Nutrient-Rich Vegetable Wastes as Substrates for Fungal Propagation: A Dual-Phase Growth Assessment

M. Ann Angel*and R. Nirmala

Department of Botany, Faculty of Science, University of Jaffna, Sri Lanka.

*Corresponding author: angelann120@gmail.com

ORCID ID: https://orcid.org/0009-0004-9391-2822

Received: 26.06.2025 Revised: 06.11.2025 Accepted: 20.11.2025 Online: 15.12.2025

Abstract Fungal cultivation is traditionally based on commercially available standard media such as Potato Dextrose Agar (PDA). However, the growing demand for economic, sustainable and environmentally friendly practices has led to increased interest in the use of alternative media. Using organic waste, especially vegetable and fruit waste, as culture media not only reduces the laboratory costs but also promotes the recycling of biomass. In addition, they can improve the growth characteristics of specific fungi depending on the nutritional profile of the residues used. This study aimed to evaluate the potential of vegetable waste, including cabbage, onion, carrot, beans, beetroot and drumstick as an alternative nutrient source for fungal cultivation. Six different fungal genera were selected for the investigation: *Aspergillus* sp., *Fusarium* sp., *Mucor* sp., *Penicillium* sp., *Rhizopus* sp. and *Trichoderma* sp. Quantitative analysis of fungal growth was conducted using spore counts obtained with a haemocytometer on the 3rd, 4th and 5th day from the day of inoculation, along with measurement of mycelial dry weight after five days from the day of inoculation. All the experiments were carried out using liquid media with Potato Dextrose Broth (PDB) serving as the control. Where Onion supported the higher spore and mycelial biomass production of *Mucor* sp. and *Rhizopus* sp. Higher spore production of *Aspergillus* sp. and *Penicillium* sp. was observed in carrot waste media. Furthermore, drumstick and cabbage highly induced the spore production of *Fusarium* sp. and *Trichoderma* sp., respectively. Moreover, *Aspergillus* sp. and *Fusarium* sp. showed higher mycelial biomass growth on cabbage waste media. Notably, several vegetables waste-based media exhibited superior performance compared to PDB, demonstrating their potential as cost-effective and sustainable alternatives for fungal cultivation.

Keywords*:* Alternative media, Cost-effective, Mycelial biomass, Potato Dextrose Broth, spore count and Vegetable waste

Introduction

Microbes are microscopic organisms found in nearly every environment on Earth, including air, water, soil, and even within living organisms. Due to their minute size, they cannot be seen with naked eye and require a microscope for observation. They play vital roles in numerous ecological and biological processes. However, researchers often describe microorganisms as a "double-edged sword" because of their double nature: Although many microbes are important for nutrient cycling. Fermentation and drug production, are beneficial, while others cause disease, food spoilage, and environmental pollution. Both types emphasize the importance of understanding and managing microbial activity for useful purposes and reducing their negative effects (Saranraj et al., 2018). They are cultivated under controlled laboratory conditions for various scientific and industrial purposes. Culture medium is used to facilitate its growth, which provides an environment enriched with essential nutrients, chemical compounds and growth factors necessary for microbial growth. If there is only a single microbial species in a culture, it is called a pure culture, but if there is more than one microbial species, it is termed a mixed culture. Before inoculation, culture medium must be sterilized to ensure that no pre-existing life forms are present, thereby preventing contamination. Culture media can be prepared in either liquid form (broth) or solidified using agents such as agar to form gels, depending on the experimental requirements. A wide variety of commercially available media are designed to meet the specific nutritional and physiological needs of different microorganisms.

Nutrient Agar (NA) is generally used for bacterial culture and Potato Dextrose Agar (PDA) is generally used for fungal culture. However, both media are expensive, which poses significant challenges- especially in education and research fields where large media are required for routine testing. High costs often limit the scope and frequency of laboratory-based microbial studies, especially in resource-limited or developing countries. Therefore, there is a growing need to develop cheaper and easily accessible alternatives to traditional culture media like PDA. These alternative media are designed to maintain or improve microbial growth performance while significantly reducing costs. Recent research is increasingly exploring the use of agricultural and urban waste as a nutritious growing medium. Specifically, researchers are focused on finding cheaper ingredients for gelling agents- specifically agar, one of the most expensive components in making solid media (Chanda et al., 2015). New methods for recycling food waste are continually being developed, especially in response to increasing global concerns about food waste generation (Ramírez et al., 2021).

Agro-industrial waste containing various components has great potential to be utilized in various regions. It serves as a valuable source of dietary fiber, polyphenols and other bioactive compounds, making it a promising source for sustainable product development (Costa et al., 2020). Vegetable and fruit by-products like stems and peels are often thrown away or used for composting. However, these parts have significant nutritional value, as they are rich in starch and protein, so it is good for the regeneration and economic production of the culture media (Jadhav et al., 2018). Research has indicated that formulations based on vegetable waste may serve as effective alternatives to conventional media, due to their high protein content and nutritional potential (Ravimannan and Pathmanathan. 2016). In recent years, such approaches have gained attention for promoting sustainability through the utilization of underused plant components—particularly those not typically consumed by humans, like vegetable skins and stems (Santos et al., 2021). Common household food waste, such as pomace, peels, husks and pods, is rich in bioactive compounds such as carotenoids, enzymes, polyphenols, essential oils, vitamins and many other phytochemicals. These biological products have shown many different applications in different fields- for example, in the production of edible films and probiotic preparations in the food industry, as well as other industrial processes to produce high-quality products. Utilizing these horticultural by-products as low-cost raw materials for value-added production represents a sustainable and innovative approach to waste management and resource recovery.

Microorganisms are broadly classified into bacteria, fungi, algae, archaea and protozoa. Among these groups, fungi are particularly important since they play a major role in the production of many industrial products that are often used in people's daily lives. The present study focuses on formulating a cost-effective culture medium for fungal growth by utilizing vegetables as a primary energy source. Fungi offer numerous advantages, including their natural role in organic matter decomposition and ecosystem balance maintenance, as well as their applications in producing antibiotics (e.g., *Penicillium* sp.), industrial enzymes, and bioinsecticides (e.g., *Beauveria bassiana*, *Metarhizium* spp.). Additionally, certain fungi, such as *Trichoderma viride*, are employed as biocontrol agents against plant pathogens, while others are used in bioremediation processes and serve as food for humans and feed for livestock (e.g., edible mushrooms). Although fungi have shown promise in the bioremediation of wastewater and textile dye effluents, their application in these areas remains limited due to the formation of dense mycelial mats, which hinder efficiency. As a result, bacterial species are often preferred in such contexts due to their higher treatment efficiency (Saranraj et al*.,* 2018).

