



International Journal of Smart Agriculture (IJSA)

ISSN: 2995-9829 (ONLINE)

VOLUME 3 ISSUE 1 (2025)



PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

Utilizing Food Waste for Sustainable Packaging: A Biodegradable Approach to Replacing Plastic

Simrah Malik^{1*}

Article Information

Received: September 20, 2024

Accepted: October 22, 2024

Published: February 18, 2025

Keywords

Biodegradable Packaging, Biofilms, Cardboard, Eco-Friendly, Foams, Food Waste, Kraft Paper, Mushroom, Plastic Packaging

ABSTRACT

Plastic is harmful to human health and is not an environmentally friendly product. Over thousands of years, plastic does not degrade or decompose. Food waste has been used for years to replace plastic or plastic derivatives or create eco-friendly biodegradable packaging material. Packaging is vital for product protection and has a high value at all stages. Different materials have been introduced to replace plastic. This article discussed the use of various food waste to replace specific plastic packaging materials. A commonly accepted strategy for building a sustainable society is to use waste biomass such as fiber, cellulose, and starch to substitute petrochemical ingredients in manufacturing plastics. Bioplastics or biodegradable polymers are plastics manufactured from biomass. Mushroom waste has been used to make an alternative to Styrofoam, Mushroom pulp or fiber utilization for the development of Kraft paper packaging has shown to be the best alternative, as it has high mechanical strength, and it is biodegradable, organic, or non-hazardous to humans. Similarly, cucumber peel was used to make biodegradable packaging films that act as an oxygen barrier in the atmosphere. Cucumber peels can be employed as Nano-fillers in bio-composite film, resulting in effective food packaging materials with low ionic conductivity. Sugar cane bagasse is also an excellent alternative to plastic film packaging. Since agricultural wastes may be turned into new value-added commodities, sugarcane bagasse waste could contribute to societal economic success while fostering a green environment. Garlic peels are also being used to create paper packaging. Garlic peel-based biodegradable packs were evaluated and confirmed to be suitable for usage as carry bags or pouches. Foams, Kraft sheets, and Biofilms are used to protect fruits and vegetables, as well as beans, cereal, grains, and other food goods. However, these food waste materials can be used to produce biodegradable packaging material as an alternative to hazardous plastic.

INTRODUCTION

Food and Food Waste

Any material taken to provide nutritional support for an organism is referred to as food. Food is normally made up of carbohydrates, lipids, proteins, vitamins, and minerals and is derived from plants, animals, or fungi (Coultaite, 2023). Food offers nutrients that the body uses to support growth, critical activities, and energy production (Coultaite, 2023). Food or food items refer to any material intended for human, domestic or wild animal consumption, including but not limited to powders, liquids, fruits, vegetables, cereals, minerals, or commercially created foods. A type of food that has been developed and processed to be marketed as a product (Coultaite, 2023).

Food waste or loss can be described as food that is not consumed (Ishangulyev *et al.*, 2019). This can occur at any point within the food supply chain: production, processing, distribution, retail and food service sales, and consumption. The world wastes one-third of the food that is produced. Food waste is all of the food that successfully is completed through the food supply chain to a finished product which is of good quality and fit for consumption but is discarded before it may rot, spoil, or expire (Alexander *et al.*, 2013). According

to FUSIONS, food waste is considered as an edible or inedible part of food that is recovered or disposed of from a particular food supply chain for recovery or disposal, including composted, crops ploughed in or not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill, or discarded to sea (Garcia-Garcia *et al.*, 2015). According to FAO, Food wastage is any food that is lost due to deterioration or waste. As a result, the term “wastage” describes both food loss and waste (Alexander *et al.*, 2013).

Food Waste Production

Food waste in underdeveloped countries is estimated to be worth US\$310 billion (Joardder *et al.*, 2019). This is astounding, given that food waste places severe limits on important production inputs such as energy and money, as well as continued demand for vital infrastructure (Nigam & Sharma, 2017). According to a more recent FAO report (2015), nearly 800 million people around the world do not have enough food to consume, and hunger and malnutrition are the leading causes of death and disease (Aamir *et al.*, 2018).

Waste Management

The term “waste management” refers to all of the

¹ Department of Food Science and Technology, University of Karachi, 74600 Karachi, Pakistan

* Corresponding author's e-mail: simrahmalik786@outlook.com

operations involved in managing waste, from collection to recycling and monitoring (Amasuomo & Baird, 2016). Waste is a term used in waste management to describe undesirable or unusable material that is produced by human activities and can take many forms. Food management is a strategic approach at the different stages of reducing food waste and its related impacts. These include the use of natural resources, production, distribution, use, and finally, with recovery or final disposal decisions (Amasuomo & Baird, 2016). Waste management refers to the systematic collection, transportation, processing, disposal, recycling, and control of different types of waste products. Such an activity helps cut down on a significant portion of money in the economy while protecting the environment (Amasuomo & Baird, 2016).

Food waste compounds can even be utilized to make liquid biofuels such as biodiesel and bioethanol (Kannah *et al.*, 2020; Singh *et al.*, 2022). Peels and pomace can be utilized to develop food-grade packaging, edible coatings, or biodegradable films, and biofuels can be used for cooking, heating, and generating electricity. Furthermore, seeds can be used in essential oil extraction, and food waste can be used to manufacture additives, preservatives, emulsifiers, stabilizers, thickeners, and other products. Pectin powder, for example, is made from apple or orange peel and provides stabilizing, sticking, or thickening properties (Gupta *et al.*, 2024).

Plastic

Plastic is projected to make up about 10% of household garbage, with the majority ending up in landfills (Azmin & Nor, 2020). Plastic has several negative consequences for human health and the environment (Alabi *et al.*, 2019). Plastic debris containing chemicals escapes from landfills due to poor management. Chemicals included in plastic or plastic garbage during transportation influence humans and the environment. Burning plastic garbage raises the risk of heart disease, causes rashes, nausea, and headaches, and harms the nervous system (Azmin & Nor, 2020).

Plastics' Unsustainable Use

Since mass production began in the year 1950, it is estimated that 9,150 million tons of plastics have been produced. Hence, so far, 30 percent is still in use, 9 percent has been recycled, and 60 percent is in landfills or the natural environment (Kim & Ruedy, 2023). The world will, therefore, be producing plastic polymer resins that equal 28,600 million metric tons by 2050, as projected by current trends (Correa-Cano *et al.*, 2023). Recent studies about the plastic packaging industry around the world put productions at 78 million tons annually worth \$260 billion. The figure is projected to reach \$490 billion by 2026. The plastics in packaging are not biodegradable. Additionally, 50 percent of all plastics are made into single-use items, including packaging products. However, global plastic recycling is expanding at a rate of 0.7 percent per year, and the technique is commonly considered to lower lifecycle net CO₂ emissions by up to

27 percent when compared to plastic created from virgin raw material feedstock. Recycling rates differ depending on the type of plastic (Ncube *et al.*, 2021). Polyethylene terephthalate (PET), used in plastic water bottles and various packaging components, is routinely recycled at a 19.5 percent weight recovery rate. Polystyrene and its variations; expanded polystyrene (EPS) and extruded polystyrene (XPS, also known as Styrofoam TM) are the least recyclable plastics, with only 0.9 percent recovery by weight (Kim & Ruedy, 2023).

