Brief Description:

When food waste is left in landfills it eventually turns into methane gas. Methane gas is 28 times more potent than carbon dioxide and after a decade it turns into carbon dioxide. Landfills have gas collection systems installed to capture methane gas. But my background research proves that when food waste ends up in landfills, significant methane is emitted to the atmosphere even with the installation of gas collection and control systems. So with this considered, I will be trying to answer the question: what would be a cost effective way of keeping food from landfills other than composting? This project looks at food waste from various industries, analyzes the important bioactive compounds found in them and the potential of utilizing them to convert into value-added products.

Waste to Wealth: Transforming Food Waste to Slash Methane in Landfill

Creating a cost effective way of keeping food from landfills other than composting. This project looks at food waste from various industries, analyzes the important bioactive compounds found in them and the potential of utilizing them to convert into value-added products.

Question:

Can keeping food out of landfills help tackle climate change?
Would keeping food out of landfills help tackle climate change?

Hypothesis:

I hypothesize that methane gas emissions in landfills can be reduced by the valorization of food waste.

Background Research:

- At COP28 (UN Climate Change Conference in 2023), it was recognised that methane emissions from the waste sector accounts for roughly 20 percent of global methane emissions from human activities.
- When food waste is dumped into landfills a chemical reaction happens over many years called anaerobic digestion turning food waste into methane gas.
- Anaerobic digestion is a process where bacteria break down organic matter in the absence of oxygen and released methane
- Methane is more than 28 times as potent as carbon dioxide at trapping heat in the atmosphere. After a decade, most emitted methane has reacted with ozone to form carbon dioxide and water. This carbon dioxide continues to heat the climate for hundreds or even thousands of years.
- As Methane is short-lived compared to carbon dioxide, achieving significant reductions would have a rapid and significant effect on atmospheric warming potential
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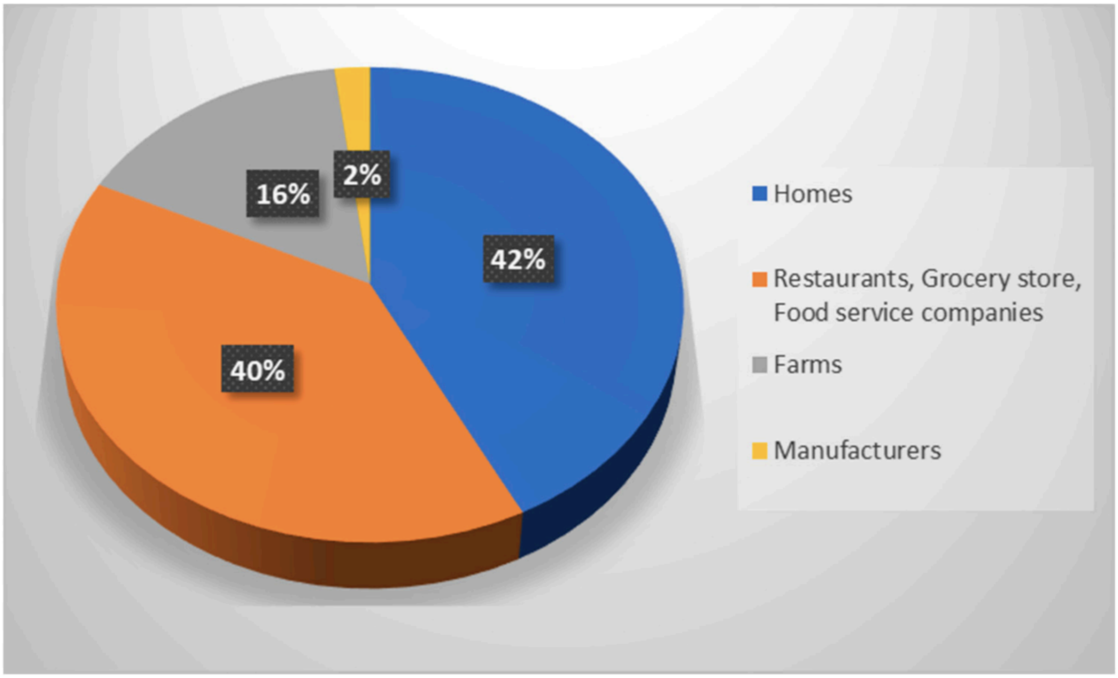


Figure 1. Percentage of food waste generated at various levels of food supply chain in America.

- 30 to 40% of the food produced by farmers globally, is never consumed.
- At the manufacturing level, more than 10% of food is wasted due to human errors.
- In America, about 30% of food is thrown away by grocery stores
- The annual value of food wasted worldwide is one trillion dollars
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9916134/

Within a landfill, several factors influence the amount of methane that is generated and emitted. These parameters include the:

- Total tonnage of landfilled material and its composition, particularly the portion that is degradable organic material such as food waste;
- Characteristics of the landfill, such as its size, cover materials, use of system for leachate recirculation, and the climate in which it is located;
- Rates at which food waste and other biodegradable (sometimes called organic) materials decompose (break down or decay);

- The schedule for installing, expanding, and maintaining operation of the landfill gas collection system after waste is deposited, and the portion of methane that is captured through landfill gas collection systems; and Portion of methane that oxidizes as it passes through the landfill cover material and is converted into carbon dioxide before going into the atmosphere.

Food Waste Decay Rate

Methane emitted from landfills is a result of organic waste decaying under anaerobic conditions. Organic waste decays over many years after it is placed in a landfill. Temperature, moisture, pH, and type of organic waste impacts how quickly it decays. Because of this decomposition pattern, the estimated methane emissions in a particular calendar year are the sum of emissions that are generated from waste disposed over a historical time horizon.

The decay rate is a first order reaction – the higher the rate, the faster the decay. For example, a decay rate of 0.02 means that half of the carbon has been degraded to methane in 34.7 years, whereas a decay rate of 0.2 means that half of the carbon has been degraded in 3.47 years

Table 1. Decay rates of various organic materials

Material	Decay rate (yr^{-1})	Number of years over which ½ of the carbon has been degraded to methane
Branches (Yard)	0.02	34.6
Cardboard	0.03	23.1
Copy paper	0.04	17.3
Dimensional lumber	0.11	6.3
Food waste	0.19	3.6
Leaves (Yard)	0.22	3.2
Grass (Yard)	0.39	1.8

Source: EPA WARM v15

Canada rule

Mandatory landfill gas collection within five years for landfills receiving less than 100,000 tonnes of waste per year.

Landfill Gas Collection Systems

https://www.epa.gov/land-research/quantifying-methane-emissions-landfilled-food-waste#:~:text=Methane%2C%20a%20powerful%20greenhouse%20gas,over%20time%20under%20anaerobic%20conditions

Methane collection in any calendar year will depend on a variety of factors, including the operating status of the landfill, whether or not the landfill has a landfill gas collection system installed, and the schedule for installing, expanding, and maintaining operation of the GCCS after waste is deposited.

Each analysis assumes that the collection system remains operational in a given area of the landfill for a 30-year period. Based on the selected decay rate, at 30 years, food waste will have decomposed 99.6% of the anaerobically degradable carbon to methane and carbon dioxide. Thus, in this scenario, modeling food waste methane generation beyond 30 years is unnecessary.

Table 2. Landfill gas collection efficiency schedule

WARM default collection scenario

Collection Efficiency	Years
0%	0 – 4
50%	5 – 9
75%	10 – 14
82.5%	15 – 20
90%	Final Cover

Source: EPA WARM v15

- Landfill gas collection systems are usually installed as a phased collection accounts for landfill operations in which some part or cells of the landfill may be actively receiving wastes and, over time, more of the landfill is permanently covered. Phased schedule with a four-year lag period before a GCCS is installed after waste is deposited, based on when landfills are obligated to install a gas collection system.

- Once the system is installed the rules allow for expansion of the gas collection system at a schedule of every two years if the landfill area is closed and five years for active areas of landfills
- LFG collection efficiency varies as a function of cover type. Three types of covers are typically used at landfills: daily, intermediate, and final.
    - Daily cover is a 15-cm soil layer that is placed on top of the active fill area of a landfill at the end of each day. Soil is sometimes used as a daily cover, but other types of materials may also be used, including textiles that are rolled over the top of the landfill and removed the following day; chemical foams, tire chips, wood chips, or shredded green waste; There are no requirements with respect to the hydraulic conductivity of a daily cover. Thus, it may be more or less restrictive to gas migration
    - Intermediate covers are used once the landfill attains a certain height and active disposal will not occur again in that area for an extended period (i.e., months or years). Intermediate covers typically consist of the available native soil at the landfill site and are 30 cm thick. Just like daily covers, intermediate covers do not have requirements with respect to hydraulic conductivity.
    - Once the landfill cell has achieved its maximal height and will no longer receive waste, a final cover system consisting of thick earthen materials and geosynthetics designed to minimize infiltration of liquids and soil erosion are placed.
    -
- Methane that is not collected by the gas collection system moves to the surface of the landfill where it can escape to the atmosphere.
- Biologically active and well-maintained soil cover systems can oxidize methane to carbon dioxide. This would account for fugitive methane emissions in landfills.

