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WASTE VALORISATION IN HORTICULTURE: A COMPREHENSIVE REVIEW

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ABSTRACT

Waste management in horticulture plays a pivotal role in achieving environmental sustainability and optimizing resource utilization. One of the primary methods for waste utilization is composting, which involves the decomposition of organic waste materials to produce nutrient-rich compost (Mehta *et al*., 2024). These days, a crucial concerning issue is arising globally to ensure nutrition security for huge population that leads to focus on production increase, quality improvement, food safety assurance and processing strategies (Jahidul Hassan *et al*., 2022). Fruits and vegetables are the most commonly consumed food products among horticulture crops. Horticultural waste such as crop trimmings, leaves, fruit or vegetable rejects, and processing residues contain cellulose, hemicellulose, lignin, and minerals which serve as excellent substrates for mushroom growth, especially for species that degrade lignocellulosic biomass (Kumla *et al.,* 2020). There are major nutritional, financial and environmental consequences associated with the large amount of peel waste produced by the fruit and vegetable-based industries and home kitchens (Bharti Gautam *et al*., 2025). This is a comprehensive review on “Waste Valorization in Horticultural crops”.
***Keywords* :** Valorisation, pivotal, organic waste, processing, nutrition security.

Introduction

World agricultural and food sector has important challenges to face in the 21st century. Amidst them, food safety and appropriate waste management stand out. Food wastes occupy an ever-increasing space in the waste treatment facilities and in the landfills. Now-a-days, many residues derived from the whole Food Supply Chain (FSC) represent the wastage of valuable resources and an environmental problem. On the one hand, in the low-income and developing countries food waste causes severe socioeconomic impacts (Gustavsson *et al*., 2011). On the other hand, the consumer’s attitudes and the massive consumption of goods and services cause the production of huge amounts of household waste in the medium/high-income countries (Usubiaga *et al*., 2017). Food is vital to the environment and to human existence; it can be used to make goods with additional value or consumed in processed forms (Bharti Gautam *et al*., 2025). Food processing is an important sector in agriculture, the scope of which has increased manifold that can help to prevent wastage of perishable commodities to a great extent. But, at the same time, the food processing industries generate a large quantity and variety of food products, provide employment to a large number of people and uplift their economic status. The utilization of waste for the production of value added products is very important in the management of food processing waste. Different types of food industries wastes are: i) Fermentation industry waste ii) Fruit and vegetable industry waste iii) Sugar and starch industry waste iv) Dairy industry waste v) Meat processing industry waste vi) coffee industry waste and vii) palm oil industry waste viii) fish processing industry waste. Most of fruit and vegetable wastes are a rich source of vital constituents like carbohydrates, proteins, fats, minerals and fibres etc. So, there is a great need to find out options which have positive values of food waste.

The options having positive values are:

i) Minimization of the waste generation,

ii) Development of value added products (Dev Raj *et al.*, 2020).

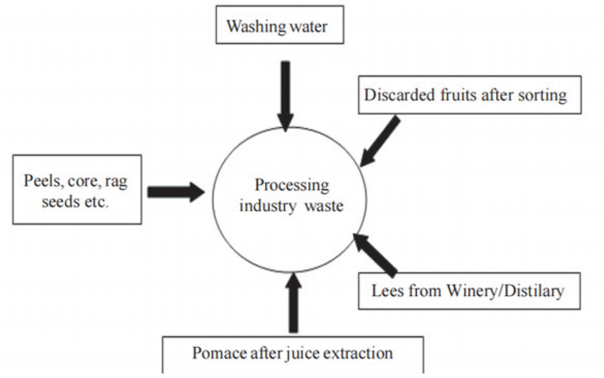

Fig. 1: The major sources of pollution load in fruit and vegetable processing industry (Joshi, 2002)

Recycling opens up new opportunities with commercial benefits, leading to the production of biofuels, enzymes, vitamins, antioxidants and various essential chemicals from industrial wastes. Embracing the concept of "Waste to Wealth" represents a modern approach to waste disposal (Mehta *et al.*, 2024).

Types of Horticultural Wastes:

Field Waste

Field waste refers to residues produced directly in farms after cultivation practices such as pruning, thinning, harvesting and crop maintenance. It includes leaves, stems, branches, grass clippings, weeds, flowers and unharvested or non-marketable fruits and vegetables. These wastes are rich in lignocellulose biomass and often remain unused, contributing to on-field decomposition, methane emission, pest carryover and nutrient imbalance (Bharti Gautam *et al.*, 2025).