Replacement of Plastic or Other Packaging Materials

In this new era of technology, food waste has been used or recycled to build biodegradable, ecologically responsible, non-hazardous food-grade packaging materials that will eventually replace plastic (Khan *et al.*, 2024). Food waste comes in various forms, such as Aloe Vera waste; which is used to manufacture biofilms or edible coatings; mushroom waste; which is used to replace polyester, and potato starch; which is used to make plastic films, bags, and coatings. Similarly, other wastes generated during the production, processing, or consumption of food can be used to replace plastic packaging (Kozlowski, 2015). Moreover, the use of biomass materials such as fiber, cellulose, and starch to substitute petrochemical ingredients in the manufacture of plastics is a widely accepted technique for creating a sustainable society. Bioplastics, often known as biodegradable polymers, are plastics manufactured from biomass. Bioplastic production helps the environment by conserving fossil fuels, lowering carbon dioxide emissions, and reducing plastic pollution. The biodegradability of bioplastic has received a lot of attention. Retailers and the food industry are both seeing an increase in packaging demand (Nadeem & Muneer, 2021). It's because traditional plastic not only takes a long time to disintegrate, but it also releases chemicals as it does so. However, because of the expensive cost of production and the low cost of petrochemical-based plastic, bioplastic is often overlooked (Azmin & Nor, 2020).

Food Packaging

Food packaging, like food, helps to keep life going. Every year, roughly 40% of plastic is used for food packaging, which is unfortunate. Packaging is often characterized as a container that stores and protects the product, including qualities like shape, design, and symbols and makes handling and commercialization easier. Given the abundance of consumer goods and the fierce rivalry among them, packaging plays a critical role in influencing customer decision-making. It acts as a "silent salesman," helping to convey product attributes and benefits to customers (Shekhar & Raveendran, 2017). In a survey of people who buy snacks, for example, packaging came in second to flavor in terms of brand preference (Steenis, 2019). According to the study, 86% of respondents would pay a greater price for a nicer container, demonstrating the relevance of packaging in consumer behavior.

Similarly, according to another study by Khan H. *et al.* 2015, highly involved consumers assess messaging content on the box to justify the price charged. This study discovered that packaging has a considerable impact on consumers' willingness to transfer brands, demonstrating the importance of packaging in the context of consumer behavior (Khan *et al.*, 2015).

While there is an increasing understanding of the effect of plastics pollution, and research on biodegradable plastics, current systems themselves are not ideal for general use, due to high costs, poor mechanical properties, and relatively poor barrier properties compared to conventional plastics. Although there is information about biodegradable packaging originating from agricultural waste, the information regarding the commercial potential, mechanical aspects, and usability of such as mushroom pulp, cucumber peel, and sugarcane bagasse for packaging is scarce. This study thereby bridges this research gap by presenting an evaluation of these food waste materials and their suitability as an efficient replacement for conventional plastic packaging; specifically, with regards to mechanical properties, biodegradation, and potential for minimizing the usage of petroleum-based plastics. Therefore, this study aimed to review the use of by products produced from the food processing industries including mushroom pulp, cucumber peels, sugarcane bagasse, and garlic peels as raw materials to provide eco-friendly packaging solutions that will eliminate the usage of plastic packaging. Due to global concerns related to pollution from emerging oil-based plastics and the inconvenience of current practical plastics, the study will limit its choice of non-hazardous, environmentally friendly, and cost-effective packaging material.

LITERATURE REVIEW

Sugarcane

Sugarcane (*Saccharum officinarum* L.) is a major sugar and bioenergy crop around the world. Extreme weather events become more frequent and intense with greenhouse gas emissions and global heat due to climate change. Based on low adaptation capability, increased susceptibility to natural calamities, and poor forecasting systems and mitigation methods, climate change is likely to have huge impacts on sugarcane production in most countries, especially among the poorer nations (Flack-Prain *et al.*, 2021; Zhao & Li, 2015). Increases in the frequency and severity of extreme climate factors brought by climate change may have a negative impact upon sugarcane production levels. The effect of climate change on sugarcane is proportional to its geographical position and adaptive capacity (Zhao & Li, 2015). Most status assessments on the consequences of climate change forecast a decrease in crop productivity. Due to the general vulnerability of crop yields and the expense of enhancing climatic conditions, climate change brings unprecedented difficulties to agriculture. Adaptive action can mitigate the negative consequences of climate change

by changing agricultural activity patterns to capitalize on new possibilities while reducing the costs correlated with negative effects (Zhao & Li, 2015).

Sugarcane Production in Pakistan

Increases in sugarcane area and yield both contributed to growth in cane output, but increasing area was a larger contributor than cane yield, except in Pakistan, where growth in sugarcane farmland and yield were roughly equal. Based on linear regression, hectareage increased by 500, 94, 237, 286, 57, 52, and 61 percent in Brazil, India, China, Thailand, Pakistan, Mexico, and Colombia, respectively, and cane yields expanded by 60, 38, 59, 70, 58, 11, and 24 percent in the last 41 years (1973–2013) (Chohan, 2019). Sugarcane acreage in the United States rose by only 31% over the same time period, while yields remained unchanged or slightly reduced (7.0%) (Zhao & Li, 2015). Bagasse, the fibrous remnant of sugarcane after crushing and extracting its juice, is one of the world's greatest agricultural residues. Sugarcane residue can be used in a variety of ways which includes paper, feed, and other materials (Loh *et al.*, 2013).

Production of Baggase Worldwide

Brazil is the leading producer with around 7,39,300 metric tons per year, followed by India, China, Thailand, Pakistan, Mexico, Colombia, Indonesia, the Philippines, and the United States (Bordonal *et al.*, 2018). This shows that the processing of such a vast number of sugarcane will unintentionally result in a large amount of waste. Because of the size of the sugarcane, the sugarcane bagasse (SCB) is enormous, posing a severe environmental threat if not addressed, necessitating this research (Ajala *et al.*, 2021).

Composition of Baggase

The primary elements of SCB, according to its analysis, include cellulose, hemicellulose, lignin, ash, and wax. SCB's composition makes it an excellent constituent for use as a reinforcing fiber in composite structures (Motaung & Mochane, 2018). To develop novel materials with specific properties and qualities both physical and chemical these, in turn, are sought after for expected results based on pre-determined goals (Loh *et al.*, 2013). SCB is an excellent raw material for composite fabrications due to its chemical composition. Chemical composition and sugar yield of sugar cane bagasse and its fractional components (percent dry matter).

Use of Sugarcane Baggase in Different Goods Manufacturing

Low fabrication costs and excellent quality green end material make SCB wastes the ideal raw material source in the production of new products. It is good due to its availability in large quantities as a by-product resulting from intensive sugar cane cultivation, which ensures stability and consistency in supply (Loh *et al.*, 2013). Complex procedures are simplified by SCB, and costs related to extraction, chemical modifications, and/

or other pre-treatments of SCB in the transformation process to ready-to-use materials may be reduced (Loh *et al.*, 2013).

SCB wastes were used in the following situations:

I. Cellulose, lignin, rind, comrind, and pith provide strength in materials made using various processes.

II. To make a composite, mix it with tapioca starch and glycerol materials;

III. Tableware packaging material made with gelatin, starch, and agar;

IV. SCB ash and sugar cane straw ash can be used to substitute cement in some cases can act as a pozzolanic addition in concrete production brick of ash;

V. To make ceramics, SCB ash is mixed with Arabic gum and water as well as refractory materials; and

VI. To make composite board, sugar cane comrind and its mixture with hardwood are combined with phenol formaldehyde resin and wax (Loh *et al.*, 2013).

