, 2019. **DOI:** http://doi.org.10.1111/are.14091

NALUNGA, A.; KOMAKECH, A. J.; JJAGWE, J.; MAGALA, H.; LEDERER, J.. Growth characteristics and meat quality of broiler chickens fed earthworm meal from Eudrilus eugeniae as a protein source. **Livestock Science**, v.245, p.104394, 2021. **DOI:** http://doi.org.10.1016/j.livsci.2021.104394

NOORZAI, S.; VERBEEK, C. J. R.; LAY, M. C.; SWAN, J.. Collagen Extraction from Various Waste Bovine Hide Sources. **Waste and Biomass Valorization**, v.11, n.11, p.5687-5698, 2020. **DOI:** http://doi.org.10.1007/s12649-019-00843-2

O'CONNOR, S.; EHIMEN, E.; PILLAI, S. C.; BLACK, A.; TORMEY, D.; BARTLETT, .J. Biogas production from small-scale anaerobic digestion plants on European farms. **Renewable and Sustainable Energy Reviews**, v.139, p.110580, 2021. **DOI:** http://doi.org.10.1016/j.rser.2020.110580

OLIVEIRA, A.C. R. D.; SILVA, J. C.; SILVA, Q. J.; BEZERRA, R. S.; PORTO, A. L. F.. Recovery of fibrinolytic and collagenolytic enzymes from fish and shrimp byproducts: potential source for biomedical applications. **Boletim Do Instituto de Pesca**, v.45, n.1, p.1-10, 2019. **DOI:** http://doi.org.10.20950/1678-2305.2019.45.1.389

OLIVEIRA, D. A.; BENELLI, P.; AMANTE, E. R.. A literature review on adding value to solid residues: egg shells. **Journal**

of Cleaner Production, v.46, p.42-47, 2013. **DOI:** http://doi.org.10.1016/j.jclepro.2012.09.045

OLIVEIRA, R. S.; ORLANDO JUNIOR, W. A.; RENATO, N. S.. Evaluation of Brazilian potential for generating electricity through animal manure and sewage. **Biomass and Bioenergy**, v.139, p.105654, 2020. **DOI:** http://doi.org.10.1016/j.biombioe.2020.105654

PARANHOS, A. G. O.; ADARME, O. F. H.; BARRETO, G. F.; SILVA, S. Q.; AQUINO, S. F.. Methane production by co-digestion of poultry manure and lignocellulosic biomass: Kinetic and energy assessment. **Bioresource Technology**, v.300, p.122588, 2020. **DOI:** http://doi.org.10.1016/j.biortech.2019.122588

PARODI, A.; GERRITS, W. J. J.; VAN LOON, J. J. A.; BOER, I. J. M.; AARNINK, A. J. A.; VAN ZANTEN, H. H. E.. Black soldier fly reared on pig manure: Bioconversion efficiencies, nutrients in the residual material, greenhouse gas and ammonia emissions. **Waste Management**, v.126, p.674-683, 2021. **DOI:** http://doi.org.10.1016/j.wasman.2021.04.001

PATWA, A.; PARDE, D.; DOHARE, D.; VIJAY, R.; KUMAR, R.. Solid waste characterization and treatment technologies in rural areas: An Indian and international review. **Environmental Technology & Innovation**, v.20, p.101066, 2020. **DOI:** http://doi.org.10.1016/j.eti.2020.101066

PAW, M. H.; KONIUSZY, A.; GAŁCZYŃSKA, M.; ZAJĄC, G.; BARGŁOWICZ, J. S.. Production of Microalgal Biomass Using Aquaculture Wastewater as Growth Medium. **Water**, v.12, n.1, p.106, 2019. **DOI:** http://doi.org.10.3390/w12010106

PERAZZOLI, S.; BRUCHEZ, B. M.; MICHELON, W.; STEINMETZ, R. L. R.; MEZZARI, M. P.; NUNES, E. O.; SILVA, M. L. B.. Optimizing biomethane production from anaerobic degradation of Scenedesmus spp. biomass harvested from algae-based swine digestate treatment. **International Biodeterioration & Biodegradation**, v.109, p.23-28, 2016. **DOI:** http://doi.org.10.1016/j.ibiod.2015.12.027