Processing Waste

Processing waste is generated when horticultural produce undergoes transformation into juice, jam, pickles, pulps, dehydrated powders or oils. It includes peels, kernels, seeds, press residues, pomace, bagasse and oil extraction cakes. These wastes are highly biodegradable and contain significant amounts of starch, proteins, fibers, essential oils, antioxidants and natural pigments. Recycling pathways include extraction of dietary fibres, bioactive compounds, enzymes, natural dyes, pectin, seed oil recovery, production of animal feed, bio-fertilizers and substrate for bioenergy generation (Jahidul Hassan *et al.*, 2022).

Post-Harvest Waste

Post-harvest waste represents losses due to mechanical damage, microbial spoilage, senescence, respiration heat, poor handling, inadequate cold chain and market rejection. It includes over-ripe, bruised, diseased, dehydrated, pest-infested, or physiologically disordered produce. These wastes accumulate mainly in storage houses, markets, distribution centres and transport chains. Post-harvest waste is a major challenge due to high perishability, especially in fruits, vegetables and flowers with high respiration rates (Kader, 2013).

Packaging Waste

Horticultural packaging waste includes synthetic plastics, films, rigid containers, paper, cardboard, composite laminates, foams, nets, straps and plant-based packaging materials discarded after use. These wastes pose long-term ecological problems due to non-biodegradability, soil and water contamination, micro plastic formation and excessive carbon footprint. Packaging waste reduction strategies emphasize reuse systems, mono-layer design, minimal ink printing, recycling coding, take-back systems and integration of natural fibres into bio-polymers. (Verghese *et al.*, 2015).

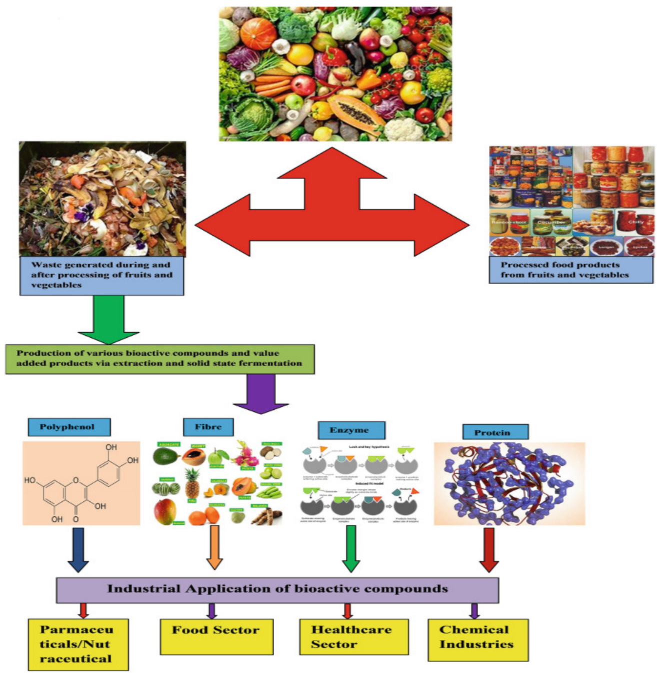

Fig. 2 : Horticultural food-waste valorisation and bioactive compound utilization. (Ravindra and Joshi, 2018).

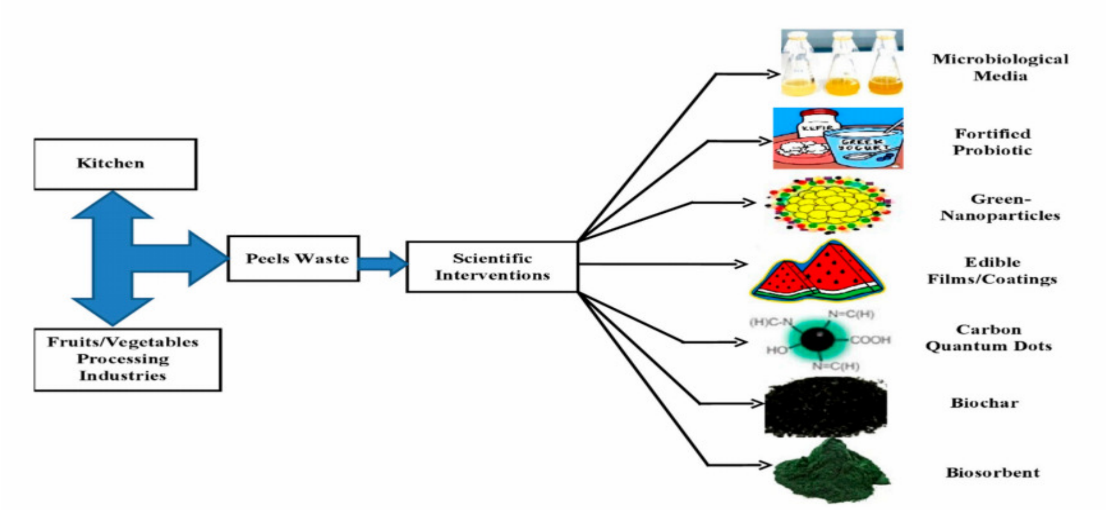

Fig. 3 : The valorisation (reuse/processing) of fruit and vegetable peel waste (or processing waste) into a variety of value-added products via "scientific interventions." (Harsh Kumar *et al.*, 18 June 2020).