Biodegradable Plastic Films by Sugarcane Bagasse and Cocoa Pod Husk

COCOA POD HUSK (CPH) and sugarcane bagasse were used to extract cellulose and fiber, respectively to create biodegradable plastic. A sample of CPH was obtained from a local chocolate factory in Pahang, Malaysia. Sugarcane bagasse, on the other hand, was obtained from a sugarcane juice shop in Kuala Kubu Bharu, Selangor, Malaysia (Azmin & Nor, 2020).

Composition of Films

The addition of cellulose to the fiber in the development of bioplastic enhances the water absorption capabilities and the drying time. Cellulose is a natural polymer that is part of the long-chain, indirect participant in the human food chain cycle. Such a polymer is applied in lots of industries, and veterinary meals and wood and paper belong to them as well as fabrics and clothing, cosmetics, and pharmaceuticals (Azmin & Nor, 2020). Many sectors employ this polymer, including veterinary meals, wood and paper, fabrics and clothing, cosmetics, and pharmaceuticals. Sugarcane bagasse is a widely available waste product that is employed in a variety of applications due to its relatively high cellulose content (Samarasekara *et al.*, 2015). The presence of cellulose in bioplastic helps prevent moisture uptake. Hydrogen bonding within the composite avoids the creation of holes through which water molecules can travel.

Making of Biodegradable Films

The use of CPH in combination with sugarcane bagasse as a bioplastic material is prepared. The best bioplastic film with balanced assessed physicochemical qualities was 75:25 (ratio of cellulose to fiber) bioplastic (different concentrations were taken), as water absorption played a vital part in selecting the appropriate bioplastic for food packaging, according to the findings. It would decrease the possibilities of molds forming on the bioplastic surface and prevent moisture transfer between the food

and the environment. This will enable the bioplastic to remain together with the food for much longer times. Furthermore, hydrophilic characteristic of cellulose-based bioplastic reduced the water vapor barrier that can lead to brittleness and undesirable mechanical properties in the packing material (Azmin & Nor, 2020). Water molecules could not penetrate into the composite, the addition or incorporation of fibers in a small amount in the bioplastic composite reduced vulnerability to water. CPH mixed with sugarcane bagasse waste will help in societal economic development as well as promote an environment, because agricultural wastes may be converted into some value-added products (Azmin & Nor, 2020).

Effectiveness of Biodegradable Films

This biodegradable cellulose and fiber-based product can be used as an environmentally friendly packaging material to help keep the environment clean. They are long-lasting, and adaptable, and can be employed in a wide range of applications (Samarasekara *et al.*, 2015).

Mushroom

Mushroom is known as Fungal Mycelium, Mycelium is a fast-growing vegetative part of a fungus which is a safe, inert, renewable, natural, and green matter. It grows in a mass of branching fibers that link with the media upon which it is developing and may be derived from biological and agricultural wastes (Angelova *et al.*, 2021). The linkages of this mycelium self-assemble at a dramatic pace, producing small miles of white tiny threads that have been used to entomb and digest seed husks into a strong, biodegradable substance. Mycelium materials might become the material of choice for a variety of applications due to the inexpensive raw materials cost and due to the environmental concern of polystyrene disposal (Abhijith *et al.*, 2018).

Edible mushrooms have traditionally been consumed as a valuable source of protein and energy, as well as to promote human overall health. They are considered nutritious foods since they are low in calories and fat while also being high in proteins, minerals, and dietary fiber (Filipa Antunes *et al.*, 2020). Fungi serve critical roles in bio-waste decomposition, nitrogen cycling, plant symbiosis, and disease, making them an essential component of terrestrial ecosystems. They are also utilized as a biological control tool against plant pests and diseases, and they can convert hazardous metals in the context of bioremediation. Fungi develop in habitats with spatiotemporal nutritional and structural variability as nutrient recyclers, biocontrol agents, and bioremediation agents. Simulated habitats such as homogeneous and heterogeneous settings, which include porous media such as dirt, might influence mycelia growth and function (Abhijith *et al.*, 2018).

Food Uses

Polysaccharides from edible mushrooms are excellent

target molecules for future and current pharmacological, nutraceutical, and functional food uses. Their numerous medicinal characteristics have been thoroughly investigated, and it appears that there is a lot of promise for using these biopolymers in food formulation to improve human health (Kumar *et al.*, 2021). To make edible coatings, chitin was extracted from mushroom stipe offcuts and transformed into chitosan. Also used as animal feed, fertilizers, bioremediation and biological treatments, bio based materials, etc. (Antunes *et al.*, 2020).

Other Uses of Mushroom Waste

Mushrooms may be recycled to create manure. It can also be used to manage crop plant diseases, to reclaim abandoned sites, and to make briquettes for use in boilers. In order to provide value-added solutions for by-products produced during mushroom cultivation and processing, various research fields have been developed. Isolated bioactive substances are now used in the manufacturing of nutraceutical and pharmaceutical products. Animal feed, fertilizer, bioremediation, energy production, bio-based products, cosmetics, and cosmeceuticals are among the numerous applications that have been investigated (Antunes *et al.*, 2020; Kumar *et al.*, 2021). A vast number of by-products are produced throughout the mushroom production process, resulting in a high environmental effect and high management expenses for the business. Caps, stipes, mushrooms that do not meet commercial criteria in terms of quality, form, or size, and discarded mushroom substrate are examples of by-products (SMS) (Okuda, 2022). SMS is made up of fungal mycelia, extracellular enzymes released by mushrooms for substance breakdown, and lignocellulosic substrates that have been discarded. These by-products are excellent in nutritional content and can be used in a variety of ways (Antunes *et al.*, 2020).

Mushroom derivatives manufactured from agricultural wastes like as stalks or seed husks with fungal mycelium, which acts as a self-assembling glue, were previously primarily considered as an edible vegetable for culinary garnishes or as a hallucinogenic, but they can now be employed for a more noble purpose (Majib *et al.*, 2023). Fungus is almost universally regarded as a bad thing, however, Mycelium is a natural glue that latches onto everything it comes into contact with, which is typically low-value organic debris such as plant stalks or cotton hulls, to form a dense network of strands (Abhijith *et al.*, 2018).

Mushroom Production

Mushroom production and consumption are expanding year after year, owing to their nutritional benefits as well as their flavor, which is being increasingly appreciated by the global population (Antunes *et al.*, 2020). Global mushroom output is estimated to be around 1.5 million tonnes, with about 90 tonnes of mushrooms sent to Europe each year from Pakistan. Despite the fact that hundreds of mushrooms exist in the wild, only about

25 species are widely consumed as food, and only a few are economically grown. Lentinula is the most common cultivated mushroom genus, accounting for around 22% of global output, while Pleurotus accounts for about 19% of global output. Agaricus and Flammulina account for 15 and 11 percent of the total volume, respectively. Researchers in Europe are exploring for ways to repurpose the large amount of trash generated by mushroom growing. Three times the quantity of waste is produced for every kilogramme of mushrooms collected. This generates more than 3 billion kg of waste per year in the EU (Guo *et al.*, 2022).