Some previous studies have demonstrated that both bacterial and fungal species can thrive on substrates derived from agricultural by-products. For example, some vegetables and fruits, including carrots, tomatoes, cabbage and pumpkin, can serve as efficient substrates for growing fungus, offering a low-cost and readily available alternative to conventional media such as Potato Dextrose Agar (PDA) (Deivanayaki and Antony iruthayaraj 2012). In a related study, researchers developed a solid bacterial culture called Cowpea Agar (CPA) using cooked cowpeas. This formulation not only supported microbial growth but also extended the

medium's shelf life to approximately three months (Annan-Prah et al., 2010). And also, another study was performed to test the suitability of starch-containing tubers such as sweet potato varieties (purple and white), cocoyam varieties (edible and non-edible), Irish potato and yam used as a substitute for Potato Dextrose Agar medium by using *Aspergillus niger* and *Aspergillus carbonarius* as test organisms. Among these, Purple sweet potato varieties showed good mycelial growth when compared to other substrates. Because of the high carbohydrate content of these agricultural products, they can be used as raw materials to formulate media for the cultivation of microorganisms, particularly fungi, which can break down the starch to soluble sugars, which can serve as a source of carbon and energy (Amadi O. C., 2012). Jadhav et al. (2017) explored the use of drumstick as an alternative substrate for supporting the growth of *E.coli*, *Serratia* sp. and *Pseudomonas* sp. and reported significant microbial proliferation across various formulations. Chanda et al. (2015) formulated a medium using a blend of Onion peel, Garlic peel and corn peel in 2:1:1 ratio, which effectively supported the growth of *Bacillus* sp., *Sarcina* sp., *Pseudomonas aeroginosa, Candida albicans* and *Saccharomyces cerevisiae*. Another study was carried out using beetroot juice as a growth and maintenance medium for the pathogenic bacteria such as *Pseudomonas aeruginosa*, *Proteus vulgaris*, *Staphylococcus aureus*, *Escherichia coli* and *Klebsiella pneumonia* by Logeshwaran et al. 2019. All the tested bacteria gave active growth after 24 hours. Sugarcane bagasse has also been reported as an energy source for the production of lipase by *Aspergillus fumigatus* (Naqvi et al., 2013). Although these studies collectively demonstrate the feasibility of using fruit and vegetable residues as nutrient sources for microbial cultivation, most of them have focused primarily on solid agar-based formulations, providing limited information on the performance of fungi in liquid cultures. Solid media are useful for colony characterization and qualitative growth assessment; however, they do not accurately reflect the nutrient availability and mass transfer conditions found in submerged fermentation systems, which are essential for industrial-scale biomass and enzyme production (Pandey et al., 2000; Amadi,2012). Therefore, the ability of waste-derived substrate to support filamentous fungi in liquid culture conditions is still poorly researched. These non-tuber vegetable wastes—such as carrot, onion, cabbage, beans, beetroot, and drumstick—contain significant levels of simple sugars, fiber and minerals that can provide balanced nutrition for fungal metabolism. In region like Sri Lanka, where vegetable wastes are largely generated through domestic, market, and agro-industrial activities the sustainable reuse of such materials is still limited (FAO, 2020; Ministry of Environment Sri Lanka, 2021). Transforming these residues into microbial growth media offers an environmentally friendly solution to reduce organic waste accumulation while simultaneously producing biologically valuable fungal biomass.

Given the evidence that plant residues can support microbial growth, further recognizing the lack of studies on non-tuber vegetable wastes and liquid-state fungal cultivation, the present research was conducted to develop and evaluate vegetable waste-based liquid media for fungal growth. This study aims to determine the suitability of six commonly available vegetable wastes—carrot, onion, cabbage, beans, beetroot, and drumstick—as nutrient sources for the growth of filamentous fungi of agricultural and industrial importance, namely *Aspergillus* sp., *Fusarium* sp., *Mucor* sp., *Penicillium* sp., *Rhizopus* sp., and *Trichoderma* sp. Two key growth parameters were assessed: spore concentration at the 3rd, 4th, and 5th day of incubation to evaluate sporulation dynamics, and mycelial dry weight on the 5th day to quantify biomass accumulation. The outcomes are expected to contribute to waste valorization, cost reduction in fungal biomass production, and the promotion of sustainable biotechnological practices. Ultimately, the study offers a practical framework for transforming readily available vegetable wastes into resource-efficient media formulations that support fungal cultivation for laboratory, industrial, and agricultural applications.

Methodology

Collection of samples and peel waste preparation

Different types of kitchen wastes, including cabbage, onion, carrot, beans, beetroot and drumstick, were cut into small pieces and shade-dried until completely dehydrated. The dried plant materials were finely ground using an electronic blender and sieved. Each powder was stored

separately in sterile, airtight containers under dry conditions to maintain its integrity for experimental use.

Preparation of vegetable waste media

The experiment was conducted in liquid media, wherein 2g of prepared powdered substrate was suspended in 50mL of distilled water and sterilized via wet heat method. Potato Dextrose Broth (PDB) was prepared as the control medium.

Preparation of fresh fungal cultures

Six different fungal genera were used as test organisms, namely *Aspergillus* sp., *Fusarium* sp., *Mucor* sp., *Penicillium* sp., *Rhizopus* sp. and *Trichoderma* sp. They were obtained from the culture collection section, Department of Botany, University of Jaffna and were sub-cultured on Potato Dextrose Agar (PDA). The inoculated plates were incubated at room temperature for 3-5 days (S.N. Sah et al., 2018).

Preparation of Inoculum

Spores were obtained from 3-day-old fungal culture, and the spore suspension was prepared by mixing the spores in 50mL of saline solution (0.85% NaCl). The initial concentration of the suspension was adjusted to 1×10^4 spores/mL and it was incubated at room temperature for 5 hours to stimulate the metabolic process of the spores (Saranraj et al., 2018).