- The data is shown in the Appendix below.

https://www.epa.gov/system/files/documents/2023-10/food-waste-landfill-methane-10-8-23-final_508-compliant.pdf

Background research result:

1. An estimated 58 percent of fugitive methane emissions from MSW landfills are from landfilled food waste.
   a. Methane emissions from landfilled food waste are a subset of the total methane emissions from MSW landfills. Landfilled food waste is contributing to more methane emissions than other landfilled materials because it degrades more quickly, and this quicker decay can occur before a GCCS is installed or expanded at the landfill.

Table 3. 2020 Snapshot: Estimated MSW landfill methane emissions

	Fugitive Methane Emissions			Methane Generation		
Contributions	mmt CO_2e (100 yr GWP)[5]	% Total	mmt CO_2e (20 yr GWP)[6]	mmt CO_2e (100 yr GWP)	% Total	mmt CO_2e (20 yr GWP)
TOTAL	94	100%	309	305	100%	1,000
Food Waste	55	58%	180	89	29%	293
Other Waste	39	42%	129	215	71%	707

Notes: Totals may not sum due to independent rounding. [a]100-year GWP of methane = 25 (consistent with the US GHG Inventory (U.S. EPA, 2022c). [b]20-year GWP of methane = 82 (U.S. EPA, 2023c).

2. An estimated 61 percent of methane generated by landfilled food waste avoids collection by landfill gas collection systems and becomes fugitive emissions (i.e., is released to the atmosphere)

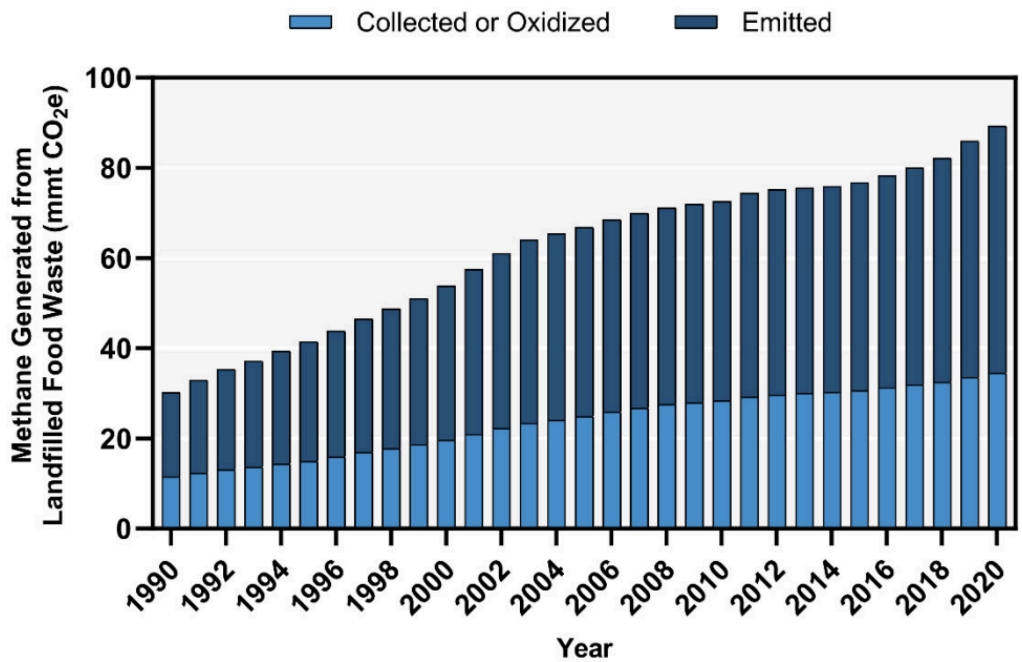


Figure 2. Fate of methane generated from landfilled food waste

3. While total emissions from MSW landfills are decreasing, methane emissions from landfilled food waste are increasing.

a. Total methane emissions from MSW landfills decreased by 43 percent from 1990 to 2020 as federal and state regulations for gas collection requirements expanded. During this same time period, methane emissions from landfilled food waste increased steadily by 295 percent. This is due to annual increases in the amount of food and all other MSW components being landfilled. Food waste emissions occur earlier and landfill operators are collecting more gas later in the landfill lifetime. Thus, for materials like biodegradable textiles, paper products, and wood, which degrade more slowly, more of the landfill gas is collected.

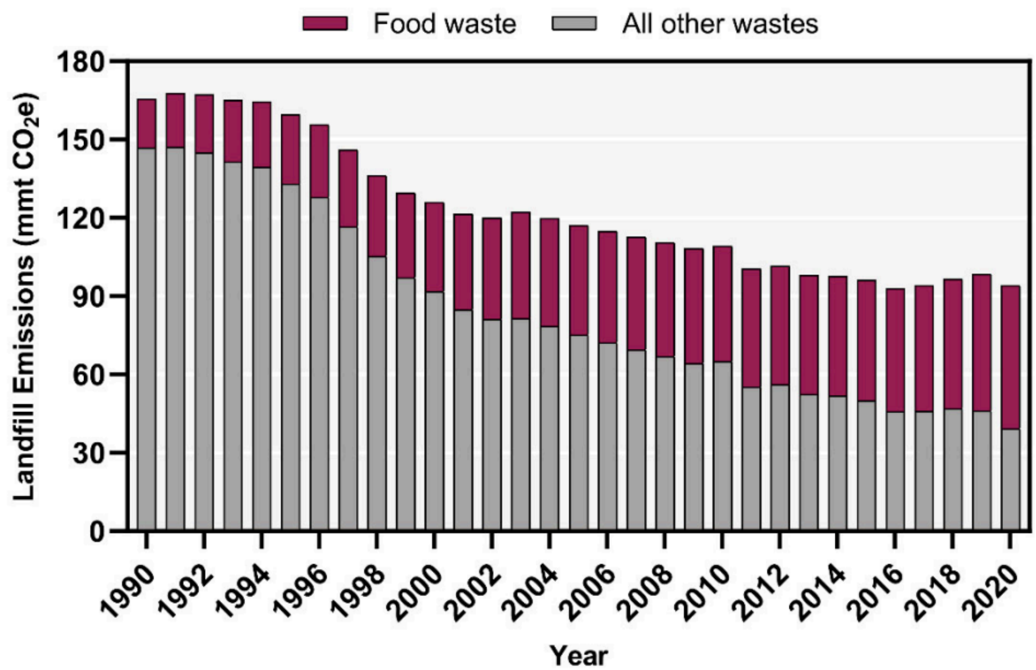
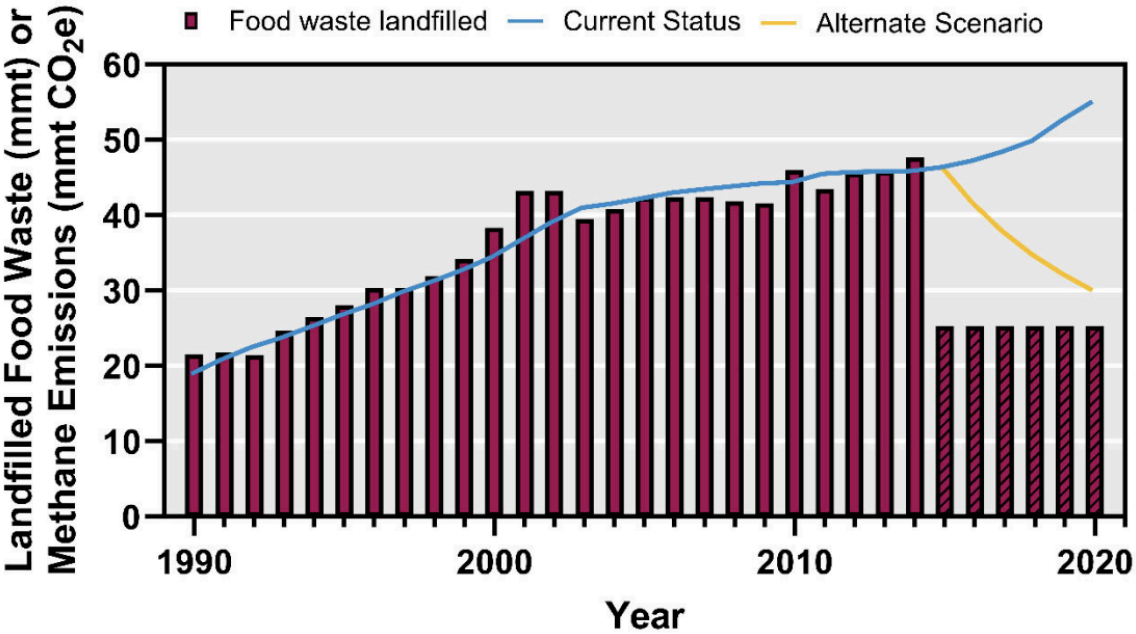


Figure 3. Contributions of food waste to methane emissions at MSW landfills.