Replacement of Polystyrene by Mushroom Waste

Polystyrene is a styrene-derived synthetic aromatic hydrocarbon polymer. Solid and foamed polystyrene both are available. Polystyrene is a brittle, inflexible, and translucent polymer. Expanded polystyrene foam, or EPS, is the material you used to call Styrofoam. It is used in home and appliance insulation, lightweight protective packaging, surfboards, foodservice and food packaging, automotive parts, roadway, and road bank stabilization systems, and other goods all employ foam polystyrene, which can contain up to 95 percent air (Wirth, 1967). Polystyrene PS foam, commonly known as expanded polystyrene, is a high-impact packaging solution used in the packaging industry to protect a wide range of products from harm during transport or storage. Moreover, polystyrene, a translucent plastic extensively used in food packaging and laboratory equipment, is employed in this composition. Styrofoam plastic is made using petrochemicals (Muthukumar *et al.*, 2024). Polystyrene is available in two varieties:

- i) Rigid
- ii) Foam, and is commonly used in food packaging

The rigid design is used to make clear food containers, plates, bowls, beverage cups and lids, cutlery, and straws (Thompson, 2013).

Toxicity or Disadvantage of Polystyrene Usage

Cancer-causing substances in polystyrene foam can leak into the food and beverages it holds, putting customers at risk. Styrene may seep into food or beverages when polystyrene foam containers are heated (Lickly *et al.*, 1995). However, the use of mushroom waste to replace polystyrene foams is a viable option. Mushroom packing keeps waste streams from accumulating in landfills, which is extremely useful to the environment. Instead of taking thousands of years to decay, it can biodegrade organically in a compost or backyard in a matter of weeks. It is used as secondary or tertiary packaging (Pohan *et al.*, 2023).

Sustainable Packaging Applications from Mycelium to Substitute Polystyrene

Since its development in the 1940s, polystyrene foam has faithfully served the world, enabling innumerable breakthroughs by supplying anything from necessary padding for packages to life-saving floating devices.

Expanded polystyrene (EPS) is a flexible synthetic polymer with a strong presence in packaging. They are also non-biodegradable, making them one of the most harmful solid pollutants to the environment (Lim *et al.*, 2021). However, its environmental impact is concerning: the completed substance can take thousands of years if not longer, to biodegrade. The last century's wonder material is structurally sound, but it is filled with defects that influence human well-being (Jose *et al.*, 2021).

With so many things getting delivered and our global rising population, the use of polystyrene packaging is increasing. EPS or Styrofoam is a petroleum-based non-biodegradable foam, considered by the EPA and International Agency for Research on Cancer as a possible human carcinogen. Such materials may pose serious implications for human health, wildlife, and aquatic environments as well as the economy (Krivanek, 2020). This packaging material, which resembles Styrofoam, is created from fungal roots and farm leftovers. The root-like structures that extend out of fungi and beneath the outer layer of the cap are known as mycelium. The product known as mycelium, on the other hand, is a bioengineered form of hyphae generated from agricultural waste with these root-like structures as binding agents. In actuality, mycelium can be used to make a wide range of products, from organic polymers to scaffolding for growing organs, but its most common and practical commercial application is packaging (Krivanek, 2020).

Mycelium foam is similar to polystyrene foam that can be utilized in the same way (Jose *et al.*, 2021). With the advantages of low-cost raw ingredients and a long-term replacement for polystyrene and other dangerous synthetic materials, this mycelia-based polymer is quickly becoming the material of choice (Mojumdar *et al.*, 2021). The use of polypropylene rather than polystyrene has also been recommended because polypropylene is a more recyclable resin-based material. However, when it comes to sustainability and environmental friendliness, the usage of polypropylene is not permitted (Abhijith *et al.*, 2018).

Substitution Method

Microbinding is a method that combines fungi with agricultural waste products such as woodchips, maize stalks, corn husks, hemp, buckwheat, wheat straw, and others. Products high in lignin and carbohydrates can be consumed by fungal mycelium, which generates energy to speed up the development and binding process. When mycelium is combined with a common product, such as wood chips, mycelium can fuse the wood chips, resulting in a strong, durable structure (Krivanek, 2020).

Myco-bond is a heat and fire-resistant, energy-absorbing, biodegradable, and low-energy input discovered by Ecovative, a New York-based start-up. It consumes only an eighth of the energy and emits only a tenth of the carbon dioxide that standard foam packing material consumes. The product is manufactured by joining the

mycelium of mushrooms, which is a mass of a filament like fibre of the fungus that feeds on organic material such as agricultural waste (Vasquez & Vega, 2019). There is a process of growth and breaking down, followed by more growth and solidifying into blocks, resulting in a substance that works similarly to polystyrene, with the exception that it decomposes when exposed to decomposition-friendly atmospheric conditions. The material lasts and serves its purpose as long as it is kept dry; leaving it outside in the air will cause it to decay. The material is easily biodegradable because it is 100% organic (Ho *et al.*, 2018). A mixture of mushroom roots as bonds and agricultural inputs such as maize husks or oat husks are placed in trays of different widths. They are left to rot and fur for at least five days in a dark warehouse, then bonded together to become a biodegradable, fire-resistant, and waterproof packaging material that will turn out to be the best substitute for polystyrene and Styrofoam. Because Mycelium has exceptional biological properties that allow it, within a few days, to produce miles of thread-like roots, the process is transformable; the creature develops extremely quick, almost like solid foam, to fit any form (Abhijith *et al.*, 2018).

The steps are as follows;

01- This material, called mycelium, consists of waste from Agaric and the morphologies of mycelium. Using this process, many different kinds of trash can be used: from hemp to wood chips to psyllium husks. The mixture takes the desired shape within a very short time—mostly within a week. This is the raw material for most mycelium products, commonly called foam.

02- On the technical side, foam is made by combining agricultural wastes with mycelium hyphae, placing the mixture in molds of any size and allowing it to sit there for almost a week in the dark. Fungi feed on agricultural wastes.

03- As it passes through the substrate, it weaves a small network of white threads on the substrate. This gradually occupies available spaces and dries to become mycelium foam. Then, the foam is extracted from the mold, and dried to stop further growth of the mycelium that would produce mushrooms or spores. It can then be used as packing material thereafter.

The best-growing temperatures are between 25 and 30 degrees Celsius. Fungal mycelium thrives in low-light, warm environments with ample aeration (Krivanek, 2020).

Effectiveness of Mushroom-Based Foam

Mushroom-based foam substituting polystyrene could be a breakthrough historical moment, however much of it is anticipated to be noticed. Mycelium is significantly stronger than polystyrene foam or polyurethane materials, regardless of the fact that it may sound otherwise due to its biological nature. It is also hydrophobic and flame-resistant, both of which are advantageous for applications such as packaging (Abhijith *et al.*, 2018).

The Beneficial Effects of the Addition of Pulped *Agaricus Bisporus* Mushroom Body Co-Product to Kraft Pulp Packaging Materials

Kraft Packaging

Kraft paper, or Kraft board, is paper or paperboard, cardboard, usually made from chemical pulp obtained by the Kraft process. Sack Kraft paper (or, in short, sack paper) is a porous Kraft paper with high elasticity and tensile strength that is quite suitable for packing products with the demand of strength and solidity (Kim & Ruedy, 2023). It is durable and long-lasting, making it perfect for heavy-duty applications that require a high level of tear resistance. It is also ideal for stylish and cost-effective packaging and wrapping. Kraft paper is completely biodegradable or compostable (Irimia & Popescu, 2023).