Inoculation of fungal suspension

1mL of prepared spore suspension was inoculated to each prepared vegetable waste medium as well as Potato Dextrose Broth medium after 5 hours and incubated at room temperature for 3 to 5 days (Saranraj et al., 2018).

Quantitative analysis of fungal growth

The spore concentration of each fungal species in the respective media was determined using a hemocytometer on the 3rd, 4th, and 5th days following inoculation. The recorded data were subsequently presented graphically to illustrate the growth pattern. In addition, the mycelial biomass was quantified by measuring the dry weight after five days of incubation. This was achieved by filtering the fungal cultures through Whatman No. 1 filter paper, followed by drying and weighing the retained mycelia.

Statistical analysis

All experiments were conducted in duplicate, and the mean values were used for graphical representation. Statistical analyses were performed using Minitab 20. One-way Analysis of Variance (ANOVA) was employed to evaluate differences among treatments, and Tukey's pairwise comparison test was applied to identify statistically significant differences at a confidence level of $p < 0.05$.

Results and Discussion

This study aims to evaluate the efficiency of different vegetable waste-based media as a cost-effective and sustainable alternative to Potato Dextrose Broth (PDB), commonly used for the cultivation of fungi. Specifically, six fungi which have industrial and environmental importance were selected for analysis: *Aspergillus* sp., *Fusarium* sp., *Mucor* sp., *Penicillium* sp., *Rhizopus* sp. and *Trichoderma* sp. The growth performance of each fungus was systematically evaluated by considering two main factors: the concentration of spores produced and the mycelial dry weight. These indicators provide a comprehensive insight into both the reproductive capacity and vegetative proliferation of the fungi, and the following results were obtained:

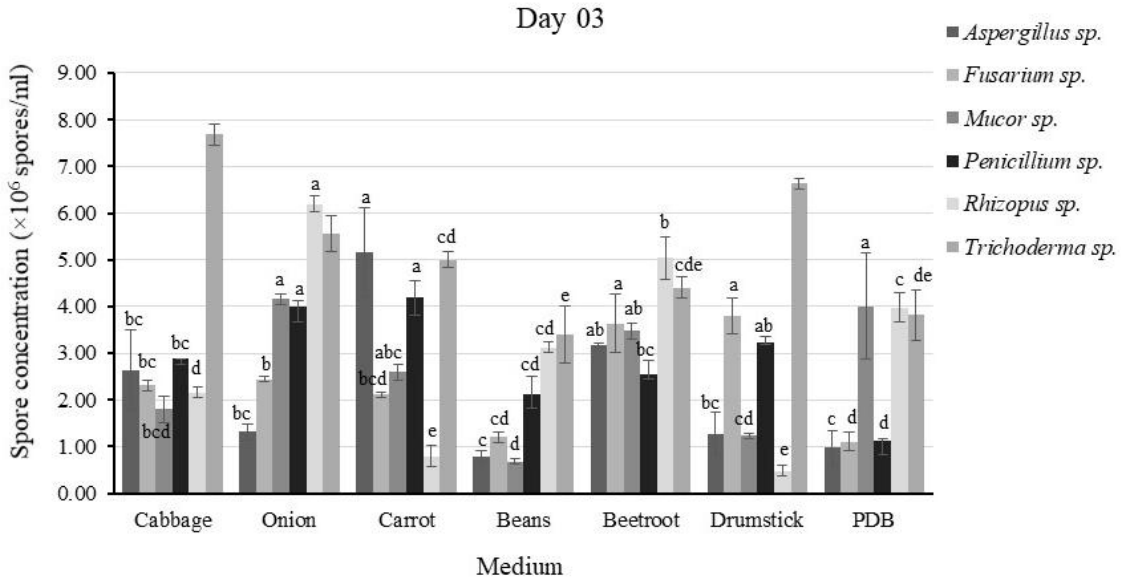

Figure 1: Spore concentration (×10^{6}spores/mL) of six fungal genera grown on different vegetable waste-based media and Potato Dextrose Broth (PDB) on Day 3. Error bars represent standard deviation (SD) of two replicates (n = 2). Different letters above bars indicate significant differences among media within each genus (one-way ANOVA followed by Tukey's HSD, $p < 0.05$). ANOVA results were significant for all genera (*Aspergillus* sp., *Fusarium* sp., *Mucor* sp., *Penicillium* sp., *Rhizopus* sp., and *Trichoderma* sp.; $p = 0.001$).

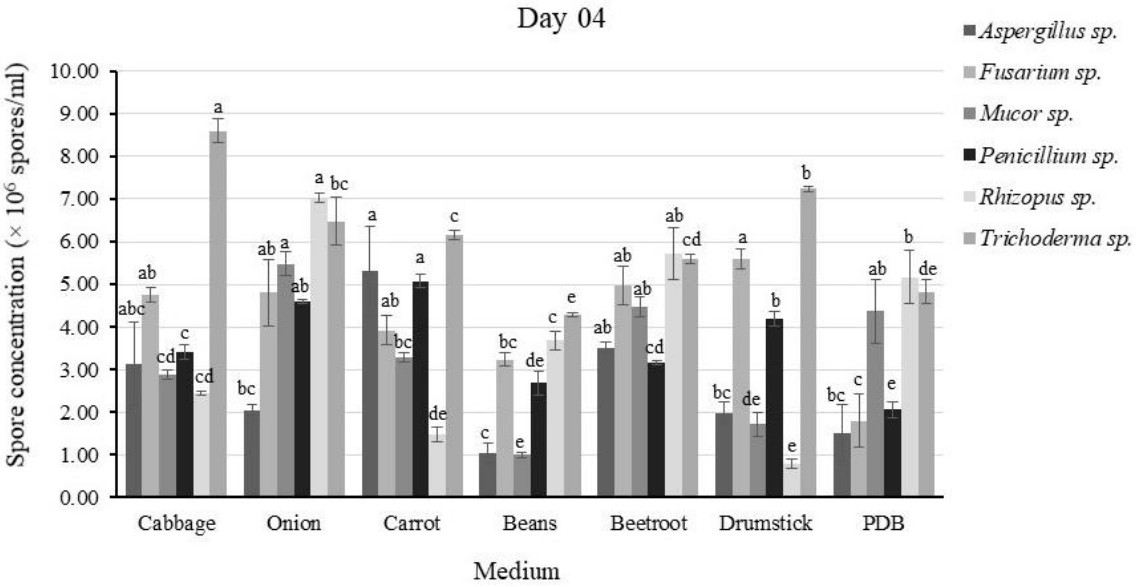

Figure 2: Spore concentration (×10^{6}spores/mL) of six fungal genera grown on different vegetable waste-based media and Potato Dextrose Broth (PDB) on Day 4. Error bars represent standard deviation (SD) of two replicates (n = 2). Different letters above bars indicate significant differences among media within each genus (one-way ANOVA followed by Tukey's HSD, $p < 0.05$). ANOVA p -values: (*Aspergillus* sp. $p = 0.003$, *Fusarium* sp. $p = 0.001$, *Mucor* sp. $p = 0.001$, *Penicillium* sp. $p = 0.001$, *Rhizopus* sp. $p = 0.001$, and *Trichoderma* sp.; $p = 0.001$).