4. For every 1,000 tons of food waste landfilled, an estimated 34 metric tons of fugitive methane emissions are released
5. Reducing food waste by 50 percent in 2015 could have decreased cumulative fugitive landfill methane emissions considerably.



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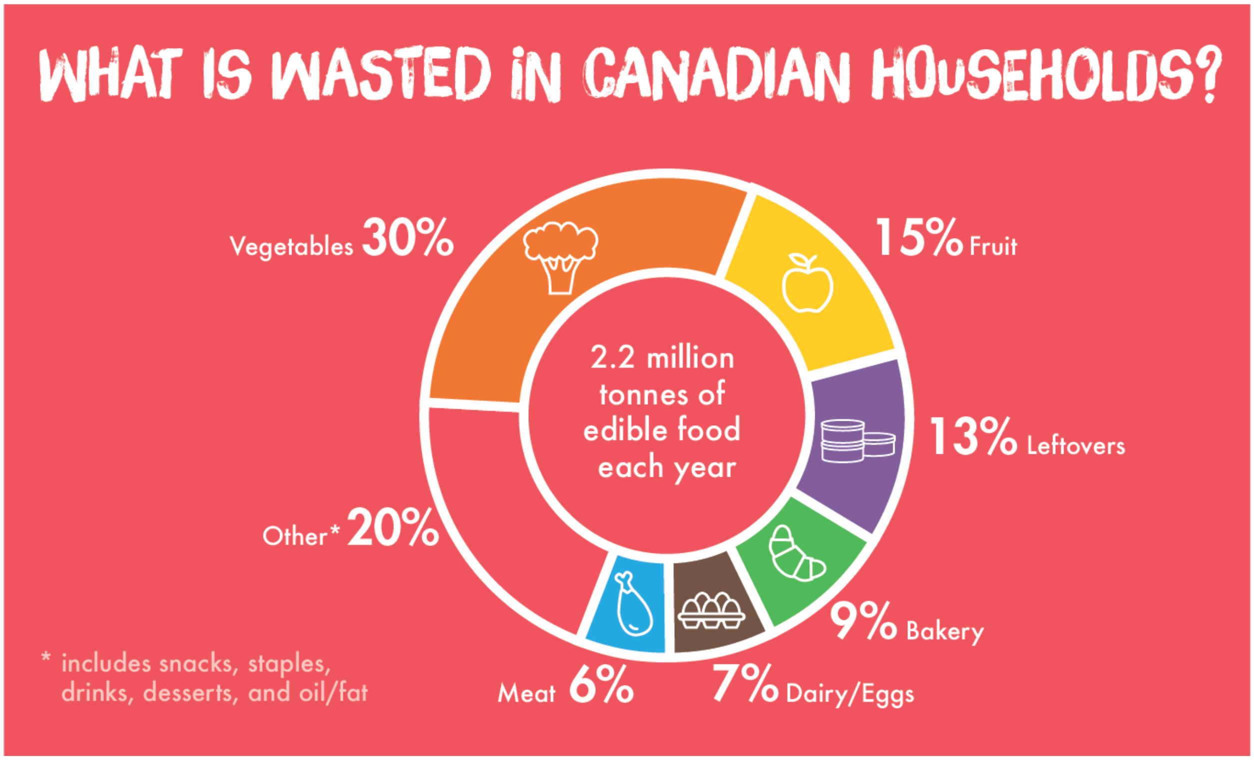
My background research proves that when food waste ends up in landfills, significant methane is emitted to the atmosphere even with the installation of gas collection and control systems. The fastest and most economical way to reduce emissions from organic waste is to simply stop putting the waste in landfills, where it off-gasses methane into the atmosphere. Composting at various stages of food production and consumption, donating food and transforming food waste into useful bioenergies and biochemicals, these are some of the ways that are talked about to help reduce methane emissions. In my project, I will be analyzing the different food valorization processes in transforming food waste or other undervalued biomass resources into a product like fuel energy, power, and biochemical or chemical synthesis/ generation.



Methods

Food Waste Generation Sources:

Cereal and pulses industry

https://eprints.whiterose.ac.uk/199454/1/processes-11-00840-v2.pdf

- Cereals, including rice, sorghum, barley, wheat, millet, corn, and buckwheat, are essential energy sources in the human diet, comprising a significant proportion of the food pyramid. During processing, cereals and pulses yield various by-products such as germ and bran.
- The malting process is a biochemical conversion of raw grains, such as barley, that transforms them into malt suitable for use in the production of beer, whiskey, and other spirits. This process involves the activation of enzymes that hydrolyze the starch present in the grain into simple sugars. The remaining cereal residue is typically considered a byproduct of the process and is commonly discarded as waste. Waste from the malting process contains a significantly higher amount of vitamin E and is a rich source of various bioactive compounds, including phytates, phenolics, and insoluble dietary fiber.
- Hydrolyzing rice bran and rice husk using cellulase also results in the production of phenolic compounds.

- The remaining shells after cocoa processing can be used to extract pectin, flat mushrooms, and livestock feed.
- second-generation bioethanol can be derived from coconut husk
- The husks from the pulses processing can be recycled to produce high-end products such as baskets, brooms, and hand fans

Fruits and vegetables:

- Fruits and vegetables are abundant in essential nutrients and contain high levels of water, soluble carbohydrates, fiber, minerals, vitamins, polyphenols, and other bioactive compounds. Despite this, they are often considered waste once they experience changes in color, undergo biochemical reactions, become infested with microbes, experience breakage or frostbite, are subjected to heat treatment, or reach levels of ripeness that make them unacceptable to consumers

- During the processes of harvesting, transportation, sales, and processing, nearly 30% of the fruits and vegetables produced were wasted. These fruit and vegetable wastes are either composted, landfilled, incinerated, or repurposed as animal feed

- One promising avenue involves the hydrolysis of cellulose and starch present in fruit and vegetable waste to extract soluble sugars that can be fermented to produce ethanol and hydrogen

- Microbial processing provides novel treatment directions for discarded fruits and vegetables, including single cell proteins , single cell oils, fermented beverages , biopigments , polyphenols, dietary fibers, food additives, enzymes, and biofuels.

- Fruit and vegetable wastes can also be fermented to produce lactic acid and succinic acid.

Dairy:

- Recent research by The Guardian indicates that approximately one-sixth of the total milk production worldwide is lost or wasted, resulting in a staggering annual wastage of around 128 million tons of milk [30]. The dairy industry generates waste due to factors such as processing, microbial spoilage, and inadequate handling.

- For example, this dairy waste is a suitable substrate for ethanol production through enzymatic digestion using brewer's yeast.
- Filamentous fungi also produce several enzymes that can break down complex carbohydrates present in dairy waste into monosaccharides. This process helps in

producing high-quality biomass that is utilized as animal feed and as single-cell protein, which has Generally Recognized as Safe (GRAS) status for human consumption.

Edible oil:

- The edible oil processing industry generates waste at each step in the refining process, including degumming, neutralization, bleaching, and deodorization.

- Historically, the oil processing industry has discharged its effluents into the soil and groundwater, resulting in the formation of oily films on aquatic surfaces. This has posed a significant threat to the survival of marine animals and led to blockages of sewage and drains due to organic matter emulsification, as well as oil methanation, exacerbating the greenhouse effect [37

- Waste from the edible oil industry, such as tocopherols, sterols, and squalene, are now extracted and used as raw materials in various industries, including the production of single-cell oil/protein for food [42], as well as in medicinal formulations and cosmetics in the form of soap stalk [43].