Use in Food Packaging

Flour, sugar, dried fruits, and vegetables are packed using Kraft paper. Recently, Enza Kraft became part of the entire specialty papers range of Charta Global, a US company. It has a gloss on one side and a coarse texture on the other, since it is machine-glazed. According to the experts, Kraft paper is safe when the food is packed. Kraft paper is the food-grade packaging material derived from wood pulp or agro-based resources that have no contamination hazards and hence perfectly safe for food (Deshwal *et al.*, 2019). Because of its clean and crisp appearance, it can also be used as a cost-effective alternative to linen tablecloths and napkins. In packaging operations, the material is used for packing, wrapping individual objects, bundling, and void fill. Kraft paper can also be utilized as load binders between palatalized product layers. Kraft paper exists in a range of colors and textures including natural brown, unbleached, heavy-duty, and bleached white. Natural Kraft paper is considered the most durable among all types of papers, and they are widely used for making bags or wrappings. It is mostly used on flour, sugar, dried fruits, and vegetables packaging (Deshwal *et al.*, 2019).

Substitution Method

Increase the utilization of mushroom production waste by blending macerated mushroom tops and stalks into moulded Kraft pulp packaging material, compare the attributes of this new material with conventional food packaging materials, specifically moulded pulp packaging (MPP) and polypropylene (PP) punnets. Corrugated cardboard fibre (CCF) blended with 30% waste mushroom caps and stalks (MW) with and without the addition of alkyl ketene dimer (AKD) (Boyaci *et al.*, 2022). Most fruits and vegetables are sold in polypropylene punnet (small plastic basket/box). This packaging material is made up of non-renewable, non-degradable material which causes environmental pollution. Both virgin and recycled plastics might pose health problems when used as food containers because of additives, no intentionally added substances (NIAS), degradation products, and contaminants (Boyaci *et al.*, 2022). As a result of the

environmental, waste management, and health challenges associated with plastic consumption, NGOs and governments have developed a slew of programmes and policies. As part of the UK Plastic Pact, the Waste & Resources Action Programme (WRAP) announced a plan in December 2020 that aims to eliminate problem plastics by lowering single-use plastic packaging and enhancing plastic recyclability (Boyaci *et al.*, 2022).

An estimated 8 million metric tons of macro plastics and 1.5 million metric tons of micro plastics enter the ocean each year. Micro plastics (smaller than 5 mm) have been found in the digestive tracts of marine animals. For over a century, moulded pulp packaging (MPP) has been widely used in the food packaging sector as a recyclable and biodegradable alternative (Singh *et al.*, 2023). Wood fiber, Non-wood fibers, and recycled paper waste fibers are among the raw materials used in MPP. Non-wood fiber co-products such as bagasse, bamboo, stalks, straws, and leaf fibers with high cellulose content and good fiber properties have also been recommended as alternative non-wood fiber sources due to the high environmental impact and shortage of virgin wood fiber. MPP was created by combining macerated waste mushroom caps and stalks (MW) with corrugated cardboard fiber (CCF) (Boyaci *et al.*, 2022).

The steps of production are as follows;

01- Mushroom pulp was obtained by juicing fresh mushrooms at the lowest speed with a household juicer. The mushroom pulp was immediately combined with an equal volume of citric acid solution (1 percent w/v) to prevent enzymatic browning. After drying in a vacuum oven at 80°C for 18 2 hours, the dry material content of mushroom pulp was assessed. CCF was mixed in at a 30:70 MW to CCF ratio based on the dry weight of the mushroom pulp, and the combination was diluted to a 4 percent slurry concentration by adding deionized water. A commercial mixer was used to blend the MW/CCF slurry for 3 minutes.

02- The blended slurry was transferred to a glass beaker and placed in an 85 °C water bath, stirring occasionally, for 15 minutes after the central temperature reached 85 °C. Following the heating, the slurry was blended for another 30 seconds, and 300 g of parts were placed onto a rectangular deckle (16 x 21.5 cm) and pressed for 10 minutes with 0.86 kg weights (28.3 cm² area each).

03- The wet sheets were placed onto rectangular plastic containers and dried at 50 °C for 18 2 hours while the edges of the wet sheets were bent downwards to give the materials a punnet form. Prior to examination, the dried punnet-shaped materials were conditioned at 25 °C for 48 hours (Boyaci *et al.*, 2022).

Physical or mechanical properties of the packaging material were rated as ± 9 . Packaging material has high strength, appropriate thickness, good quality, or it is considered as a best alternative to polypropylene packaging. Fresh mushroom (*A. bisporus*) stored at 4 °C for 7 days in MW/CCF, MW/CCF + AKD, MPP and PP punnets.

Effectiveness of Mushroom Pulp in Kraft Paper Production

Mushroom pulp or fiber utilization for development of kraft paper packaging has shown to be best alternative, as it has high mechanical strength, & it is biodegradable, organic, or non-hazardous to humans (Boyaci *et al.*, 2022).

MATERIALS AND METHODS

Selection Criteria

For the completion of this review, recent research and review articles/publications related to waste management and packaging materials were taken into consideration. The aim of the research was centered around the efficiency of packaging material that is produced from waste of food products and its effect on shelf life. Data has been taken from electronic databases: Google Scholar, Web of Science, NCBI, Hindawi, ResearchGate, Science Direct, Scopus, PubMed, and AGRICOLA.

For this study, we searched the literature for articles addressing the production of waste and its utilization in food packaging. Studies were selected from different years ranging between 2013 to 2024 using keywords 'packaging,' 'packaging material,' 'mushroom,' 'kraft packaging,' 'biodegradable packaging,' 'ecofriendly packaging material,' 'cucumber peels,' 'sugarcane baggase,' 'ginger peels,' 'paper board,' and 'food wrapping films.' Search keywords were combined using proximity operators (NEAR, NEXT, WITHIN) and Boolean (AND, OR) operators.

RESULTS AND DISCUSSION

Cucumber

Cucumber (*Cucumis sativus*) is a member of the Cucurbitaceae family, one of the well-known creeping vine plants whose cylindrical fruits are consumed as vegetables (Mallick, 2022). Pakistan is the world's 50th largest cucumber producer, farming the crop on 4.6 million hectares and producing 61 thousand tons of cucumber with an average yield of 13.2 tons per hectare. Cucumber is grown on 2.27 million hectares worldwide, yielding roughly 83.7 million tons with an average yield of 37 tons per hectare (Qamar *et al.*, 2017). Cucumber peels are being used as a packaging alternative, celluloses, hemicellulose, and pectin were isolated from this processed material and used to create new bio-materials that can be used as Nano-fillers in bio-composites (Prasanna & Mitra, 2020). Cucumber peels have a higher cellulose content than other peel wastes, which can be used to make food packaging materials, according to researchers at the Indian Institute of Technology (IIT) Kharagpur (Prasanna & Mitra, 2020).