Branches of Horticulture and Their Waste Utilization:

The valorisation of horticulture waste consists of obtaining different compounds from them or through their use in a process. As mentioned above the activity in horticulture crops are frequently associated with the production of large amounts of waste with several potential applications (Lobo *et al.*, 2019).

Pomology (Fruit science) and Olericulture (Vegetable science)

- Pomology is a branch of horticulture that deals with the scientific study of fruit crops, including fruit biology, production, breeding, post-harvest handling, storage and value addition (International Society for Horticultural Science).
- Olericulture is the branch of horticulture concerned with the science and cultivation of vegetable crops, including their growth, production, harvesting, storage, processing and utilization for culinary and industrial purposes (CABI).

➢ **Major Waste Generators in Fruits**

i. **Banana**: 20–30% fruit waste; 2–3 times more biomass in field residues - Banana Biomass Utilization (Padam *et al.*, 2014).

ii. **Citrus fruits**: 50% of processed fruit mass becomes peel/pomace waste - Citrus Peel Waste Recovery (Sagar *et a*l., 2018).

iii. **Mango:** 35–60% of fruit becomes waste in pulp/juice industry - Mango Waste Bio-refinery Potential (Torres-León *et al.*, 2018).

iv. **Apple:** 20–30% post-harvest losses due to bruising & diseases short shelf life losses **-** Bio Resource Technology **(**Joshi *et al.*, 1996).

v. **Pineapple:** 40–50% waste in fresh-cut and processing units - Pineapple Waste Bioconversion (Ketnawa *et al.*, 2020).

➢ **Major Waste Generators in Vegetables**

i. **Tomato:** 25–40% processing residue + high field rejection; mechanical and cold-chain damage – (Mourtzinos *et al.*, 2019)

ii. **Potato:** 30–40% peel waste in processing; storage sprouting/rot losses – (Arapoglou *et al.*, 2010)

iii. **Onion:** 20–30% trimming loss + fungal spoilage during storage – (Sharma *et al.*, 2015.)

iv. **Cauliflower:** 40–50% biomass is leaf/stalk waste + floret trimming in processing – (Singh *et al.*, 2016)

v. **Cabbage:** 25–35% outer leaf rejection in supply chain + rapid wilting – (Kumar *et al.*, 2019)

vi. **Chilli:** 20–30% post-harvest losses due to decay, handling and drying inefficiencies – (Sreenivas *et al.*, 2021)

❖ **Valorisation Methods:** Types of waste from Peels, leaves, stems, spoiled vegetables, seeds, pomace, damaged fruits.

Pectin Extraction

Pectin is a structural hetero polysaccharide present in the cell wall of all terrestrial plants and is basically composed of α (1,4) linked D-galactrounic acid residues. They can be found in most fruit pomaces and after extraction and purification can be added as gelling agents in numerous food products such as jams, fillings and sweets. Pectin is highly valued as a functional food ingredient as it contains dietary fibres, lactic acid, pigments, vinegar, natural sweeteners and cellulose (Lobo *et al*., 2019)

Fruit wastes used: Mango peel, Citrus peel (richest sources)

Uses: Jam, Jelly, Edible Films, Pharma Binders. **Advances:** Ultrasound-Microwave Assisted, Enzyme-Assisted Extraction.

Vegetable wastes used: Tomato Peels/Pomace, Pumpkin Rind (Secondary Source)

Uses: Hydrocolloids, Edible Films, Gelling Agents **Advances:** Ultrasound And Microwave Assisted Extraction

Process:

Peel collection → washing → drying → powdering → acid/ enzymatic/ ultrasound/ microwave extraction → filtration → precipitation → purified pectin → horticultural/ food/pharma use (Ciriminna *et al*., 2019).

Polyphenol & Antioxidant Recovery

Most of the bioactive compounds obtained from horticultural waste are polyphenols, which have been considered important due to their ability to scavenge free radicals and prevent oxidative reactions in food. The biological basis to explain the health benefits of poly-phenols relates to their well-established antioxidant properties. From a structural point of view, polyphenols can be classified into two major distinguishable classes. The first and largest one is the flavonoids, whose basic structure includes 2 benzene rings (A and B) that are linked through 3 carbon atoms that frequently form an oxygenated pyran heterocyclic ring (C). The second class of polyphenols, defined as non-flavonoid phenolics, includes a more heterogeneous group of compounds with an important subclass, the phenolic acids (Lobo *et al*., 2019).