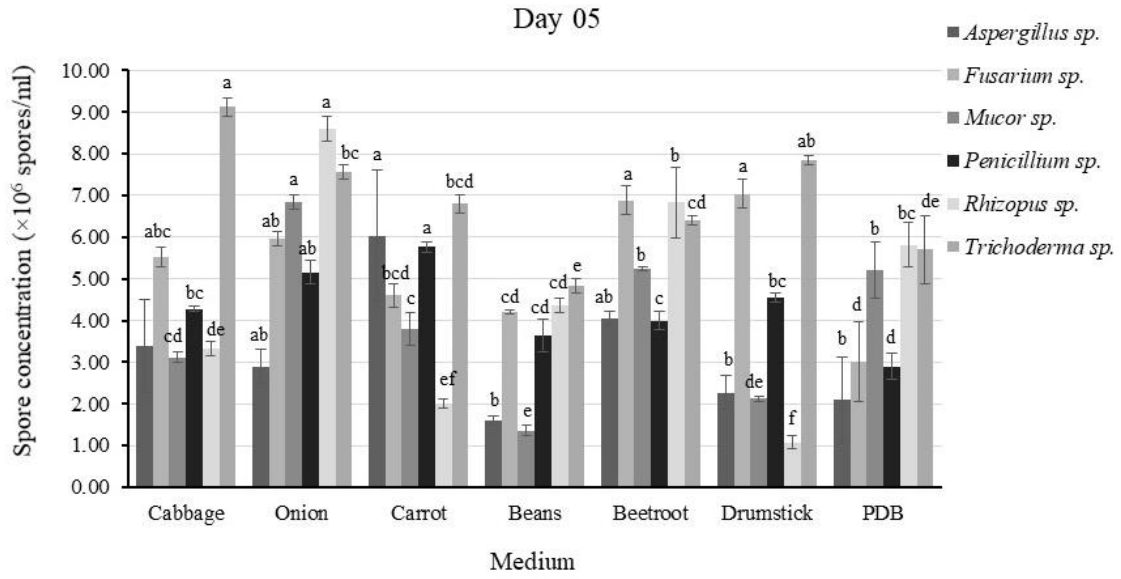

Figure 3: Spore concentration (×10^{6}spores/mL) of six fungal genera grown on different vegetable waste-based media and Potato Dextrose Broth (PDB) on Day 5. Error bars represent standard deviation (SD) of two replicates (n = 2). Different letters above bars indicate significant differences among media within each genus (one-way ANOVA followed by Tukey's HSD, $p < 0.05$). ANOVA p-values: (*Aspergillus* sp. p = 0.015, *Fusarium* sp. p = 0.001, *Mucor* sp. p = 0.001, *Penicillium* sp. p =0.001, *Rhizopus* sp. p =0.001, and *Trichoderma* sp.; p = 0.001)

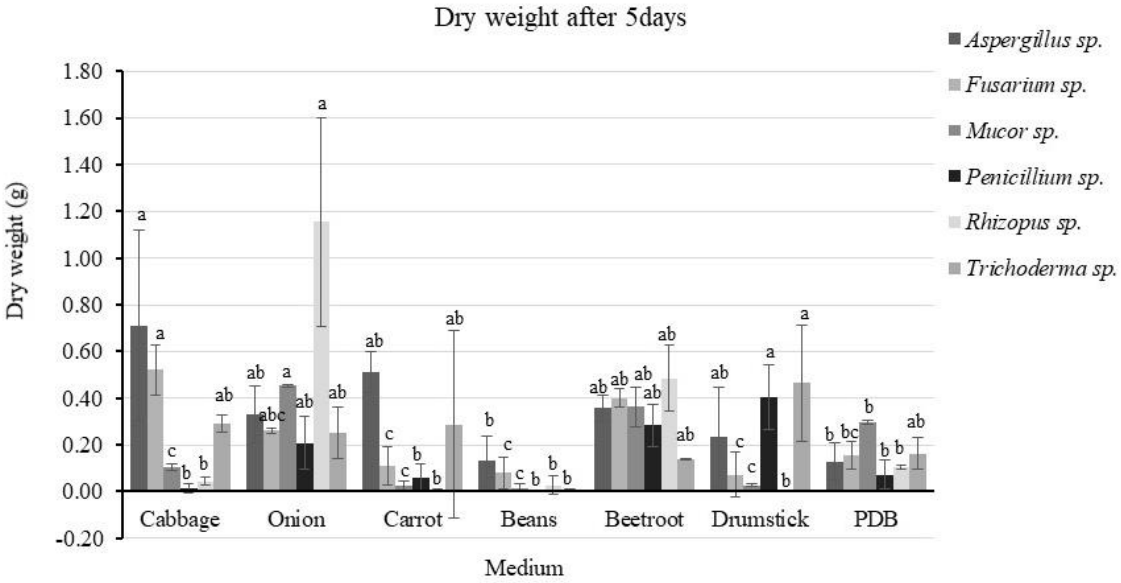

Figure 4: Dry weight of six fungal genera grown on different vegetable waste-based media and Potato Dextrose Broth (PDB) after 5 days of incubation. Error bars represent standard deviation (SD) of two replicates (n = 2). Different letters above bars indicate significant differences among media within each genus (one-way ANOVA followed by Tukey's HSD, $p < 0.05$). ANOVA p -values: (*Aspergillus* sp. p = 0.033, *Fusarium* sp. p = 0.003, *Mucor* sp. p = 0.001, *Penicillium* sp. p =0.012, *Rhizopus* sp. p =0.002, and *Trichoderma* sp.; p = 0.040)