Meat, Poultry, and eggs:

- According to recent data from an online database [44] the worldwide production of meat, including beef, poultry, sheep, and pork, has risen to 345.17 million tons in 2022, compared to almost 330.51 million tons in 2018

- Feathers, hair, skin, horns, hooves, soft tissue, deboning remnants, and bones are among the most prevalent industrial waste materials

- Slaughterhouse waste is a fertile source of nutrients that can be utilized to generate various value-added products such as biogas, blood for food and non-food applications, biomass, and methane.

- Biodiesel has been produced from pork fat waste through fermentation with Staphylococcus xylosus, chicken manure biochar via pseudo-catalytic transesterification reactions, and eggshells via homogeneous catalysts for transesterification of triglycerides with methanol [50]. It has significant potential in the development of pharmaceutical and cosmetic products.

Seafood and aquatic life:

- Marine ecosystems serve a vital role in the global food supply, providing approximately 20% of the world's food for human consumption, and as a result, are integral to supporting the needs of the planet's growing population

- In general, 50–70% of raw seafood is wasted annually

- Consequently, a large amount of waste is produced, including inedible fractions such as shrimp shells, crab shells, prawn waste, fish scales, and endoskeleton shells of crustaceans. Globally, about six to eight million tons of crab, shrimp, and lobster shells are produced, with Southeast Asia accounting for 1.5 million tons.

- Waste from the seafood processing industry has the potential to yield functional and bioactive compounds through hydrolysis mediated by enzymes.

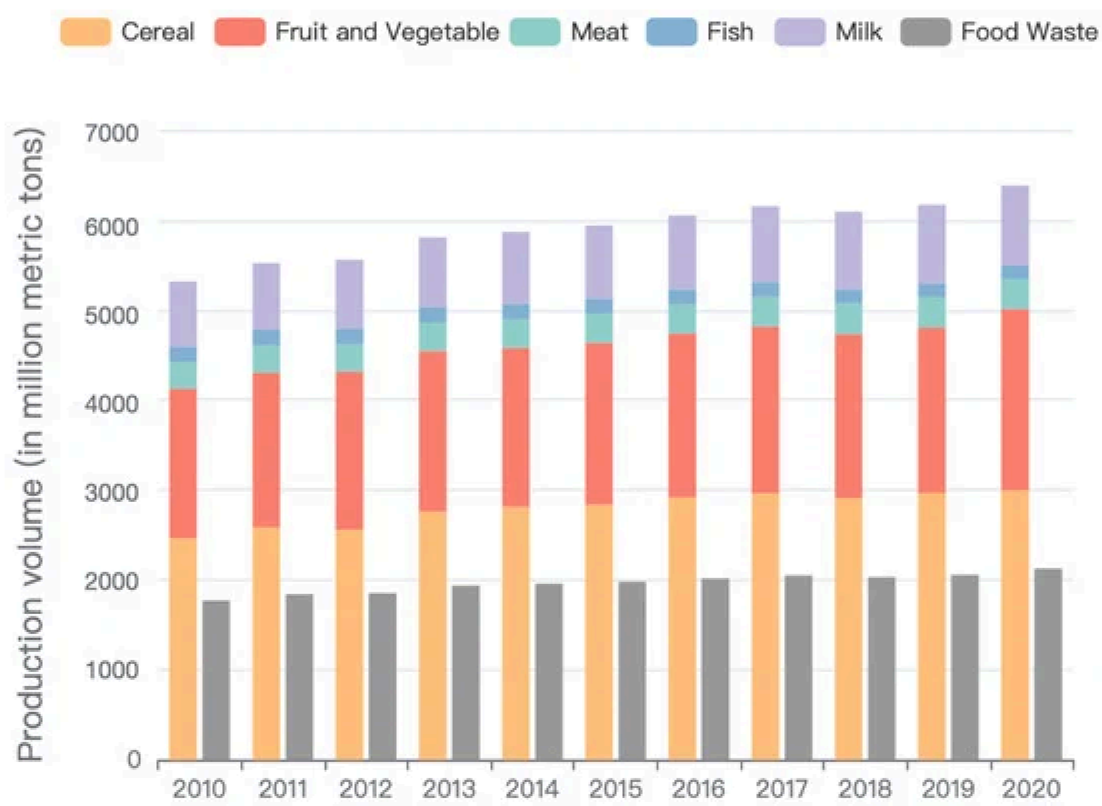
Agricultural Waste:

- Agricultural waste encompasses a variety of materials, such as straw, bagasse, molasses, spent grains, husks (rice, maize, and wheat), shells (walnut, coconut, and groundnut), skins (banana, avocado), plant debris, and animal and poultry manure [58].

- According to a report by the FAO [59], approximately 250 million tons of inedible plant waste from different crop processing methods were generated as agricultural waste [60]

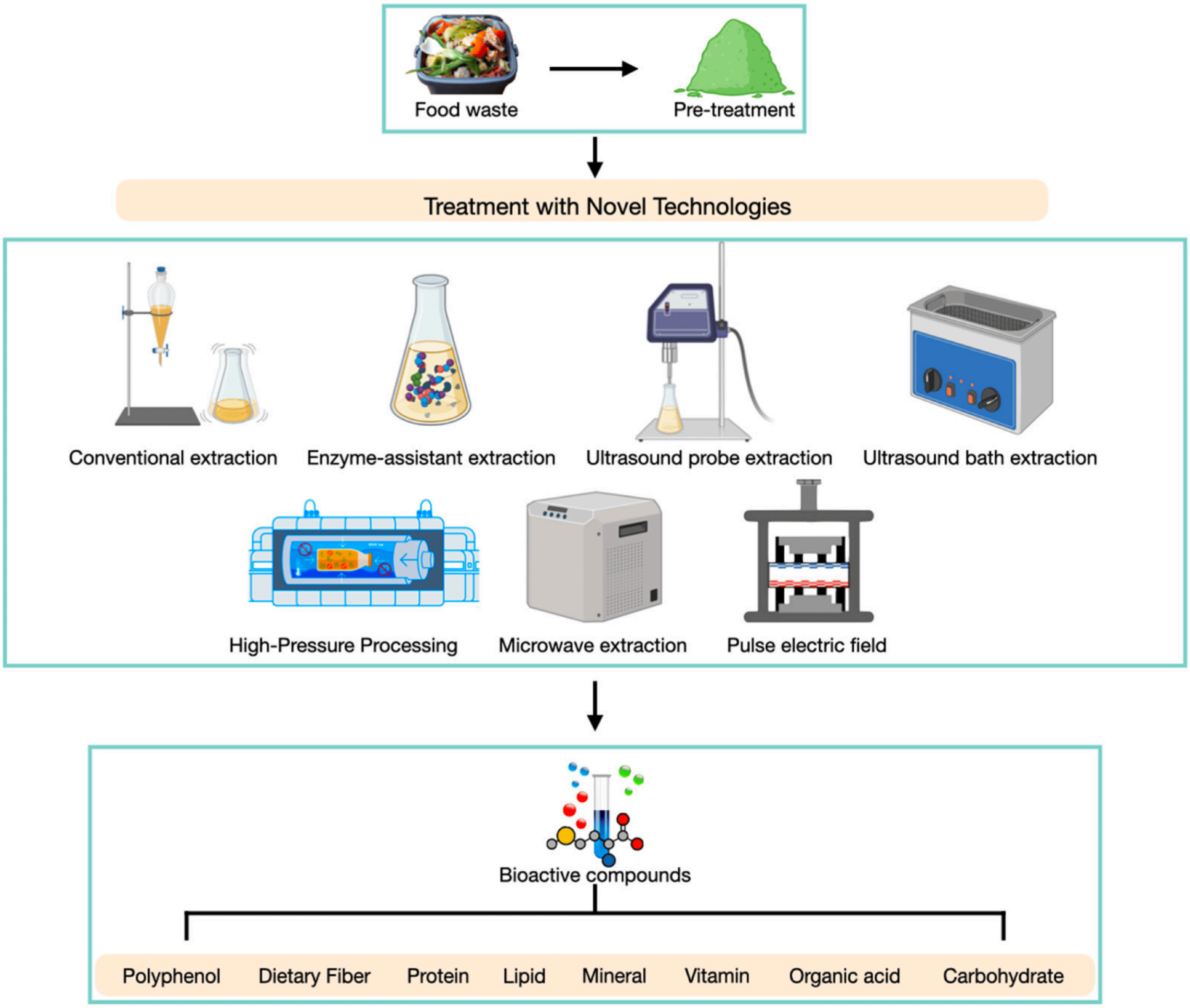
- Conventional methods of disposing of agricultural waste typically involve either incineration or allowing the waste to decompose in fields, which can result in significant air pollution and contribute to the contamination of soil, water, and food

- Agricultural wastes are biodegradable organic wastes containing various nutrients such as polysaccharides (starch, cellulose, hemicellulose), proteins, lignin, fiber, minerals, vitamins, and others



Technologies for Food Waste Utilization for Low Carbon Footprints

Current researchers recommend novel approaches to circulate waste by producing energy and bio-active compounds [23]. Improved methods of Hydrothermal carbonization, dendro liquid energy (DLE), ultra-fast hydrolysis, anaerobic digestion, composting and pretreatment allow to procure energy, biofuels, fertilizers and material for other industries.