Fruit wastes used: Grape seeds and skins, Banana peel, Mango kernel

Uses: Nutraceuticals, Natural Preservatives

Advances: Spray-Drying, Nano-Encapsulation, Stability Boosting

Process:

Waste biomass → drying/size reduction → solvent or enzyme-assisted extraction → centrifugation/filtration → concentration → (encapsulation if advanced) → stable antioxidant/phenolic products → nutraceutical & horticultural applications. (López-Ramos *et al*., 2023)

Fibre Extraction & Bio composites

Natural fibres have become much more apparent as an alternate to synthetic fibers, not just for textiles but also for a diverse variety of other applications (De Queiroz *et al*., 2020). Natural fibres are biodegradable, as contrast to manmade fibres, which are frequently employed in the textile industry (Kozlowski and Mackiewicz, 2020). When combined with alternative manufacturing practices, they have the potential to increase the value of products while also bringing social and environmental benefits (Fletcher, 2012).

Fruit wastes used: Banana pseudo stem fibre, Pineapple leaf fibre, Apple pomace

Uses: Biodegradable Packaging, Trays, Polymer Reinforcement
Advances: Nano-Cellulose Composites, High-Tensile Bio-Boards

Vegetable wastes used: Cauliflower/Cabbage Leaves & Stalks, Carrot Tops, Pumpkin Vines

Uses: Biodegradable Composite Boards, Polymer Reinforcement, Tea-Bag Substrates **Advances:** Nano-Fibre Isolation, Hemicellulose-Reinforced Composites

Process:

Biomass waste → fibre isolation → chemical/ steam/enzymatic pre-treatment → micro/ Nano-fibre extraction → bio composite reinforcement/ blending → biodegradable boards/ packaging → horticultural and industrial use (Hassan, 2018 and Mohanty *et al*., 2016)

Bioenergy (Biogas & Bioethanol)

The waste from fruit and vegetable processing industries being rich in biodegradable substances can be used for production of biogas. Biogas is produced by anaerobic digestion of fruit and vegetable wastes. Apple pomace/orange peel can be used for biogas production. During this process, the complex polymers are first hydrolysed into simple substances by acid forming bacteria and finally these are digested anaerobically by the methanotropic bacteria and methane gas is liberated (Dev Raj *et al*., 2020).

Fruit wastes used: Banana peel and stem, Pineapple peel, Papaya culls

Vegetable wastes used: Potato Peel, Tomato Field Biomass, Onion Tops, Pumpkin Pulp

Uses: Biogas via Anaerobic Digestion; Bioethanol via Fermentation
Advances: microbial consortia + enzymatic hydrolysis

Process:

Fruit biomass waste → shredding → pre-treatment (if advanced: enzymatic/ microbial) → Fermentation → bioethanol Anaerobic digestion → biogas → renewable energy for horticulture systems. (Zainuddin *et al.*, 2021)

Bio char & Activated Carbon Adsorbents

Bio char is a stable carbon-rich solid generated by pyrolysis as a result of the thermochemical decomposition of organic feedstock material at high temperatures under oxygen-free conditions. Different types of food waste have been used for the production of bio char and its yield and physicochemical properties have been reported in detail. Bio char is generally used to remove different types of pollutant containing heavy metals from contaminated water bodies. (Harsh Kumar *et al.*, 2020).

Fruit wastes used: Citrus peel carbon, Banana peel carbon

Vegetable wastes used: Carrot Peels, Chilli Biomass, Onion Skins, Tomato Plant Residues

Uses: Water Purification, Dye & Heavy Metal Adsorption

Advances: Microwave Pyrolysis, KOH/H_3PO_4 Chemical Activation → High Surface Area

Process:

Fruit peel waste → dehydration/drying → thermochemical treatment / microwave pyrolysis → chemical activation (KOH/H_3PO_4) → high-surface activated carbon / bio char → water/soil/environmental applications in horticulture. (Rodríguez and Molina 2022)

On-Farm Composting & Soil Amendment

The multi-fold increase in production of processed products during past few decades has also enhanced the quantity of waste material after processing. Proper disposal of waste material is becoming an issue which all industrialists confronts, especially those settled in cities, where the land cost is very high. Moreover, over the time, environment protection agencies have also started questioning the unorganized disposal of waste material; as it affects the surrounding environment and causes nuisance if not handled properly. So, during the recent years, the disposal of waste material has become a challenge to the processors, as different agencies are pressurizing for an environment friendly treatment of waste material. Therefore, composting is one of the best methods for solving the problems of waste material disposal (Dev Raj *et al.*, 2020).

Fruit wastes used: Mixed orchard and processing wastes such as mango, banana, pineapple, apple culls, leaves, peels.