Spore production

Spore production varies considerably across different vegetable waste substrates. Among the six fungal genera tested, *Trichoderma* sp. showed higher spore production, reaching 9.12×10^6 spores/mL when cultivated in the media formulated with cabbage. This finding indicates that cabbage waste provides the highly favourable nutrient profile for enhancing the sporulation of *Trichoderma* sp. Onion waste-based media significantly supported the spore development of two zygomycetous fungi: *Mucor* sp. and *Rhizopus* sp., which recorded spore concentrations of 6.84×10^6 spores/mL and 8.60×10^6 spores/mL, respectively. This indicates that onion waste contains specific nutrients or bioactive compounds, that can stimulate the reproductive process of zygomycetes better than PDB. *Aspergillus* sp. and *Penicillium* sp. demonstrated their highest levels of spore production when grown in carrot-based media, reaching concentrations of 6.04×10^6 spores/mL and 5.76×10^6 spores/mL, respectively. Based on the results, drumstick-based medium was identified as the most effective substrate for supporting the reproductive growth of *Fusarium* sp., yielding a spore concentration of 7.04×10^6 spores/mL. Conversely, beans and beetroot supported comparatively lower spore yields for most fungi, with *Aspergillus* sp. (1.60×10^6 spores/mL) and *Mucor sp.* (1.36×10^6 spores/mL) showing minimal sporulation in beans, suggesting possible nutrient limitations or the presence of inhibitory compounds in legume-derived waste.

Mycelial biomass

The trend in the dry weight of the fungi further confirms the suitability of some vegetable waste for fungal proliferation. Notably, *Rhizopus* sp. showed the highest biomass in onion medium with 1.1540 g of mycelia. Similarly, *Mucor* sp. produced substantial biomass (0.4540 g) in the same medium, suggesting that onion waste supports the vegetative growth of zygomycetes effectively. *Aspergillus* sp. showed maximum biomass accumulation (0.7110 g) in cabbage-based medium, followed by carrot (0.5116 g), indicating these substrates were well-suited for the vegetative growth of this genus. *Penicillium* sp. recorded the highest mycelial biomass (0.4026 g) in drumstick medium, which was significantly higher than that observed in PDB (0.0731 g), suggesting that drumstick waste may serve as a cost-effective substitute for conventional media in cultivating this genus. In contrast, beans-based medium consistently resulted in the lowest biomass across all fungi, with values ranging from 0.0049 g in *Penicillium* sp. to 0.1302 g in *Aspergillus* sp., indicating its limited suitability as a growth substrate.

Correlation between spore production and mycelial biomass

Comparative analysis of total spores and mycelial biomass revealed different growth responses of six fungal genera in various vegetable waste media. For example, *Trichoderma* sp. showed the highest spore production in cabbage which is also associated with higher mycelial biomass, suggesting that cabbage waste promotes reproductive and vegetative growth of this fungus. In the case of *Rhizopus* sp., and *Mucor* sp., onion waste media supported the highest sporulation along with the highest mycelial biomass, suggesting that this substrate supports both reproductive and vegetative growth phases effectively for zygomycetes. On the other hand, *Aspergillus* sp. demonstrated its highest spore production in carrot-based medium, while its biomass was comparatively moderate, indicating a preference for reproductive growth over vegetative expansion in this medium. A similar trend was observed for *Penicillium* sp., which showed high sporulation in carrot medium but with low mycelial biomass. The observed patterns highlight the importance of medium composition in influencing the balance between vegetative and reproductive phases in fungal development.

The use of two complementary parameters is an established method in both mycological and industrial microbiological research, as it allows a comprehensive understanding of the response of fungi under different nutrient conditions. Spore concentration is a key parameter for evaluating the reproductive potential of a fungus as it reflects its ability to generate viable propagules under given conditions. Especially for applications such as biocontrol, where high sporulation is essential for long-term viability and field efficacy (Mukherjee et al., 2013). Furthermore, spore yield has also been used to evaluate the adaptability of fungi to alternative nutrient sources, such as agricultural and

vegetable waste-based media (El-samawaty et al., 2012). The dry weight of the mycelia defines the vegetative growth of the fungus and reflects its ability to use nutrients from the environment to expand its hyphae network. Biomass analysis is important in the study of fermentation, in the production of industrial enzymes and in biotechnological applications (Arora and Gill., 2001). Higher mycelial dry weight indicates that the medium supports strong fungal growth, which may also result in greater metabolic activity and production of secondary metabolites. For example, the study by Saravanakumar et al. (2016) reported that some plant growth media increase the yield of the enzyme in *Trichoderma* sp. By measuring spore production and biomass, researchers can distinguish between conditions that promote fungal proliferation and reproductive development. Often, optimal vegetative growth provides the basis for successful sporulation, although those two are not always directly correlated. Some media may favour one over the other. And understanding this balance is critical to selecting or developing media for fungal growth (Pandey et al., 2000).

Shade drying in room temperature is generally preferred for preparing plant materials intended for culture media formulation. These methods help minimize the loss of heat-sensitive bioactive compounds that serve as sources of carbon, nitrogen, and energy for microbial growth. In contrast, direct sunlight especially uv radiation and high temperature can denature proteins, oxidize phenolic compounds, and degrade pigments and vitamins such as vitamin C and the B-complex, thereby reducing the nutritional quality of the medium (Adewole et al., 2022 and Liaotrakoon et al., 2022).

Saline solution (especially 0.85% NaCl) was used to prepare spore suspension. It is isotonic to most fungal and bacterial cells. This isotonicity is very important because it prevents osmotic shock, which can happen if the spores are suspended in pure water or hypertonic solution. Osmotic shock can damage or kill the spores and reducing their viability. By using isotonic saline, the integrity of the fungal spores can be maintained during suspension. Moreover, saline does not promote spore germination, just keep the spores in a viable state until they are introduced into the culture medium (Pitt and Hocking 2009). Fungal spores are often dormant when they are harvested. Incubating them in a saline solution for several hours allows gradual hydration, necessary to activate their metabolic process. This will help to prepare the spores for subsequent germination and growth when they are introduced into the culture medium (Dantigny et al*.,* 2005).