Despite the fact that customers are intentionally avoiding single-use plastic, it is still widely used in food packaging. Natural biopolymers cannot compete in this market because they lack strength, elongation, barrier properties, optical properties, and, in some situations, biological safety. Because of the abundance of hydroxyl groups, cellulose nanocrystals generated from cucumber peels

have changeable characteristics, resulting in improved biodegradability and biocompatibility (Trache *et al.*, 2017). Due to unique qualities such as a high surface area to volume ratio, lightweight, and outstanding mechanical properties, these Nano-cellulose materials have emerged as robust, renewable, and cost-effective materials for the near future. As a result, when used as Nano-fillers in bio-composites films, such nanocrystals can provide effective food packaging materials with low oxygen permeability (Trache *et al.*, 2017). Cucumber peels had a higher cellulose content (18.22%) than other peel waste, according to the research. It also revealed more about cucumber cellulose's crystalline, thermal, and colloidal properties, as well as a 65.55 percent acid hydrolysis yield, making the material a powerful Nano-filler reinforcement as a Bio-Nano composite. This provides the mechanical, barrier, optical, rheological, and nontoxic qualities that are necessary for food packaging materials with a high market potential to replace plastic (Prasanna & Mitra, 2020).

Effectiveness

This nontoxic, biodegradable, and biocompatible product has no negative health or environmental impacts, which therefore makes it have a great market potential by making the treatment of organic waste that contains high cellulose content viable (Prasanna & Mitra, 2020). The gradual adoption of petroleum-based plastics in food packaging over several decades has posed numerous issues, as these polymers are indestructible sources of pollution, with approximately 60% of them going to waste and the remainder being recycled only once. More research and product development focusing on diverse biopolymers derived from macromolecules or microbial polymers could make the sector more appealing to packing material makers by raising awareness and providing alternative products at reasonable pricing (Prasanna & Mitra, 2020).

Food-Wrapping Films Made from Waste Cucumber Peels

Nano fillers could be made with cellulose Nano crystals derived from discarded cucumber peels. These Nano fillers could be used to make bio composite film for food wrapping that is both biodegradable and biocompatible. Hydrogels, paper, coating additives, and optically clear films could all benefit from the Nano crystals. Fruit peels are high in cellulose, which has potential usage in food packaging materials, according to earlier studies. Cucumber peels, which are equally high in cellulose, were not investigated in any of the research (Prasanna). Cucumber peels were dried and pulverised to remove cellulose. Using particular chemicals, the cellulose was subsequently transformed to cellulose nanocrystals. This packaging material is not only being used in food packaging but also being used for pharmaceuticals, sents, etc. (Prasanna & Mitra, 2020).

Garlic

Fresh garlic, *Allium sativum* L., is an agricultural plant

belonging to the family Liliaceae. Black garlic, or BG, is colloquially known as high-temperature and high-humidity fermentation for a long time. The process of this fermentation turns the colour of garlic cloves dark, and their taste becomes sweet while it changes the texture of garlic cloves to be chewy and jelly-like. Fermentation time varies from culture to producers and their purposes (Kimura *et al.*, 2017). Garlic's long history of use in food, as well as acute, chronic, and inhalation investigations, show no credible adverse biological effects, despite their limitations. BG's exact roots are uncertain and debatable. However, BG has been consumed for millennia in South Korea, Japan, and Thailand, and was just recently brought to Taiwan and other nations. High-end chefs have gotten a lot of attention in the last several years (Melguizo-Rodríguez *et al.*, 2022).

Garlic Production

Garlic production in 2017 totaled 28.2 million tons, grown on 1.58 million hectares with an annualized rate of 17.8 tons per hectare. With 22.2 million tons of garlic produced, China is the world's leading producer. China is also the world's largest exporter, trailed by Spain. Indonesia is the largest importer of fresh garlic, followed by Brazil and Malaysia (Srivastava *et al.*, 2012). Garlic is grown on 8.1 thousand hectares in Pakistan, yielding 70.9 thousand tons with an average yield of 8.8 tons per hectare. The country's production is growing at 0.74 percent per year, far slower than the country's population growth rate of 2.1 percent and the global rate of 5.8 percent. This means that until the country's domestic production rate improves, it will be forced to export. Imports, which are already growing at an alarming rate of 14% per year, are becoming increasingly important. In 2017, it had risen to US\$68 million (Saif *et al.*, 2020).

Pakistan's per hectare garlic production is less than half of the global average, and it is improving at only 0.60 percent per year, compared to a global average of 3.6 percent per year, meaning that Pakistan is losing its competitive edge both domestically and internationally. Pakistan's competitive advantage has also eroded. Because it has a slower pace of production growth than the rest of the world Pakistan was invaded by the US in 2001. Furthermore, Pakistan has not benefited from the fast-growing global garlic industry (Hussain *et al.*, 2014).

Anticipated Investment in Production of Garlic

The government will commence these interventions, which will be carried out in conjunction with the private sector, including farmers, processors, traders, and their groups and associations. The overall anticipated investment in this cluster development/upgradation plan for all clusters is around US\$5.84 million. The public sector will bear about 82 percent of the total investment in the form of strengthening the garlic research and extension system, capacity building of stakeholders along the value chain, and incentives to encourage farm mechanization and the construction of village cold

storages, while the private sector will bear the remaining 18 percent. Approximately 62% of the investment will be required at the manufacturing level, with the remaining 38% at the value chain level (Nurmalina & Agustian, 2023).

Although Punjab province contributes a significant portion of the total garlic acreage in the country (38 percent), its share of output is very modest (34 percent). Because it has the largest output in the country, Khyber Pakhtunkhwa (KP) has a bigger share of garlic production than it does in the area. As a result, KP is the country's leading garlic producer. Punjab and KP account for the lion's share of overall garlic production (nearly 79%). Sindh's garlic production share is significantly lower than its area shares due to the lowest per-hectare yield in the country (Hussain *et al.*, 2014).

Garlic Peel Waste Management

1) Garlic peel pulp preparation- Garlic peels are gathered as waste from a variety of food processing enterprises. The stems and cloves are removed. The peels were washed before being boiled with soda ash and mixed to make pulp.

2) Head pulp preparation after collecting and sorting the paper and paperboards, they are pulped.

3) Biodegradable packaging material development. This garlic purée is combined with the pulp from the head of cardboard cartons containing the necessary amount of starch solution. The pulp is crushed, dried, and shaped into papers that can be formed into packages or bags depending on the demands of the consumer.

The biodegradable packs manufactured from garlic peels were tested and found to be suitable for use as carry bags or pouches. It can be utilized as an environmentally beneficial alternative to lessen the existing impact of plastics and other harmful materials. In the packaging industry, there is an excessive use of paper. These packets can be made available in a variety of sizes. This packaging can be recycled and repurposed. This will be a novel approach to the problem to foster a greener environment in the packaging field (Chaudhary *et al.*, 2021).

There is a need for further studies on the use of various types of food waste materials for biodegradable packaging materials, on the enhancement of the mechanical properties of these packaging materials as well as on the uplifting of the pilot-scale packaging materials for commercial purposes. Research should be carried out on how to incorporate food waste into natural polymers/nanomaterials in a way that increases its strength and barrier properties to match that of plastics. Furthermore, biodegradable materials should also be applied to fields different from the food packaging industry, like pharmaceutical, cosmetic and consumer goods industry. Therefore, only at the end of each of these stages, it is possible to focus on economic assessment, such as cost-benefit analysis and evaluation of potential market demand for sustainable packaging.