Vegetable wastes used: Cabbage, Cauliflower, Leafy Greens, Carrot Tops, Pumpkin Vines, Tomato Plant Waste

Uses: on-farm compost for orchards, mulching, bio-fertilizer base

Advances: Microbial inoculated composting for faster decomposition and higher NPK

Process:

Orchard/fruit-waste mix → shredding → (co-composting if advanced: microbial inoculation) → controlled composting → maturation → nutrient enriched compost → use in orchards, mulching and soil amendment (Awasthi, 2020).

Floriculture (Flower crops)

Floriculture is the branch of horticulture concerned with the commercial cultivation, production, management and marketing of flower and ornamental crops including cut flowers, loose flowers, bedding plants, pot plants, fillers, foliage plants and landscaping ornamentals. (ICAR)

➢ **Major waste in floriculture**

- Following the harvest of flowers, the entire plant, along with any damaged or unsold flowers, is considered waste.
- Non-marketable flowers rejected for colour deviation, petal injury, size defects, bent stem, pests, or deformity.
- Petals and flowers removed during extraction of essential oils, pigments, or flower distillates.

However, the remaining flowers can undergo a process of drying and grinding, while cut flowers can be utilized for creating dried flower arrangements, contributing to a burgeoning industry. These dried flowers offer versatile possibilities, as they can be painted, coloured, or dyed. Various floral products, including cards, pictures, wall hangings, arrangements, potpourris and pomanders, can be crafted from these processed flowers. (Shehrawat *et al.*, 2015). After processing like extraction what is left is made into "Press Petal Cakes". Which is used in multiple ways.

❖ **Valorisation Methods:**

Compost / Vermicomposting Production

Process:

Press petal → pH adjustment & shredding → partial drying (reduce moisture 60–70%) → mix with bulking agents (dry leaves/coco peat/cow dung 1:2) →

pre-decomposition 7–10 days → introduce earthworms (*Eisenia fetida*) → vermicompost 30–45 days → sieving → enriched fertilizer (Dayanand Sharma *et al*., 2018)

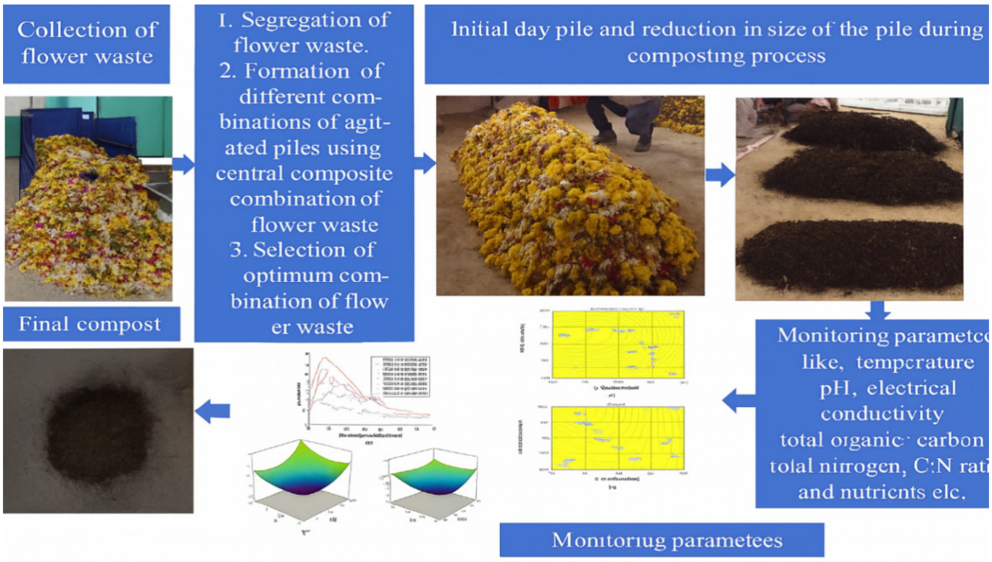

Fig. 3: Process of Compost Preparation.

Activated Carbon / Bio-adsorbent for Water Purification:

The char becomes an attractive by-product, with applications including production of activated carbons (ACs), which is useful as a sorbent for air pollution control as well as for wastewater treatment [3]. ACs are carbons of highly microporous form with both high internal surface area and porosity and commercially the most common adsorbents used for the removal of organic compounds from air and water streams. They also often serve as catalysts and catalyst supports. The market is indeed vast.

Process:

Spent petals/press cake → carbonization (400–500 °C, limited O_2) → chemical activation (H_3PO_4/KOH) → washing → drying → floral activated carbon (Ioannidou *et al*., 2007).