Fungal sporulation is a complex physiological process influenced by several nutritional parameters, primarily available carbon and nitrogen sources as well as essential micronutrients. These specific nutritional requirements for optimal sporulation can vary considerably among fungal species. Consequently, a single culture medium may not uniformly support spore production across different fungal genera or species. Potato Dextrose Agar (PDA) remains one of the most widely adopted media for fungal cultivation. However, alternative culture media such as Potato Carrot Agar, Malt Dextrose Agar, Yeast Extract-Phosphate Medium, Czapek Yeast Autolysate Agar (CYA), and Malt Extract Agar are also extensively used in both research and industrial applications, depending on the growth and sporulation requirements of the target fungal species. V8 Vegetable Juice Agar has been developed as a nutritionally complex medium containing extracts from eight different vegetables—carrot, spinach, tomato, celery, parsley, beets, watercress, and lettuce. This medium has proven especially effective for the cultivation of oomycetes and other plant-associated fungi such as *Phytophthora* sp. (Hardina et al.,2020). Furthermore, certain plant tissues have been found to play a significant role in stimulating fungal sporulation. For example, autoclaved pine needles have been shown to induce the formation of pycnidia in specific species within the Botryosphaeriaceae family (Crous et al., 2006). Similarly, branch segments of *Sophora japonica* have been reported to enhance sporulation in endophytic fungi isolated from lichens (Li et al., 2007).

Overall, the results of this study underscore the potential of vegetable waste-based media as effective alternatives to conventional culture media for fungal cultivation. By evaluating both spore concentration and mycelial biomass, this research provides valuable insight into the reproductive and vegetative development of fungi under nutritionally diverse conditions. The variation in fungal responses across different media highlights the influence of specific plant-derived nutrients on

fungal physiology, especially regarding sporulation efficiency and biomass accumulation. These findings not only contribute to the growing interest in sustainable microbiological practices but also pave the way for cost-effective, eco-friendly approaches in large-scale fungal cultivation. Future work may focus on optimizing formulations and expanding their use for industrial and biocontrol applications.

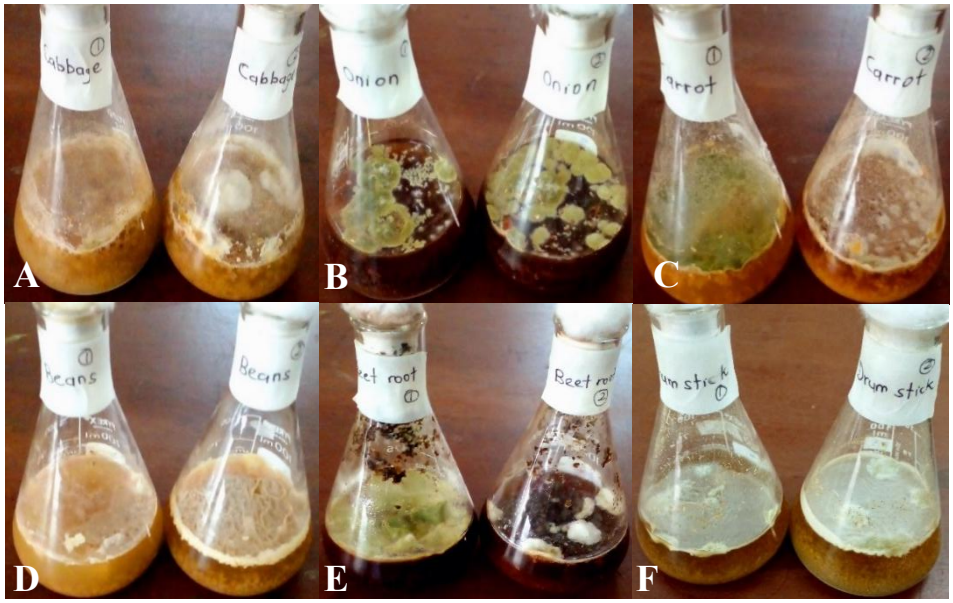

Figure 5: Growth of *Aspergillus* sp. on various vegetable waste media after five days of incubation: A- Cabbage, B- Onion, C- Carrot, D- Beans, E- Beetroot, F- Drumstick

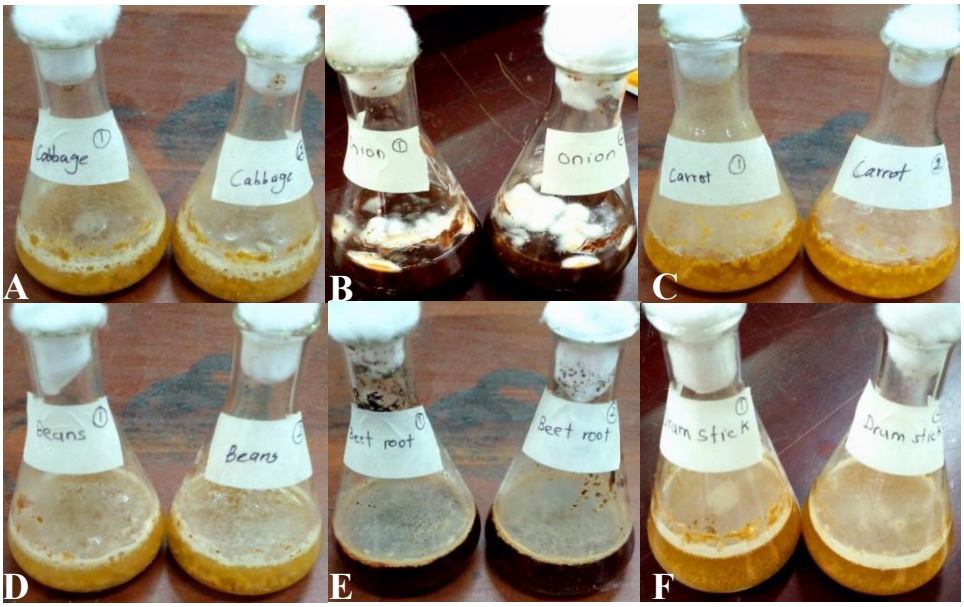

Figure 6: Growth of *Fusarium* sp. on various vegetable waste media after five days of incubation: A- Cabbage, B- Onion, C- Carrot, D- Beans, E- Beetroot, F- Drumstick