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Biorefinery solutions for different types of food waste

Value-added products obtained from various food waste sources and their potential use in the food industry.

Supercritical fluid extraction is well positioned for the valorization of tomato residues prior to disposal, because it remains an environmentally safe extraction process, especially when using carbon dioxide as the solvent

Supercritical fluid extraction:

Supercritical fluid extraction (SFE) is a process that uses supercritical fluids, such as carbon dioxide (CO_2), to extract desirable compounds from various substances. In the context of food waste, SFE with CO_2 can be a valuable technique for extracting valuable compounds from food waste streams, thereby reducing waste and potentially obtaining useful products.

Here's how supercritical fluid extraction using carbon dioxide works in the context of food waste:

1. **Supercritical Carbon Dioxide**: Carbon dioxide is chosen as the supercritical fluid because it can easily reach a supercritical state under relatively mild conditions of pressure and temperature. In its supercritical state, CO_2 exhibits properties of both a gas and a liquid, making it an excellent solvent for extracting compounds from various substances.

2. **Preparation of Food Waste**: Food waste is typically prepared by grinding or shredding it into smaller particles to increase the surface area and facilitate extraction. This step is essential to ensure efficient extraction of target compounds.

3. **Extraction Process**: The prepared food waste is placed in an extraction vessel, where it is exposed to supercritical CO_2. The CO_2 is pressurized and heated to reach its supercritical state, typically around 31°C and 74 bar pressure.

4. **Solvent Properties**: In its supercritical state, CO_2 behaves like a solvent, capable of dissolving a wide range of compounds including oils, fats, pigments, flavors, and other bioactive molecules present in the food waste.

5. SCF-CO_2 has proven particularly effective for extracting non-polar and moderately polar compounds. However, its lower polarity does present a limitation when it comes to extracting polar compounds. This challenge can be mitigated by optimizing the SCF extraction process with the use of a co-solvent, thereby extending the range of compounds that can be efficiently extracted [61]. Polar compounds, e.g., polyphenols, can be extracted using SCFs in combination with co-solvents (methanol, ethanol, and acetone) as they enhance the solvating power, solubility, and extractability of polar compounds

6. **Selective Extraction**: One of the significant advantages of SFE with CO_2 is its selectivity. By adjusting the pressure, temperature, and other extraction parameters, it is

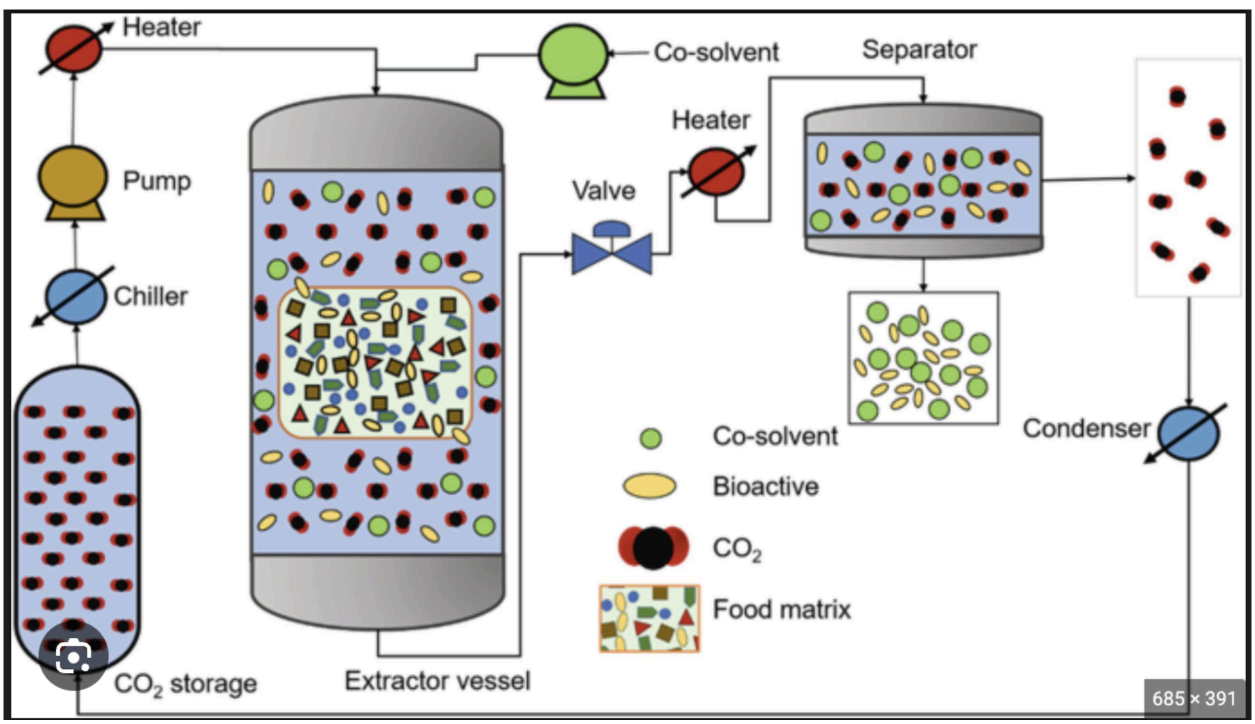
possible to selectively extract specific compounds while leaving others behind. This selectivity allows for the targeted extraction of valuable compounds from the food waste.

7. **Separation and Collection**: After the extraction process, the supercritical CO2, now laden with dissolved compounds, is depressurized, returning it to its gaseous state. As CO2 returns to its gas form, it leaves behind the extracted compounds. These compounds can then be collected, often through a separation process, leaving behind the CO2 for recycling or reuse in subsequent extractions.

8. **Applications**: Supercritical fluid extraction using carbon dioxide can be used to extract various valuable compounds from food waste, including essential oils, antioxidants, flavors, and bioactive compounds. These extracted compounds can have applications in food, pharmaceuticals, cosmetics, and other industries, contributing to waste reduction and the development of value-added products from food waste streams.

9. After the process if the cosolvent and the extract are still mixed together it will get separated in many numbers of ways for example: distillation, absorption, liquid-liquid extraction, and more.

In summary, supercritical fluid extraction using carbon dioxide offers an efficient and environmentally friendly method for extracting valuable compounds from food waste, thereby reducing waste and providing opportunities for the development of sustainable products.



[Influence of the Supercritical Fluid Extraction (SFE) on Food Bioactives | SpringerLink]