CONCLUSION

This review article describes the various biodegradable packaging available from materials that are biodegradable by microbes such as bacteria, fungi, or algae. Two of the most common types of biodegradable packaging are cardboard or paper, and bio-based plastics. Bioplastics can be made from corn starch, mushrooms, seaweed, and sugarcane, among other plant-based resources. Bio-based plastics are currently being used as alternatives to petroleum-based plastics. According to the book *Introduction to Bioplastics Engineering*, plastic will be reduced by 15–20 percent by 2025.

REFERENCES

- Aamir, M., Ahmad, H., Javaid, Q., & Hasan, S. M. (2018). Waste not, want not: a case study on food waste in restaurants of Lahore, Pakistan. *Journal of Food Products Marketing*, 24(5), 591-610.
- Abhijith, R., Ashok, A., & Rejeesh, C. (2018). Sustainable packaging applications from mycelium to substitute polystyrene: a review. *Materials today: proceedings*, 5(1), 2139-2145.
- Ajala, E., Ighalo, J., Ajala, M., Adeniyi, A., & Ayanshola, A. (2021). Sugarcane bagasse: a biomass sufficiently applied for improving global energy, environment and economic sustainability. *Bioresources and Bioprocessing*, 8, 1-25.
- Alabi, O. A., Ologbonjaye, K. I., Awosolu, O., & Alalade, O. E. (2019). Public and environmental health effects of plastic waste disposal: A review. *Journal of Toxicology and Risk Assessment*, 5(021), 1-13.
- Alexander, C., Gregson, N., & Gille, Z. (2013). Food waste. In *The handbook of food research* (Vol. 1, pp. 471-483). Routledge.
- Amasuomo, E., & Baird, J. (2016). The concept of waste and waste management. *Journal of Management & Sustainability*, 6(2), 88.
- Angelova, G. V., Brazkova, M. S., & Krastanov, A. I. (2021). Renewable mycelium-based composite: A sustainable approach for lignocellulose waste recovery and an alternative to synthetic materials—A review. *Zeitschrift für Naturforschung C*, 76(11-12), 431-442.
- Antunes, F., Marçal, S., Taofiq, O., Morais, A. M. M. B., Freitas, A. C., Ferreira, I. C. F. R., & Pintado, M. (2020). Valorization of mushroom by-products as a source of value-added compounds and potential applications. *Molecules*, 25(11), 2672.
- Azmin, S. N. H. M., & Nor, M. S. M. (2020). Development and characterization of food packaging bioplastic film from cocoa pod husk cellulose incorporated with sugarcane bagasse fiber. *Journal of Bioresources and Bioproducts*, 5(4), 248-255.
- Bordonal, R. d. O., Carvalho, J. L. N., Lal, R., De Figueiredo, E. B., De Oliveira, B. G., & La Scala, N. (2018). Sustainability of sugarcane production in Brazil. A review. *Agronomy for Sustainable Development*, 38, 1-23.
- Boyaci, D., Onarinde, B., Aiyedun, S., Waldron, K. W., May, D., & Tucker, N. (2022). The beneficial effects of the addition of pulped *Agaricus bisporus* mushroom body co-product to Kraft pulp packaging materials. *Cleaner Materials*, 3, 100049.
- Chaudhary, B. U., Lingayat, S., Banerjee, A. N., & Kale, R. D. (2021). Development of multifunctional food packaging films based on waste Garlic peel extract and Chitosan. *International Journal of Biological Macromolecules*, 192, 479-490.
- Chohan, M. (2019). Impact of climate change on sugarcane crop and remedial measures-a review. *Pakistan Sugar Journal*, 34(1), 15-22.
- Correa-Cano, M. E., Burton, K., Mueller, M., Kouloumpis, V., & Yan, X. (2023). Quantification of Plastics in Agriculture and Fisheries at a Regional Scale: A Case Study of South West England. *Recycling*, 8(6), 99.
- Coulter, T. (2023). *Food: The chemistry of its components*. Royal Society of Chemistry.
- Deshwal, G. K., Panjagari, N. R., & Alam, T. (2019). An overview of paper and paper-based food packaging materials: Health safety and environmental concerns. *Journal of Food Science and Technology*, 56, 4391-4403.
- Flack-Prain, S., Shi, L., Zhu, P., da Rocha, H. R., Cabral, O., Hu, S., & Williams, M. (2021). The impact of climate change and climate extremes on sugarcane production. *GCB Bioenergy*, 13(3), 408-424.
- Garcia-Garcia, G., Woolley, E., & Rahimifard, S. (2015). A framework for a more efficient approach to food waste management. *International Journal of Food Engineering*, 1(1), 65-72.
- Guo, J., Zhang, M., & Fang, Z. (2022). Valorization of mushroom by-products: a review. *Journal of the Science of Food and Agriculture*, 102(13), 5593-5605.
- Gupta, R. K., Ali, E. A., Abd El Gawad, F., Daood, V. M., Sabry, H., Karunanithi, S., & Srivastav, P. P. (2024). Valorization of fruits and vegetable waste byproducts for the development of sustainable food packaging applications. *Waste Management Bulletin*.
- Ho, B. T., Roberts, T. K., & Lucas, S. (2018). An overview on biodegradation of polystyrene and modified polystyrene: The microbial approach. *Critical Reviews in Biotechnology*, 38(2), 308-320.
- Hussain, N., Ali, S., Miraj, N., & Sajjad, M. (2014). An estimation of technical efficiency of garlic production in Khyber Pakhtunkhwa Pakistan. *International Journal of Food and Agricultural Economics (IJFAEC)*, 2(2), 169-178.
- Irimia, A., & Popescu, C.-M. (2023). Bioactive paper packaging for extended food shelf life. *Coatings*, 13(9), 1658.
- Ishangulyyev, R., Kim, S., & Lee, S. H. (2019). Understanding food loss and waste—Why are we losing and wasting food? *Foods*, 8(8), 297.
- Joardder, M. U., Masud, M. H., Joardder, M. U., & Masud, M. H. (2019). Causes of food waste. In *Food preservation in developing countries: Challenges and solutions* (pp. 27-55). Springer.
- Jose, J., Uvais, K., Sreenadh, T., Deepak, A. V., & Rejeesh,