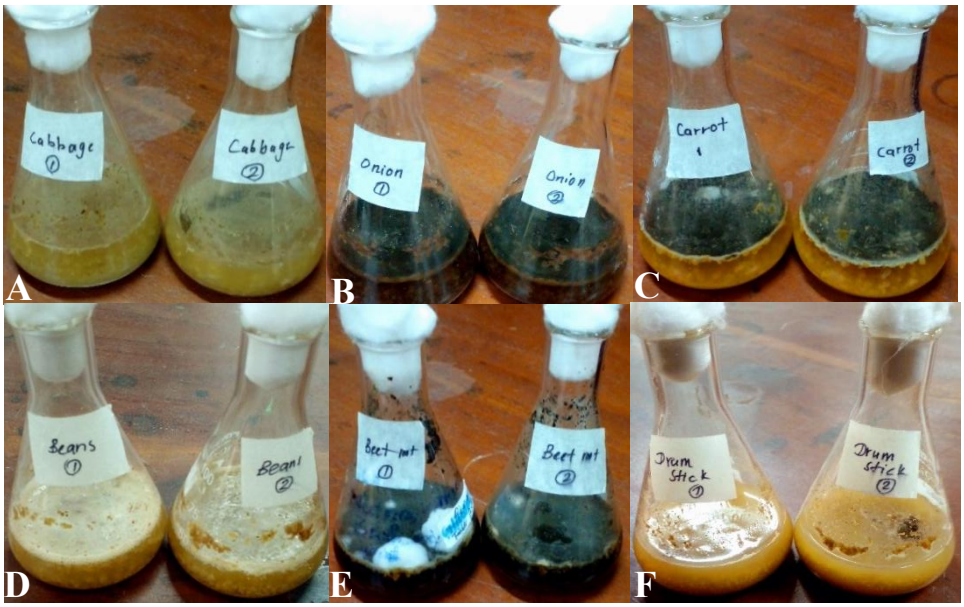

Figure 7: Growth of *Mucor* sp. on various vegetable waste media after five days of incubation: A- Cabbage, B- Onion, C- Carrot, D- Beans, E- Beetroot, F- Drumstick

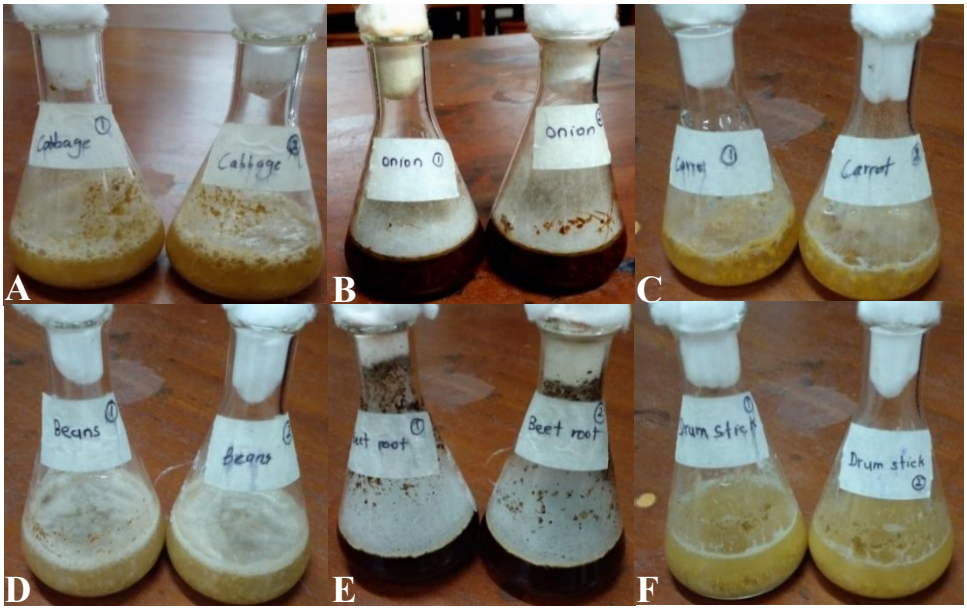

Figure 8: Growth of *Rhizopus* sp. on various vegetable waste media after five days of incubation: A- Cabbage, B- Onion, C- Carrot, D- Beans, E- Beetroot, F- Drumstick

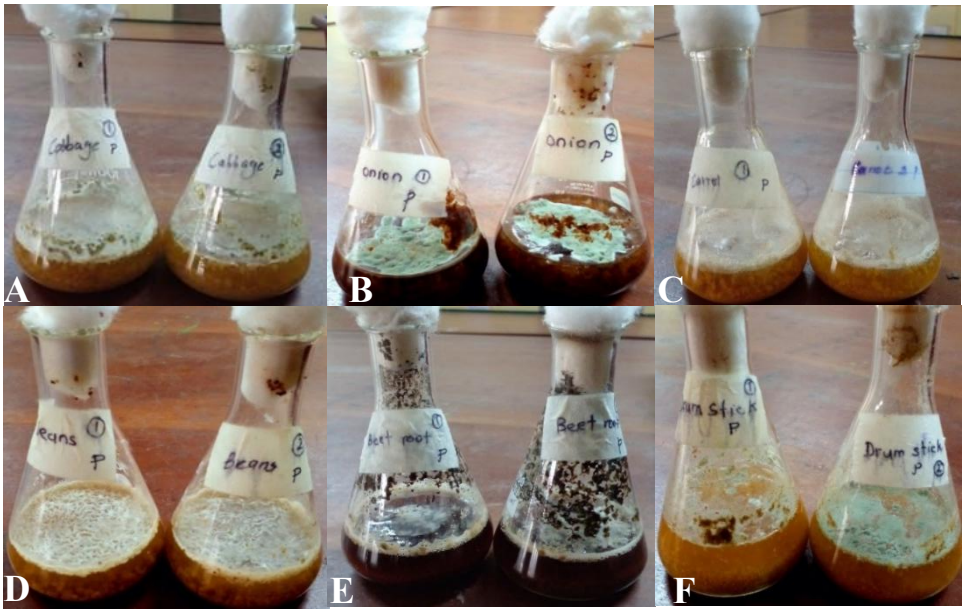

Figure 9: Growth of *Penicillium* sp. on various vegetable waste media after five days of incubation: A- Cabbage, B- Onion, C- Carrot, D- Beans, E- Beetroot, F- Drumstick