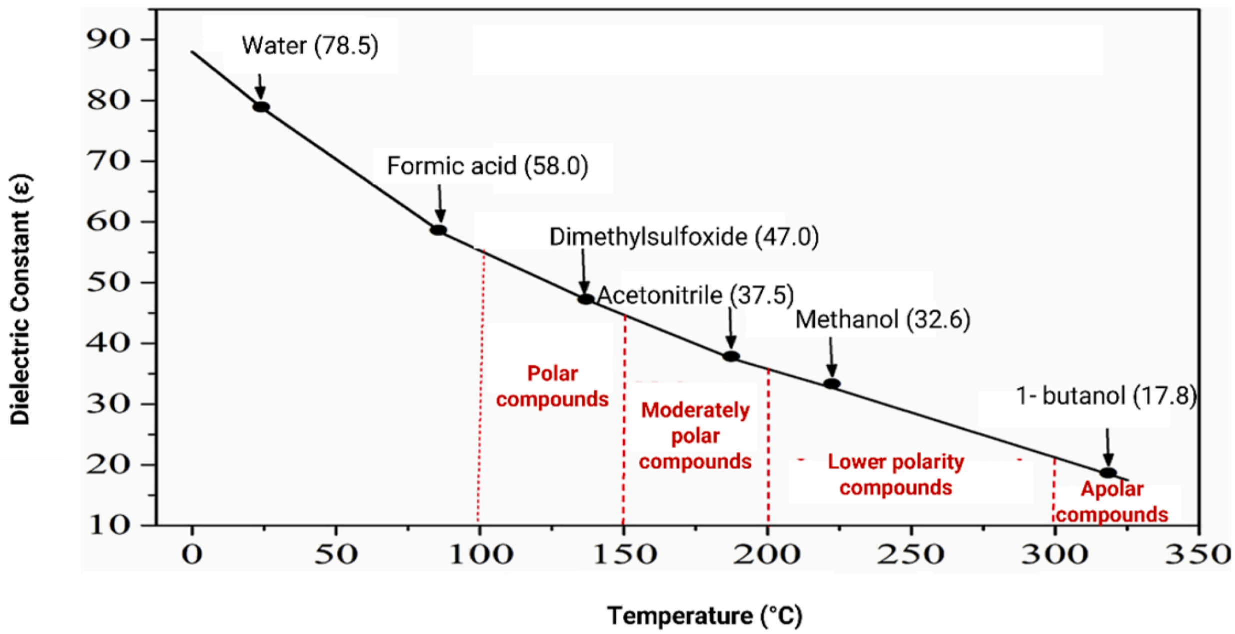
Technique:	Sample:	Treatment condition:	Overall outcome
SFE-CO_2, 15.5% ethanol as co-solvent	Tomato and peach peels	350 bar, 59 °C, 5 g/min, 30 min	91% and 94.2% carotenoid(pigment) recovery, with considerable content of β-carotene and lutein(type of carotenoid containing vitamin A)
SFE-CO_2, 5% ethanol as co-solvent	Apple pomace	30 MPa, 45 °C, 2 L/h, 2 h	Higher antioxidation, 5.63 TEA/g of extract as compared to conventional method
SFE-CO_2, 5% ethanol as co-solvent	Grape (*Palomino fino*) pomace	400 bar, 55 °C, 0.8 g/min, 3 h	2176 mg/100 g resveratrol on dry basis
SFE-CO_2, ethanol as co-solvent 7%	Broccoli (*Brassica oleracea* var. italica) stem and leaves	443 bar, 40 °C, 31 g/min	β-carotene, chlorophylls, phytosterols, and phenolic compounds
SC-CO_2, ethanol as a co-solvent 10%	Tomato (*Lycopersicon esculentum* L.) waste, seeds and skins	150 bar, 20 °C, and 5 mL/min	Lycopene 205 mg per 100 g and β-carotene 75 mg per 100 g of extracted oleoresin
SFE-CO_2, ethanol as co-solvent	Grape (*Vitis vinifera* L.) skin, seeds and pomace	250 bar, 60 °C, 2 mL/min	Trans-resveratrol, β-sitosterol, α-tocopherol, and ascorbic acid

Subcritical water extraction:

Subcritical water refers to high-temperature and high-pressure water. A unique and useful characteristic of subcritical water is that its polarity can be dramatically decreased with increasing temperature. Therefore, subcritical water can behave similar to methanol or ethanol. This makes subcritical water a green extraction fluid used for a variety of organic species.

- When temperature and pressure are increased, changes occur in physical and chemical properties of water: an increase in diffusivity and a constant decrease in viscosity, surface tension and dielectric constant, and latter weakening of hydrogen bonds

- All these changes in the physical and chemical properties of water allow this type of extraction to be more efficient than commonly used techniques



- When temperature increases, dielectric constant decreases. For example, at 250°C at atmospheric pressure of 25 bar the dielectric constant of water reduces to around 25.
- Thus, at these temperatures and pressures, water becomes capable of extracting compounds of medium to low polarity, similarly to organic solvents

1. Extraction Process: Prepared food waste is loaded into an extraction vessel, which is sealed to prevent the escape of water vapor.

2. Heat and Pressure Application: The extraction vessel is heated to the desired temperature, typically ranging from 100°C to just below 374°C, depending on the target compounds and the characteristics of the food waste being processed. Pressure is also applied to keep the water in its liquid state.

3. Extraction of Compounds: As water remains in its liquid state under subcritical conditions, it exhibits unique solvent properties, enabling it to penetrate the cell walls of the food waste material and dissolve various compounds.

4. Retention of Target Compounds: One of the advantages of subcritical water extraction is its selectivity. By adjusting the temperature and pressure parameters, it is possible to selectively extract specific compounds while leaving undesirable components behind.

5. Collection and Separation: After the extraction process is complete, the extract containing the target compounds is separated from the residual food waste material. This may involve filtration, centrifugation, or other separation techniques.

Compound	Raw material	Extraction condition
Polyphenols	Potato peel Grape skin Red grape pomace Pumpkin leaves Spent coffee grounds Apple by-products Onion skin Wheat straw	100–240 C; 60 bar; 30–120 min 100–160 C; 100 bar; 40 s 40–140 C; 68 bar 100–220 C; 10–50 min 160–180 C; 35–55 min 25–200 C; 103 bar; 3–17 min 170–230 C; 30 bar; 30 min 130–270 C; 1.7–54 bar; 10 and 30 min
Carbohydrates	Spent coffee ground Citrus peel and apple pomace Sugar beet pulp Peach pomace Onion bulbs and skins Peanut shell Corn stalks	150–210 C; 20–60 bar; 5–15 min 100–140 C (citrus peel) and 130–170 C (apple pomace); 5 min 110–130 C; 80–120 bar; 20–40 min 40–80 C; 10–80 min; 99.8–319.8 C; 5 min 180–240 C; 60–480 s 280–390 C; 25–40 s
Proteins and amino acids	Shrimp cephalothorax by-products Waste fish entrails Okara Deoiled rice bran Mackerel liquid waste	230–280 C; 27.8–201.8 bar; 5–30 min 19.8–449.8 C; 350 bar; 90 min; flow rate of 40 cm3 min1 70–260 C; 2–120 min 100–220 C; 1.03–39.7 bar; 0–30 min 90–190 C; 50 bar; 1 or 2.5 h
Oils and fatty acids	Squid by-product entrails Olive pomace Rice bran	169.8–379.8 C; 7.92–300 bar; 1–40 min 160–200 C; 5–25 bar; 260–350 s 120 and 240 C; 10 and 20 min

Enzyme assisted extraction:

https://www.mdpi.com/1422-0067/23/4/2359

1. Food waste is prepared: gathered, chopped, crushed, and added enzymes. These are done to increase the surface area of the waste. Enzymes are added to the prepared food waste material.
2. The process of Enzymatic hydrolysis (the process by which enzymes break down complex organic molecules into simpler compounds) begins.
3. The conditions for enzymatic hydrolysis, including pH, temperature, enzyme concentration, and reaction time, are optimized to maximize the efficiency of biomass

extraction. The parameters may vary based on the enzymes used and the composition of the food waste.

4. After the process is complete, the resulting mixture is separated to recover the desired biomass components.

Enzymes:	**Producent:**	**Substrate:**	**pH:**	**Temp. °C:**	**Time:**
Xylanase cocktail	*A. niger*	Citrus fiber	4.5−6.5	50	120 min
Cellulase	*A. niger*	Coffee by-products	5.0−6.0	50	30−20 min
Cellulase from Celluclast 1.5L	*T. reesei*	Banana peel	6.0−7.0	50	120 h
Pectinase	*A. niger*	**Guava pulp**	2.97−3.97	45	3–90 min
Pectinase	*A. niger*	Blackcurrant	5−6	60	10−90 min
Heat stable alpha-amylase	*Bacillus sp.*	Oat flours	5.0−9.0	100	15−75 min

Extraction using ultrasounds:

Ultrasound-assisted extraction produces a phenomenon known as cavitation, which entails the production, growth and collapse of bubbles. Ultrasounds have effects that accelerate heat and mass transfer via the disruption of plant cell walls, leading to improved release of the target compounds from several natural sources.

https://www.sciencedirect.com/science/article/pii/S135041772300456X#b0085
https://www.tandfonline.com/doi/full/10.1080/19476337.2017.1411978

Particle Size Reduction:

- Food waste is prepared: collected, chopped, grinded. These are done to increase the surface area of the food waste.

Solvent Selection:

- Based on the compound wanted to be extracted, a suitable solvent is chosen. These solvents include water, ethanol, or a mixture of both.

Ultrasound-Assisted Extraction:

- The prepared food waste is then mixed with a selected solvent.
- The mixture is then subjected to ultrasound irradiation. Ultrasound waves cause cavitation, which generates microbubbles in the solvent. When these bubbles

collapse, they create intense local heating, pressure, and micro-streaming, facilitating the release of compounds from the biomass into the solvent.