Handmade Paper / Biodegradable Packaging Sheets: (**Sheth *et al*., 2021**)

The paper primarily was made of marigold flowers (*Calendula officinalis*) obtained from a flower market. A variant of the paper also included the use of tuberoses (*Polianthes tuberosa*) along with the marigold flowers. Other materials used were waste corn husks obtained from corn sellers, rice water and peels obtained from potatoes (*Solanum tuberosum*). An important tool for making the paper was the mold and deckle (Muraleedharan & Perumal, 2010; Hasimun *et al*., 2021). Miscellaneous materials, tools and equipment required were newspapers, plastic trays, grinders, ladles and vessels used for boiling.

Process:

Press cake petals → wash → alkali pulping (NaOH 2–4%) → pulp beating → sheet formation → sun-drying → handmade floral paper.

Incense / Dhoop Stick Production:

Dried and decayed flowers are considered waste material and thus, dumped in landfills, various waterbodies, etc. The example is of a country like Srilanka and India, where about 40% of the total production of flowers are unsold and wasted daily.

Flowers like Genda are used to make incense sticks, while roses are converted to rose water. In Lucknow at Kathwara village the Chandrika Devi temple, huge quantity of flowers is offered to the deity every day. The womenfolk use these floral waste to make incense sticks and sell to the small time retailers in the village markets, which becomes a source of income for them (Waghmode *et al*., 2016).

Process:

Spent petals/press cake → Drying → Powdering (petal biomass powder, dhoop agarbatti mix) → Mixing with binder (jigat/gum/charcoal 1:1:0.2) → Extrusion/Rolling → Slow drying → Rose/Mogra/Floral incense sticks → Packaging.

Plantation, Spices, Medicinal & Aromatic crops:

A. Plantation Crops

Perennial, commercially cultivated crops grown on large estates for economic products like fibre, oil, latex, beverages or nuts, usually managed with long-term agricultural practices.

Examples:
Coconut, Arecanut, Oil palm, Rubber, Coffee, Tea, Cocoa, Cashew

B. Spices

Plant-derived aromatic or pungent agricultural commodities used primarily for flavouring, seasoning, colouring, or preserving foods. They originate from specific plant parts such as rhizomes, seeds, bark, fruits, or leaves.

Examples:

Turmeric (rhizome), Ginger (rhizome), Chilli (fruit), Black pepper (berry/fruit), Coriander (seed + leaf), Cumin (seed), Cardamom (seed pod), Cinnamon (bark).

C. Medicinal Plants

Plants that contain bioactive phytochemical compounds used in traditional or modern medicine for disease prevention, treatment, or health enhancement.

Examples:
Ashwagandha, Aloe vera, Senna, Black nightshade, Periwinkle, Neem, Tulsi (holy basil), Kalmegh, Amla.

D. Aromatic Crops

Crops cultivated for extraction of essential oils, fragrance compounds and aromatic metabolites used in perfumery, cosmetics, food additives, pharmaceuticals and natural flavouring industries.

Examples:
Lemongrass, Palmarosa, Vetiver, Mint, Basil, Ajwain, Lavender, Eucalyptus (Srinivasu *et al*., 2023).

Table 1: Major waste of Plantation, spices and medicinal and aromatic crops.

Group	Main crops (examples)	Major wastes
Plantation	Coconut, Arecanut, Oil palm, Rubber, Coffee, Tea, Cocoa	Husks, shells, coir pith, fronds, trunks, pruning wood, coffee pulp/husk, tea waste, processing effluents
Spices	Turmeric, Ginger, Chilli, Pepper, Coriander, Cumin etc.	Cleaning/grading waste, peels, stalks, spent spice residue from oil/oleoresin extraction
Medicinal & aromatic crops	Lemongrass, Mint,Basil, Ajwain, Ashwagandha, etc.	Spent biomass after distillation/extraction, offcuts (stems, leaves, roots), hydrosols, powdering dust

Valorisation Methods:

Plantation Crops

Coir pith composting / co-composting

Coir pith has high lignin and C:N ratio; composting + co-composting (with dung, manure, legume biomass) turns it into a good organic manure and growing medium. Accelerated composting methods can complete decomposition in about 21 days using selective microbial consortia. Co-composting coir pith with other organic wastes improves nutrient content and reduces lignin and C:N. (Bera *et al*., 2025)

Process: (typical TNAU/CPCRI technology):
Coir pith → pre-wetting → C:N adjustment (urea/manure) → fungal inoculation (e.g. *Pleurotus sajor-caju*) → piling & turning (aerobic composting ~30–45 d) → curing & sieving → coir pith compost.

Coir pith vermicomposting:

Refined vermicomposting of coir pith (after fungal pre-composting) significantly reduces toxicity and improves nutrient status. High-value organic fertilizer for PSMA crops; improves soil physical properties and microbial activity (Mani Jayakumar *et al*., 2022).

Process:
Pre-composted coir pith + cattle dung/legume biomass → windrow beds → inoculate earthworms (*Eudrilus eugeniae* etc.) → 45–60 days vermicomposting → harvesting & sieving → vermicompost.