PÉREZ, J.; MUÑOZ-DORADO, J.; LA RUBIA, T.; MARTÍNEZ, J.. Biodegradation and biological treatments of cellulose, hemicellulose and lignin: an overview. **International Microbiology**, v.5, n.2, p.53-63, 2002. **DOI:** http://doi.org.10.1007/s10123-002-0062-3

PRASAD, M. N. V.. Aquatic Plants for Phytotechnology. In: **Environmental Bioremediation Technologies**. Berlin: Springer Berlin Heidelberg, 2007. p.259-274. **DOI:** http://doi.org.10.1007/978-3-540-34793-4_11

PRECZESKI, K. P.; DALASTRA, C.; CZAPELA, F. F.; KUBENECK, S.; SCAPINI, T.; CAMARGO, A. F.; ZANIVAN, J.; BONATTO, C.; STEFANSKI, F. S.; VENTURIN, B.; FONGARO, G.; TREICHEL, H.. Fusarium oxysporum and aspergillus sp. as keratinase producers using swine hair from agroindustrial residues. **Frontiers in Bioengineering and Biotechnology**, v.8, 2020. **DOI:** http://doi.org.10.3389/fbioe.2020.00071

RACIOPPO, A.; SPERANZA, B.; CAMPANIELLO, D.; SINIGAGLIA, M.; CORBO, M. R.; BEVILACQUA, A.. Fish loss/waste and low-value fish challenges: state of art, advances, and perspectives. **Foods**, v.10, n.11, 2725, 2021. **DOI:** http://doi.org.10.3390/foods10112725

RAJEEV, B.. **Valorization of agri-food wastes and by-products.** Elsevier, 2021. **DOI:** http://doi.org.10.1016/C2020-0-01248-X

RAMIREZ, J.; MCCABE, B.; JENSEN, P. D.; SPEIGHT, R.; HARRISON, M.; VAN DEN BERG, L.; O'HARA, I.. Wastes to profit: a circular economy approach to value-addition in livestock industries. **Animal Production Science**, v.61, n.6, p.541-550, 2021. **DOI:** http://doi.org.10.1071/AN20400

REIKE, D.; VERMEULEN, W. J. V.; WITJES, S.. The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. **Resources, Conservation and Recycling**, v.135, p.246-264, 2018. **DOI:** http://doi.org.10.1016/j.resconrec.2017.08.027

RIOS, C. M.; HOFMANN, A.; MACKENZIE, N.. Sustainability-Oriented Innovations in Food Waste Management Technology. **Sustainability**, v.13, n.1, p.210, 2020. **DOI:** http://doi.org.10.3390/su13010210

SACHS, J. D.. From Millennium Development Goals to Sustainable Development Goals. **The Lancet**, v.379, n.9832, p.2206-2211, 2012. **DOI:** http://doi.org.10.1016/S0140-6736(12)60685-0

SALAMA, E.-S.; KURADE, M. B.; ABOU-SHANAB, R. A. I.; EL-DALATONY, M. M.; YANG, I.-S.; MIN, B.; JEON, B.-H.. Recent progress in microalgal biomass production coupled with wastewater treatment for biofuel generation. **Renewable and Sustainable Energy Reviews**, v.79, p.1189-1211, 2017. **DOI:** http://doi.org.10.1016/j.rser.2017.05.091

SALOMONE, R.; SAIJA, G.; MONDELLO, G.; GIANNETTO, A.; FASULO, S.; SAVASTANO, D. .Environmental impact of food waste bioconversion by insects: Application of Life Cycle Assessment to process using Hermetia illucens. **Journal of Cleaner Production**, v.140, p.890-905, 2017. **DOI:** http://doi.org.10.1016/j.jclepro.2016.06.154

SAMANTA, G.; TAMANG, Y.. Feeding value of azolla (Azolla pinnata) in goats. **Annales de Zootechnie**, v.44, n.1, p.62-62, 1995. **DOI:** http://doi.org.10.1051/animres:19950532