- The extraction can be performed at various frequencies and amplitudes depending on the specific requirements of the extraction process. Optimal conditions should be determined through experimentation.

Application of Extracts:

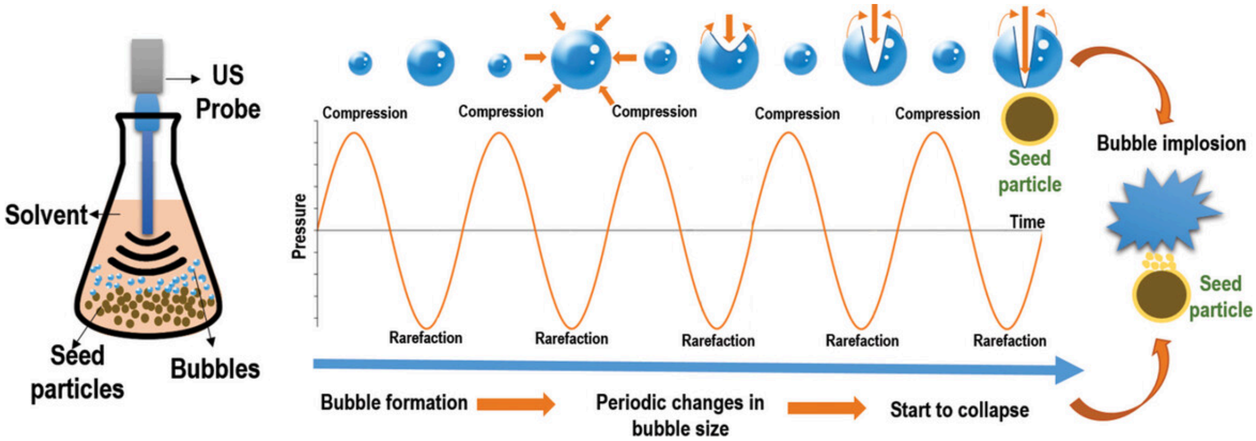
- The extracted compounds can be used in various applications such as food additives, nutraceuticals, pharmaceuticals, and cosmetics.

Scale-Up Potential: Ultrasound-assisted extraction can be scaled up for industrial applications, making it suitable for processing large quantities of food waste in commercial settings.

Fruit source:	Target compounds:	Extraction conditions:
Avocado peels	Bioactive compounds	Ethanol 38.46 %, 44.06 min, 50 °C, 37 kHz
Sichuan red orange peel	Tangeretin & nobiletin	Ethanol 85 %, LS 20:1 mL/g, 40 min, 50 °C, 150 W, 20 kHz
Mandarin peel	Phenolic content	48 °C, 56.71 W, 40 min, 38.5 kHz
Mandarin peels	Pectin	80 °C, 37 kHz, 30 min
Orange peel	Carotenoids	35 min, 42 °C, LS 15 mL/g
Orange peels	Antioxidants	30 min, 60 °C, 15 mL/g
Orange peel	Bioactive compounds	400 W, 30 min, Ethanol 50 %

Advantages of Ultrasound Extraction:

- Reduced extraction time compared to conventional methods.
- Lower solvent consumption.
- Minimal thermal degradation of heat-sensitive compounds.
- Environmentally friendly process.
- Scalable for industrial applications.



Microwave assisted extraction:
https://www.mdpi.com/2304-8158/10/2/279
http://article.sapub.org/10.5923.j.food.20170701.03.html

Firstly, the selective absorption of microwave energy by the water glands inside the sample matrix favors localized heating above or near the boiling point of water causing expansion and rupture of cell walls by disrupting the interaction between the solute and active site of the matrix through the splitting of hydrogen bonds, van der Waals force, and dipole attraction. Second, the disrupted cell promotes the mass transfer of the solvent into the sample matrix and bioactive compounds into the solvent. Third, extracted bioactive compounds then dissolve into the surrounding solvent.

Grinding or Size Reduction: Food waste is prepared: collected, chopped, grinded. This helps enhance the efficiency of compound extraction.

Solvent Selection: Based on the compound wanted to be extracted, a suitable solvent is chosen. These solvents include water, ethanol, or a mixture of both.

Extraction Conditions: The prepared food waste is mixed with the selected solvent in a suitable container or vessel. The mixture is then subjected to microwave irradiation under controlled conditions of temperature, pressure, and time.

Microwave Heating: Microwave energy is applied to the sample, causing the solvent molecules to rapidly heat up. As the temperature of the solvent increases, it facilitates the breakdown of cell walls and the release of target compounds from the biomass matrix into the solvent.

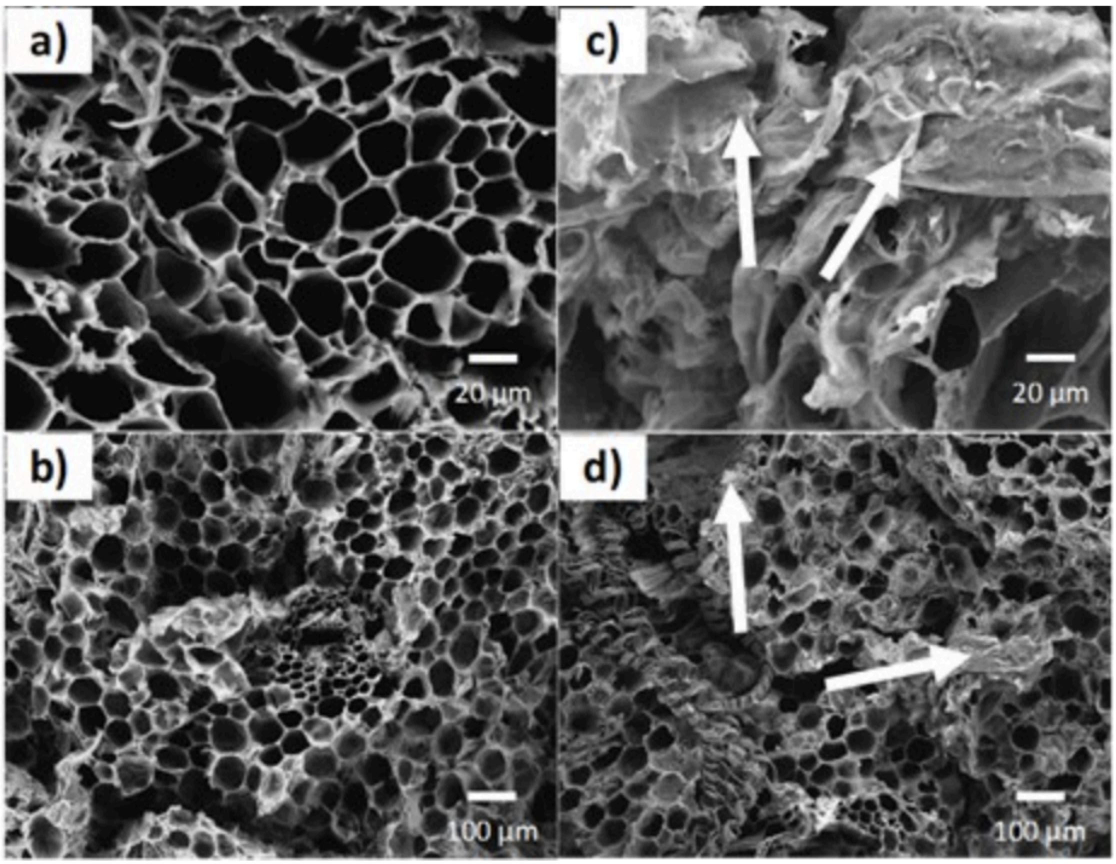
Cooling and Filtration: After the extraction process is complete, the mixture is allowed to cool to room temperature. It is then filtered to separate the solvent extract containing the desired compounds from the solid residue.