- C. (2021). Investigations into the development of a mycelium biocomposite to substitute polystyrene in packaging applications. *Arabian Journal for Science and Engineering*, 46, 2975-2984.
- Kannah, R. Y., Merrylin, J., Devi, T. P., Kavitha, S., Sivashanmugam, P., Kumar, G., & Banu, J. R. (2020). Food waste valorization: Biofuels and value added product recovery. *Bioresource Technology Reports*, 11, 100524.
- Khan, H., Lee, R., & Lockshin, L. (2015). Localising the packaging of foreign food brands: a case of Muslim consumers in Pakistan. *Journal of Product & Brand Management*, 24(4), 386-398.
- Khan, M. R., Sadiq, M. B., Vápenka, L., Volpe, S., Rajchl, A., & Torrieri, E. (2024). Role of quality assessment of the recycled packaging material in determining its safety profile as food contact material. *Waste Management*, 188, 72-85.
- Kim, Y., & Ruedy, D. R. (2023). Mushroom packages: an ecovative approach in packaging industry. In *Sustainable Development and Environmental Stewardship: Global Initiatives Towards Engaged Sustainability* (pp. 199-223). Springer.
- Kimura, S., Tung, Y. C., Pan, M. H., Su, N. W., Lai, Y. J., & Cheng, K. C. (2017). Black garlic: A critical review of its production, bioactivity, and application. *Journal of Food and Drug Analysis*, 25(1), 62-70.
- Kozłowski, M. (2015). Recycling of Food Packaging Materials. *Functional Polymers in Food Science: From Technology to Biology*, 1, 355-399.
- Krivanek, S. (2020). *Fungal mycelium: The key to a sustainable future*.
- Kumar, H., Bhardwaj, K., Sharma, R., Nepovimova, E., Cruz-Martins, N., Dhanjal, D. S., Singh, R., Chopra, C., Verma, R., & Abd-Elsalam, K. A. (2021). Potential usage of edible mushrooms and their residues to retrieve valuable supplies for industrial applications. *Journal of Fungi*, 7(6), 427.
- Kumar, K., Mehra, R., Guiné, R. P., Lima, M. J., Kumar, N., Kaushik, R., Ahmed, N., Yadav, A. N., & Kumar, H. (2021). Edible mushrooms: A comprehensive review on bioactive compounds with health benefits and processing aspects. *Foods*, 10(12), 2996.
- Lickly, T., Lehr, K., & Welsh, G. (1995). Migration of styrene from polystyrene foam food-contact articles. *Food and Chemical Toxicology*, 33(6), 475-481.
- Lim, Y., Izhar, T., Zakarya, I., Yusuf, S., Zaaba, S., & Mohamad, M. (2021). Life cycle assessment of expanded polystyrene. *IOP Conference Series: Earth and Environmental Science*, 763, 012080.
- Loh, Y., Sujun, D., Rahman, M. E., & Das, C. A. (2013). Sugarcane bagasse—The future composite material: A literature review. *Resources, Conservation and Recycling*, 75, 14-22.
- Majib, N. M., Sam, S. T., Yaacob, N. D., Rohaizad, N. M., & Tan, W. K. (2023). Characterization of fungal foams from edible mushrooms using different agricultural wastes as substrates for packaging material. *Polymers*, 15(4), 873.
- Mallick, P. K. (2022). *Evaluating potential importance of cucumber (Cucumis sativus L.-Cucurbitaceae): A brief review*.
- Melguizo-Rodríguez, L., García-Recio, E., Ruiz, C., De Luna-Bertos, E., Illescas-Montes, R., & Costela-Ruiz, V. J. (2022). Biological properties and therapeutic applications of garlic and its components. *Food & Function*, 13(5), 2415-2426.
- Mojumdar, A., Behera, H. T., & Ray, L. (2021). Mushroom mycelia-based material: An environmentally friendly alternative to synthetic packaging. In *Microbial polymers: Applications and ecological perspectives* (pp. 131-141). Springer.
- Motaung, T. E., & Mochane, M. J. (2018). Systematic review on recent studies on sugar cane bagasse and bagasse cellulose polymer composites. *Journal of Thermoplastic Composite Materials*, 31(10), 1416-1432.
- Muthukumar, J., Kandukuri, V. A., & Chidambaram, R. (2024). A critical review on various treatment, conversion, and disposal approaches of commonly used polystyrene. *Polymer Bulletin*, 81(4), 2819-2845.
- Nadeem, H., & Muneer, F. (2021). Plastics Versus Bioplastics. *Materials Research Foundations*, 99.
- Ncube, L. K., Ude, A. U., Ogunmuyiwa, E. N., Zulkifli, R., & Beas, I. N. (2021). An overview of plastic waste generation and management in food packaging industries. *Recycling*, 6(1), 12.
- Nigam, R., & Sharma, S. (2017). Food waste management. *Amity Journal of Energy & Environment Studies*, 3, 1-8.
- Nurmalina, R., & Agustian, A. (2023). Assessing the sustainability of garlic production for determining strategies in the Garlic Sustainable Development Program. *IOP Conference Series: Earth and Environmental Science*, 1082, 012032.
- Okuda, Y. (2022). Sustainability perspectives for future continuity of mushroom production: The bright and dark sides. *Frontiers in Sustainable Food Systems*, 6, 1026508.
- Pohan, J. N., Kusumawati, Y. A., & Radhitanti, A. (2023). Mushroom mycelium-based biodegradable packaging material: A promising sustainable solution for the food industry. *E3S Web of Conferences*, 385, 01005.
- Prasanna, N. S. (n.d.). Scope of cellulose nanotechnology in biodegradable food packaging. In I. D. Healey (Ed.), *Cellulose nanotechnology* (p. 30). Springer.
- Prasanna, N. S., & Mitra, J. (2020). Isolation and characterization of cellulose nanocrystals from Cucumis sativus peels. *Carbohydrate Polymers*, 247, 116706.
- Qamar, A., Ashfaq, M., & Khan, M. (2017). Resource use efficiency and return to scale analysis in off-season cucumber production in Punjab, Pakistan. *Sarhad Journal of Agriculture*, 33(1), 47-52.
- Saif, S., Hanif, M. A., Rehman, R., & Riaz, M. (2020). Garlic. In *Medicinal plants of South Asia* (pp. 301-315). Elsevier.
- Samarasekara, A., Somasuntharam, P., & Umadaran, S. (2015). Development of environmentally friendly cellulose-containing packaging products from waste

- materials.
- Shekhar, S. K., & Raveendran, P. (2017). Perceptions and attitudes towards the silent salesman. *International Journal of Business Innovation and Research*, 14(1), 104-121.
- Singh, A., Singhanian, R. R., Soam, S., Chen, C. W., Haldar, D., Varjani, S., Chang, J. S., Dong, C. D., & Patel, A. K. (2022). Production of bioethanol from food waste: Status and perspectives. *Bioresource Technology*, 360, 127651.
- Singh, A. K., Itkor, P., Lee, M., Shin, J., & Lee, Y. S. (2023). Promoting sustainable packaging applications in the circular economy by exploring and advancing molded pulp materials for food products: A review. *Critical Reviews in Food Science and Nutrition*, 63(32), 11010-11025.
- Srivastava, S., Sharma, U., Singh, B., & Yadava, H. (2012). A profile of garlic production in India: facts, trends and opportunities. *International Journal of Agriculture, Environment and Biotechnology*, 5(4), 477-482.
- Steenis, N. D. (2019). *Consumer response to sustainable packaging design* [Doctoral dissertation, Wageningen University and Research]. Wageningen University & Research Repository.
- Thompsett, D. (2013). Polystyrene. In *Construction materials reference book* (pp. 249-267). Elsevier.
- Trache, D., Hussin, M. H., Haafiz, M. M., & Thakur, V. K. (2017). Recent progress in cellulose nanocrystals: sources and production. *Nanoscale*, 9(5), 1763-1786.
- Vasquez, E. S. L., & Vega, K. (2019). Myco-accessories: Sustainable wearables with biodegradable materials. In *Proceedings of the 2019 ACM International Symposium on Wearable Computers* (pp. 135-142).
- Wirth, H. (1967). New applications for polystyrene foam. *Journal of Cellular Plastics*, 3(10), 463-467.
- Zhao, D., & Li, Y. R. (2015). Climate change and sugarcane production: potential impact and mitigation strategies. *International Journal of Agronomy*, 2015(1), 547386.