SARANGI, P. K.; ANAND SINGH, T.; JOYKUMAR SINGH, N.; PRASAD SHADANGI, K.; SRIVASTAVA, R. K.; SINGH, A. K.; CHANDEL, A. K.; PAREEK, N.; VIVEKANAND, V.. Sustainable utilization of pineapple wastes for production of bioenergy, biochemicals and value-added products: A review. **Bioresource Technology**, v.351, p.127085, 2022. **DOI:** http://doi.org.10.1016/j.biortech.2022.127085

SARKAR, N.; GHOSH, S. K.; BANNERJEE, S.; AIKAT, K.. Bioethanol production from agricultural wastes: An overview. **Renewable Energy**, v.37, n.1, p.19-27, 2012. **DOI:** http://doi.org.10.1016/j.renene.2011.06.045

SARSAIYA, S.; JAIN, A.; KUMAR AWASTHI, S.; DUAN, Y.; KUMAR AWASTHI, M.; SHI, J.. Microbial dynamics for lignocellulosic waste bioconversion and its importance with modern circular economy, challenges and future perspectives. **Bioresource Technology**, v.291, p.121905, 2019. **DOI:** http://doi.org.10.1016/j.biortech.2019.121905

SCHÖGGL, J.-P.; STUMPF, L.; BAUMGARTNER, R. J.. The narrative of sustainability and circular economy - A longitudinal review of two decades of research. **Resources, Conservation and Recycling**, v.163, p.105073, 2020. **DOI:** http://doi.org.10.1016/j.resconrec.2020.105073

SCHROEDER, P.; ANGGRAENI, K.; WEBER, U.. The Relevance of Circular Economy Practices to the Sustainable Development Goals. **Journal of Industrial Ecology**, v.23, n.1, p.77-95, 2019. **DOI:** http://doi.org.10.1111/jiec.12732

SEKOAI, P. T.; GHIMIRE, A.; EZEOKOLI, O. T.; RAO, S.; NGAN, W. Y.; HABIMANA, O.; YAO, Y.; YANG, P.; YIU FUNG, A. H.; YORO, K. O.; DARAMOLA, M. O.; HUNG, C.-H.. Valorization of volatile fatty acids from the dark fermentation waste Streams-A promising pathway for a biorefinery concept. **Renewable and Sustainable Energy Reviews**, v.143, p.110971, 2021. **DOI:** http://doi.org.10.1016/j.rser.2021.110971

SHANAB, S. M. M.; HANAFY, E. A.; SHALABY, E. A.. Water Hyacinth as Non-edible Source for Biofuel Production. **Waste and Biomass Valorization**, v.9, n.2, p.255-264, 2018. **DOI:** http://doi.org.10.1007/s12649-016-9816-6

SHANABLEH, A.; ABDALLAH, M.; TAYARA, A.; GHENAI, C.; KAMIL, M.; INAYAT, A.; SHABIB, A.. Experimental characterization and assessment of bio- and thermo-chemical energy potential of dromedary manure. **Biomass and Bioenergy**, v.148, p.106058, 2021. **DOI:** http://doi.org.10.1016/j.biombioe.2021.106058

SHANKAR, A.; SAINI, S.; SHARMA, K. K.. Fungal-integrated second-generation lignocellulosic biorefinery: utilization of agricultural biomass for co-production of lignocellulolytic enzymes, mushroom, fungal polysaccharides, and bioethanol**. Biomass Conversion and Biorefinery**, 2022. **DOI:** http://doi.org.10.1007/s13399-022-02969-1

SHEN, X.; HUANG, G.; YANG, Z.; HAN, L.. Compositional characteristics and energy potential of Chinese animal manure by type and as a whole. **Applied Energy**, v.160, p.108-119, 2015. **DOI:** http://doi.org.10.1016/j.apenergy.2015.09.034

SIDDIQUI, S. A.; RISTOW, B.; RAHAYU, T.; PUTRA, N. S.; WIDYA YUWONO, N.; NISA', K.; MATEGEKO, B.; SMETANA, S.; SAKI, M.; NAWAZ, A.; NAGDALIAN, A.. Black soldier fly larvae (BSFL) and their affinity for organic waste processing. **Waste Management**, v.140, p.1-13, 2022. **DOI:** http://doi.org.10.1016/j.wasman.2021.12.044

SINGH, L. R.; VISHWAVIDYALAYA, D. S.. Medicinal and ecological potential of Kaseru (Scirpus grossus) a review. **Journal Of Harmonized Research in Pharmacy**, v.6, n.3, p.51-53, 2017.