Advantages of microwave-assisted extraction:

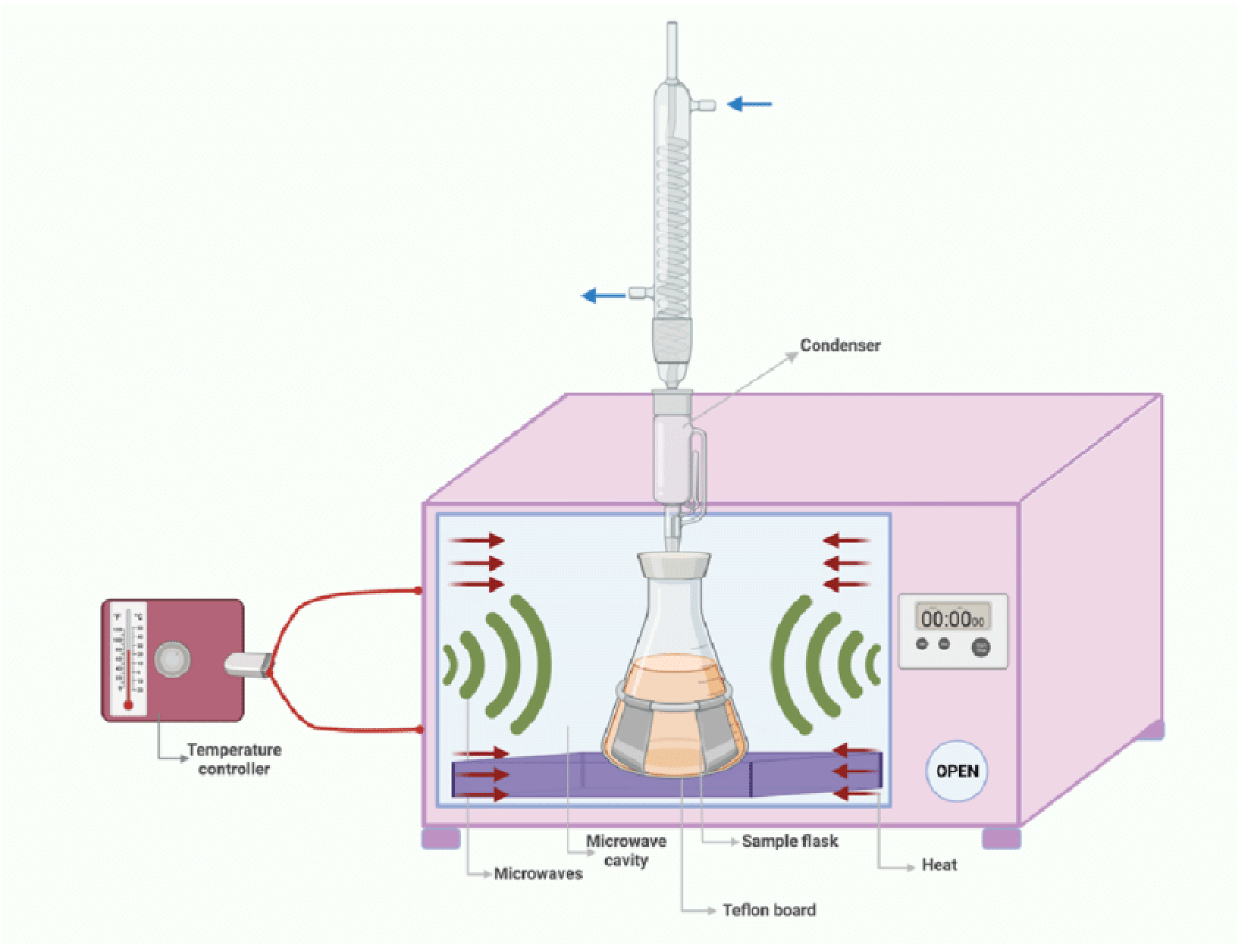
- shorter extraction times
- reduced solvent consumption,
- improved extraction efficiency

https://bioresources.cnr.ncsu.edu/resources/microwave-assisted-extraction-of-functional-compounds-from-plants-a-review/

Figures 2a and 2b (without microwaves) show the complete morphology of the plant sample, while in Figs. 2c and 2d (with microwaves), the lignin structure is seen to be broken, and an individual fiber can be observed, indicating significant structural damage.



Sources:	Compounds:	Temperature:	Solvent/Co-solvent
Vine prune residues	Total phenolic content	120	Ethanol -water
Ocimum basilicum	Polyphenols	-/442	Ethanol
Mangifera indica leaves	Mangiferin	-/272	Water
Red grape pomace	Phenolics	50/200	Water-ethanol
Cabbage leaves	Phenolic content	~50/100	Ethanol



Results:

Method	Advantages	Limitations
Ultasound https://www.sciencedirect.com/science/article/pii/S135041772300456X#s0070 https://www.mdpi.com/2304-8158/11/14/2035	• Reduced extraction time compared to conventional methods. • Lower solvent consumption. • Minimal thermal degradation of heat-sensitive compounds.	• More research needs to be performed on the cost-effectiveness of the treatment when applied in a large scale. • The flow-through systems work well when the viscosities of the medium is low to medium. More studies

	• Environmentally friendly process. • Ultrasound accelerates the disintegration of large chunks of food waste into fine particles, thereby increasing the mass transfer and hence the diffusion of bioactives from food waste into the extraction medium. • Ultrasound has been shown to be effective in extracting value-added materials from wheat waste, vegetable waste, oil palm fronds, wheat straw, rice straw, rice hull, sugarcane bagasse, and spent coffee waste.	needs to be done in this area to find the optoimium viscosity levels of the medium. • In-depth studies are needed so that the energy efficiency of ultrasonication can be improved.
Microwave assisted extraction https://bioresources.cnr.ncsu.edu/resources/microwave-assisted-extraction-of-functional-compounds-from-plants-a-review/	- shorter extraction times - reduced solvent consumption, - improved extraction efficiency Despite the disadvantages associated with MAE, its advantages are overwhelming. In general, MAE techniques are excellent in terms of its extraction efficiency, technique stability and reproducibility and also the ability to retain the functional values of extracted active compounds.	non polar solvent should normally be discouraged as they are poor absorbents for microwave heating. In other circumstances, applications of non polar solvent cannot be avoided in MAE as the solubility of extract of interest is higher as compared to polar solvents. The contradicting facts have clearly generated some difficulties in selecting solvents for MAE. However, many polarity associated problems can be overcome by adding

		modifiers into non polar solvents to enhance the microwave absorbing capacity of the solvent

Results to effective as it summarizes the economic benefit of this process

https://www.mdpi.com/2227-9717/11/3/840

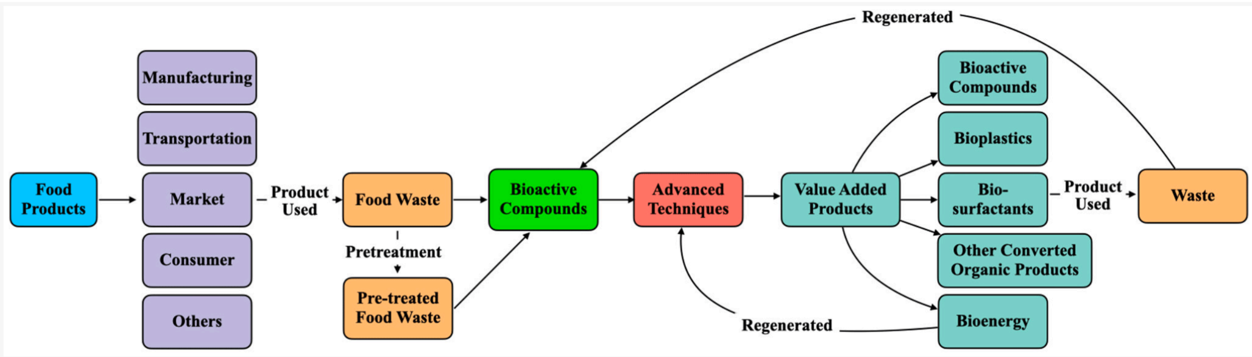
- My research has shown that numerous bioactive compounds can be derived from food waste.
- Various advantages are provided by these methods
  - Reducing waste
  - Create new economic prospects and promote a circular economy
  - Develop functional food ingredients, cosmetics, and dietary supplements.

- Limitations of these techniques:
  - Most techniques are in their early stages of development
  - Excessive extraction costs due to expensive equipment, solvents, and energy being a significant obstacle.
  - Undesirable extraction rates,

- Advancements needed in this technology:
  - Improve the efficiency of the extraction processes
  - Develop new methods that are more environmentally friendly
  - Use of more green solvents

Ultimately, the goal of the project is to find alternate ways other than compositing and breathe new life into waste with the background of the urgent problem of global FW production as a driving force. Going forth from this, the next steps of this project would be to advance and expand on this topic, channeling food waste to factories where food waste is utilized to make new products.

Ultimately, the goal of this project is to show alternative ways other than composting of food waste., as an urgent problem in the world is the large amount of methane production and countries are not providing effective alternatives to counter this growing problem. Going forth from this, the next steps of this project would be to advance and expand on this topic, opening companies in which food waste would be channeled towards them where these techniques would be utilized and improved.



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