Bio char / Energy:

Shells, husks, fronds, trunks → chipped / dried → briquettes / pellets / boiler fuel, or pyrolysed to biochar for soil application. Coconut shells → carbonization → shell charcoal / activated carbon (used in water and air purification) (Srinivasu *et al*., 2023).

Process:
Dry biomass (shells / pruning wood) → slow pyrolysis (350–550 °C, limited O_2) → quenching & grinding → bio char → soil application/ filter media.

Spices

Main wastes

- After solvent/steam extraction of oils/oleoresins from chilli, cumin, celery, pepper, ginger, turmeric etc., 80–90 % of the original spice remains as spent residue (Sowbhagya, 2019).

Dietary fibre–rich flours & food ingredients

Key example – chilli spent residue (CHSR):

CHSR contains ≈ 44 % total dietary fibre and ≈ 20 % protein, with good mineral and polyphenol content (Sowbhagya, 2019).

Process:
Spent spice residue → drying (tray/ fluidized bed) → grinding → sieving → fibre-rich flour → blending into bakery products, snacks, meat analogues, etc.

Recovery of residual phytochemicals (curcumin, capsaicinoids, piperine)

Residual curcuminoids, capsaicinoids, essential oils etc. can be extracted from spent turmeric, chilli, ginger and pepper using ethanol, acetone, or their mixtures as greener solvents. (Madhusankha, Siow & Thoo, 2023)

Process:

Dried spent residue → solvent extraction (food-grade ethanol/ aqueous ethanol) → filtration → solvent recovery (rotavap / distillation) → concentrated extract → formulation into nutraceuticals, natural colours, and preservatives.

Biopolymer films, coatings and Nano emulsions

Recent work shows spice by-products can be converted into active packaging films, edible coatings and Nano emulsions, using their antioxidants and antimicrobials to extend shelf life (Zhang *et al*., 2025)

Process:
Spent spice extract (polyphenol-rich) → incorporation into biopolymer matrix (starch/gelatin/chitosan) → casting & drying → active film.

Medicinal & Aromatic Plants (MAPs)

Major waste generators

- Steam/ hydro-distillation of lemongrass, mint, basil, eucalyptus, etc. [**distillation spent biomass** (leaves, stems, roots)].
- Extraction industries (ethanol/ supercritical CO_2) → exhausted marc and process water.
- Trimmings, stems and off-grade plant parts from cultivation.

MAP residues have been reviewed as an important biomass under the **circular economy** approach.

Extraction of high-value phytochemicals from MAP waste

Reviews highlight complete recycling of MAP biomass to isolate phenolics, antioxidants, enzymes and essential oils from so-called "waste" streams. (Rohan *et al*., 2025)

Process:
Spent MAP biomass → solvent or supercritical CO_2 extraction → separation/purification → phytochemical concentrates (antioxidants, antimicrobials) → use in pharma, cosmetics, bio-pesticides.

Bio-sorbents and bio-pesticides

MAP wastes (powders, chars) can act as bio-sorbents for removal of dyes and metals from wastewater and as raw material for bio-pesticide formulations due to their bioactive compounds (Yarin *et al*., 2022)

Mushroom cultivation

It is generally treated as part of horticulture, especially under "specialty crops" / protected cultivation and in schemes of the National Horticulture Board (NHB) in India. NHB and other agencies describe mushroom as a *major horticulture product* and provide subsidy for mushroom units under horticulture programmes (Mohit, 2022).

- A recent work "A New Recycling Method through Mushroom Cultivation Using Food Waste" explicitly defines mushroom cultivation using food/agricultural waste as a "recycling method," highlighting both waste management and food production benefits (Barua *et al*., 2024).

✓ **What "waste" is used for cultivation?**

Most cultivated mushrooms are grown on lignocellulose wastes from horticulture and agriculture, for example:

a. **Cereal & pulse residues** – paddy straw, wheat straw, maize stalks, soybean straw, bajra stalk, cotton stalk etc.
b. **Fruit & vegetable processing wastes** – peels and trimmings of carrot, potato, onion, cucumber, etc. and fruit pomace or pulp residues.
c. **Plantation / industrial residues** – sugarcane bagasse, coffee husk, tea waste, sawdust, corn cobs, etc.

These wastes are rich in cellulose, hemicellulose and lignin, which mushrooms (especially *Pleurotus,* *Agaricus, Volvariella*) can break down with their enzymes (Singh *et al.*, 2014).