SKAGGS, R. L.; COLEMAN, A. M.; SEIPLE, T. E.; MILBRANDT, A. R.. Waste-to-Energy biofuel production potential for selected feedstocks in the conterminous United States. **Renewable and Sustainable Energy Reviews**, v.82, p.2640-2651, 2018. **DOI:** http://doi.org.10.1016/j.rser.2017.09.107

SODA, S.; MISHIMA, D.; INOUE, D.; IKE, M.. A co-beneficial system using aquatic plants: bioethanol production from free-floating aquatic plants used for water purification. **Water Science and Technology**, v.67, n.11, p.2637-2644, 2013. **DOI:** http://doi.org.10.2166/wst.2013.188

SOLOMON, D.; MESERET, M.; ADMASU, S.. Poultry feed resources and chemical composition of crop content of scavenging indigenous chicken. **Journal of World's Poultry Research,** v.9, n.6, p.247-255, 2019. **DOI:** http://doi.org.10.36380/scil.2019.ojafr34

SONG, Q.; LI, J.; ZENG, X.. Minimizing the increasing solid waste through zero waste strategy. **Journal of Cleaner Production**, v.104, p.199-210, 2015. **DOI:** http://doi.org.10.1016/j.jclepro.2014.08.027

SORATHIYA, L. M.; FULSOUNDAR, A. B.; TYAGI, K. K.; PATEL, M. D.; SINGH, R. R.. Eco-friendly and modern methods of livestock waste recycling for enhancing farm profitability. **International Journal of Recycling of Organic Waste in Agriculture**, v.3, n.1, p.50, 2014. **DOI:** http://doi.org.10.1007/s40093-014-0050-6

ST-HILAIRE, S.; CRANFILL, K.; MCGUIRE, M. A.; MOSLEY, E. E.; TOMBERLIN, J. K.; NEWTON, L.; SEALEY, W.; SHEPPARD, C.; IRVING, S.. Fish Offal Recycling by the Black Soldier Fly Produces a Foodstuff High in Omega-3 Fatty Acids. **Journal of the World Aquaculture Society**, v.38, n.2, p.309-313, 2007. **DOI:** http://doi.org.10.1111/j.1749-7345.2007.00101.x

TIMSINA, J.. Can Organic Sources of Nutrients Increase Crop Yields to Meet Global Food Demand? **Agronomy**, v.8, n.10, p.214, 2018. **DOI:** http://doi.org.10.3390/agronomy8100214

TODHANAKASEM, T.; WU, B.; SIMEON, S.. Perspectives and new directions for bioprocess optimization using Zymomonas mobilis in the ethanol production. **World Journal of Microbiology and Biotechnology**, v.36, n.8, p.112, 2020. **DOI:** http://doi.org.10.1007/s11274-020-02885-4

TREGIDGA, H.; LAINE, M.. On crisis and emergency: Is it time to rethink long-term environmental accounting? **Critical Perspectives on Accounting**, v.82, p.102311, 2022. **DOI:** http://doi.org.10.1016/j.cpa.2021.102311

TRIPATHI, N.; HILLS, C. D.; SINGH, R. S.; ATKINSON, C. J.. Biomass waste utilisation in low-carbon products: harnessing a major potential resource. **Npj Climate and Atmospheric Science**, v.2, n.1, p.35, 2019. **DOI:** http://doi.org.10.1038/s41612-019-0093-5

URANGA, J.; ETXABIDE, A.; GUERRERO, P.; DE LA CABA, K.. Development of active fish gelatin films with anthocyanins by compression molding. **Food Hydrocolloids**, v.84, p.313-320, 2018. **DOI:** http://doi.org.10.1016/j.foodhyd.2018.06.018

USEPA. **Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities.** USEPA, 2018.

VERMA, S.; RAY, A. K.; DE, B. K.. Bioconversion of heptanal to heptanol by Saccharomyces cerevisiae. **Yeast**, v.27, n.5, p.269-275, 2010. **DOI:** http://doi.org.10.1002/yea.1750

WAN, C.; LI, Y.. Effectiveness of microbial pretreatment by Ceriporiopsis subvermispora on different biomass feedstocks. **Bioresource Technology**, v.102, n.16, p.7507-7512, 2011. **DOI:** http://doi.org.10.1016/j.biortech.2011.05.026

WANG, Y.-S.; SHELOMI, M.. Review of Black Soldier Fly

(Hermetia illucens) as Animal Feed and Human Food. **Foods**, v.6, n.10, p.91, 2017. **DOI:** http://doi.org.10.3390/foods6100091

WEBSTER, C. D.; RAWLES, S. D.; KOCH, J. F.; THOMPSON, K. R.; KOBAYASHI, Y.; GANNAM, A. L.; TWIBELL, R. G.; HYDE, N. M.. Bio-Ag reutilization of distiller's dried grains with solubles (DDGS) as a substrate for black soldier fly larvae, *Hermetia illucens*, along with poultry by-product meal and soybean meal, as total replacement of fish meal in diets for. **Aquaculture Nutrition**, v.22, n.5, p.976-988, 2016. **DOI:** http://doi.org.10.1111/anu.12316

WEI, Z.; XU, C.; LI, B.. Application of waste eggshell as low-cost solid catalyst for biodiesel production. **Bioresource Technology,** v.100, n.11, p.2883-2885, 2009. **DOI:** http://doi.org.10.1016/j.biortech.2008.12.039

WELFLE, A.; ALAWADHI, A.. Bioenergy opportunities, barriers and challenges in the Arabian Peninsula: Resource modelling, surveys & interviews. **Biomass and Bioenergy**, v.150, p.106083, 2021. **DOI:** http://doi.org.10.1016/j.biombioe.2021.106083

YAMAGISHI, K.; KIMURA, T.; WATANABE, T.. Treatment of rice straw with selected Cyathus stercoreus strains to improve enzymatic saccharification. **Bioresource Technology**, v.102, n.13, p.6937-6943, 2011. **DOI:** http://doi.org.10.1016/j.biortech.2011.04.021

YATOO, A. M.; RASOOL, S.; ALI, S.; MAJID, S.; REHMAN, M. U.; ALI, M. N.; EACHKOTI, R.; RASOOL, S.; RASHID, S. M.; FAROOQ, S.. Vermicomposting: an eco-friendly approach for recycling/management of organic wastes. In: **Bioremediation and Biotechnology.** Cham: Springer International Publishing, 2020. (p.167-187). **DOI:** http://doi.org.10.1007/978-3-030-35691-0_8

ZAKARIA, Z.; SALLEH, N. H. M.; MOHAMED, A. R.; ANAS, N. A.; IDRIS, S. N. A.. Optimization of protein content in earthworm-based fish feed formulation for catfish (Clarius gariepinus). **Sains Malaysiana**, v.41, n.9, p.1071-1077, 2012.

ZANG, Y. T.; BING, S.; ZHANG, Y. Z.; SHENG, X. W.; SHU, D. Q.. Effects of Dietary Supplementation With Earthworm Powder on Production Performance, Blood Characteristics, and Heavy Metal Residues of Broiler Pullets. **Journal of Applied Poultry Research**, v.27, n.4, p.609-615, 2018. **DOI:** http://doi.org.10.3382/japr/pfy024

ZHOU, Y.; XIAO, R.; KLAMMSTEINER, T.; KONG, X.; YAN, B.; MIHAI, F.-C.; LIU, T.; ZHANG, Z.; KUMAR AWASTHI, M.. Recent trends and advances in composting and vermicomposting technologies: a review. **Bioresource Technology**, v.360, p.127591, 2022. **DOI:** http://doi.org.10.1016/j.biortech.2022.127591