General process:

1. **Collection & chopping** – Horticultural residues (e.g. paddy straw, vegetable peels) are chopped and cleaned.
2. **Moistening & supplementation** – Moisture adjusted (~60–70%) and sometimes supplemented with bran or gypsum.
3. **Pasteurization/sterilization** – Hot water treatment, steaming, or chemical pasteurization to reduce competing microbes.
4. **Inoculation (spawning)** – Mushroom spawn (mycelium grown on grain) is mixed with this prepared waste substrate.
5. **Incubation** – Mycelium colonizes the waste, converting it into a white fungal biomass.

Fruiting – Under proper temperature, humidity and ventilation, fruit bodies (mushrooms) emerge from the colonized waste "blocks" or bags.

Table 2: Waste type suitable for Mushroo cultivation

Waste type	Why suitable for mushrooms	Reference
Banana leaves	High cellulose, soft fiber, easily colonized by Pleurotus	Kumar *et al.*, 2020
Vegetable waste compost	Nutrient rich, balanced supplements, reduces competing microbes when pasteurized	Shashitha *et al.*, 2016
Corn cobs	Porous structure, good aeration, lignocellulosic	Chang & Miles, 2004
Plantation residues	Low-cost horticultural waste stream, enzyme-digestible by mycelium	Otieno *et al.*, 2022

In this way, horticultural waste becomes the primary raw material for mushroom production instead of being burnt or dumped (Shashitha *et al.*, 2016, Ojwang *et al.*, 2022)

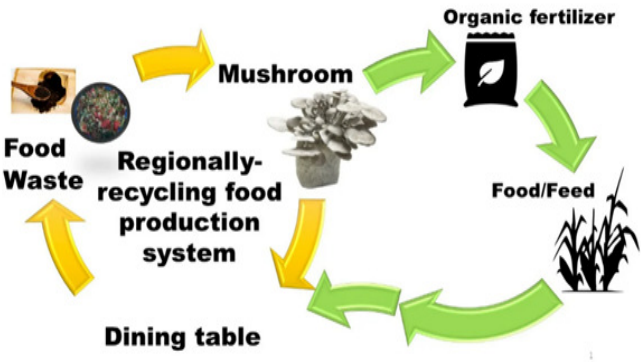

Fig. 4: Mushroom cultivation using horticultural residues (banana leaf, corn cob and vegetable waste blends) (Kumar *et al.*, 2020)

Conclusion

Horticultural value chains produce substantial volumes of organic and lignocellulosic residues arising from cultivation, post-harvest handling, processing and spent substrate streams. Sector-wise waste includes non-marketable produce from fruits and vegetables, floral biomass from trimming and unsold flowers, pruning and stem residues from plantation crops, rhizome and leaf waste from spices, as well as extraction discards from medicinal and aromatic plants. Additionally, mushroom production systems generate high-load residues such as spent mushroom substrate (SMS), casing soil waste and mycelial blocks remaining after harvest. Collectively, these wastes possess high moisture content, elevated biodegradability and unutilized phyto-nutrient fractions, making them environmentally reactive when not stabilized. The magnitude of post-harvest losses is extensively high in perishable commodities, primarily due to sub-optimal storage infrastructure, inadequate pre-cooling, disrupted cold chain logistics, improper maturity indexing, mechanical injuries and uncontrolled physiological processes such as respiration, ethylene biosynthesis, enzymatic browning and transpiration-driven mass loss. Nearly 45% of total horticultural production is reported to become waste across global fresh produce systems owing to these systemic constraints, emphasizing inefficiencies in handling, packaging, storage and processing steps (Gustavsson *et al.*, 2011). The unmanaged decomposition of such biomass under anaerobic conditions in landfills or open dumps accelerates methanogenesis and carbon dioxide emissions, thereby elevating the greenhouse gas (GHG) footprint and contributing to global warming potential. Organic matter-rich horticultural residues also produce acidic leachates and microbial hazards if left untreated, increasing environmental pollution risks (Ioannidou & Zabaniotou, 2007). Plantation residues and wood-based waste components specifically undergo slow biodegradation due to recalcitrant lignin structures, but are efficiently decomposed by white-rot fungi and ligninolytic enzymatic machinery, proving their importance in spent biomass biotransformation (Pointing, 2001). Thus, horti-waste mismanagement results in dual threats: (i) economic value destruction through commodity loss and (ii) increased environmental hazards due to destabilized carbon and emissions, highlighting the need for advanced bioconversion, waste recovery and circular horticultural systems.

✓ **Future scope:**

i. **Mushroom Waste (SMS) Scope**

- Converting **Spent mushroom substrate** into:
  - Nano-cellulose fibres
  - Biodegradable packaging foam
  - Organic fertilizers
  - Bio char for soil carbon improvement

ii. **Lignocellulose waste bioenergy and biopolymer valorisation**

- Improved Pre-treatment & Delignification Technologies.
- Lignin Valorisation — from Waste to Valuable Polymers & Materials
- Nano cellulose & 3D-Manufacturing

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