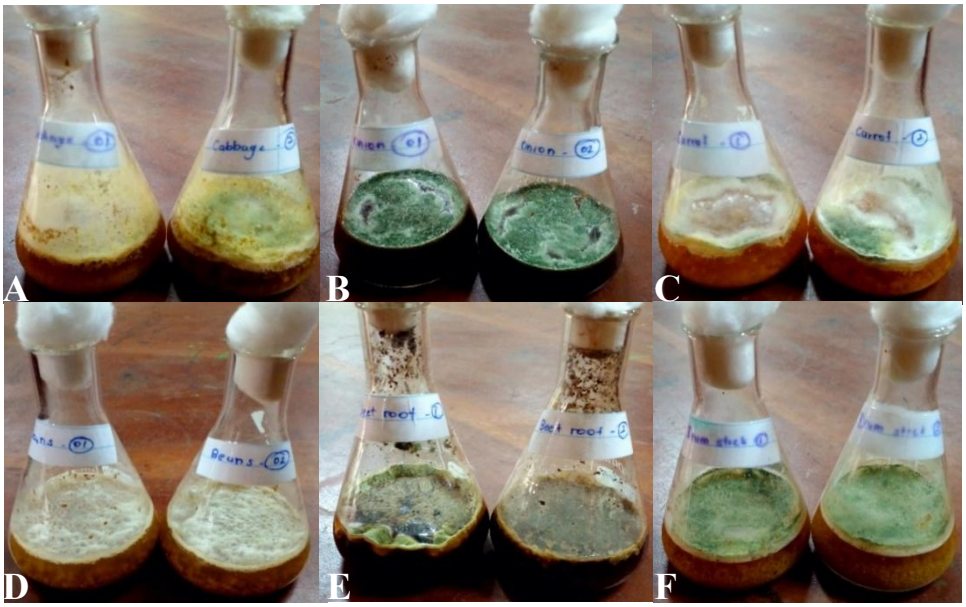

Figure 10: Growth of *Trichoderma* sp. on various vegetable waste media after five days of incubation: A- Cabbage, B- Onion, C- Carrot, D- Beans, E- Beetroot, F- Drumstick

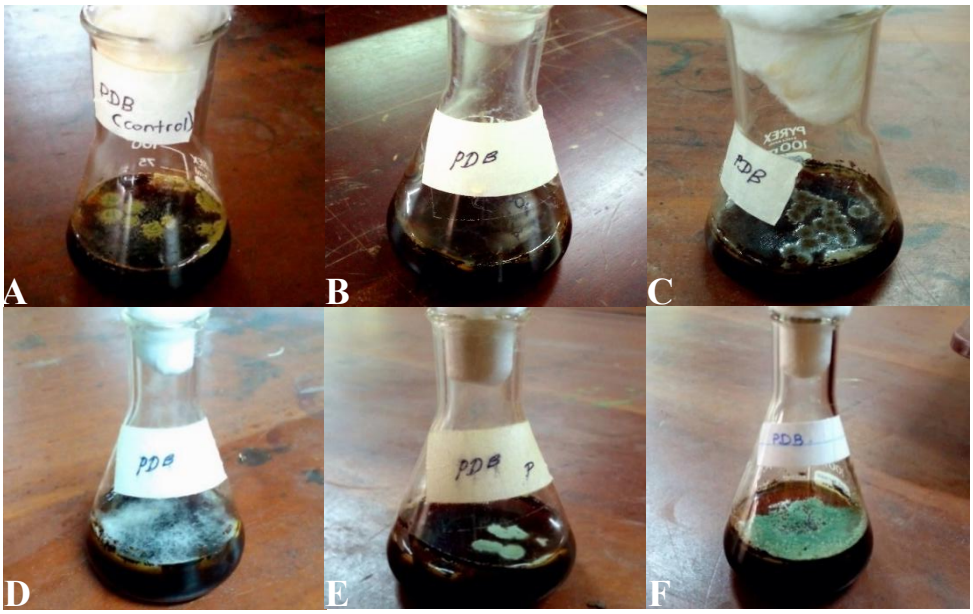

Figure 11: Fungal growth on Potato Dextrose Broth (PDB- control) after five days of incubation: A- *Aspergillus* sp., B- *Fusarium* sp., C- *Mucor* sp., D- *Rhizopus* sp., E- *Penicillium* sp., F- *Trichoderma* sp.

Conclusion

This study demonstrates the potential of using commonly discarded vegetable wastes—such as cabbage, onion, carrot, beans, beetroot, and drumstick—as cost-effective and eco-friendly alternatives to conventional Potato Dextrose Broth (PDB) for the cultivation of various fungal genera. Both spore concentration and mycelial dry weight data revealed that certain vegetable-based media not only supported fungal growth but, in several cases, outperformed the standard medium.

Notably, cabbage-based medium facilitated the highest spore production in *Trichoderma* sp., while onion waste proved optimal for *Mucor* sp. and *Rhizopus* sp.. Additionally, carrot and drumstick media supported maximum sporulation in *Aspergillus*, *Penicillium*, and *Fusarium* species, respectively. In terms of vegetative growth, onion waste media promoted higher mycelial biomass in *Mucor* sp. and *Rhizopus* sp., emphasizing their effectiveness as nutrient sources. Meanwhile, the vegetative growth of *Aspergillus* sp. and *Fusarium* sp. was highly induced by the media incorporated with cabbage. Finally, the media made up of drumstick waste highly promoted the mycelial growth of *Trichoderma* sp. and *Penicillium* sp. These results underscore the nutrient adequacy of vegetable waste substrates for fungal metabolism and their adaptability across multiple genera.

The use of vegetable waste as culture media offers a dual advantage—reducing organic waste accumulation and providing renewable feedstock for enzyme, spore, and biomass production relevant to biocontrol, fermentation, and biofertilizer industries. Future studies should focus on optimizing nutrient compositions, evaluating enzyme yields, and validating large-scale applications to enhance industrial relevance.

Overall, this research bridges the gap between waste management and fungal biotechnology by transforming locally available vegetable residues into valuable bioprocessing resources, contributing to both environmental sustainability and economic resilience.

Acknowledgements

I wish to express my sincere gratitude to the Department of Botany, University of Jaffna, for providing the laboratory facilities and technical support necessary for the successful completion of this research project. Special thanks are extended to the laboratory staff for their assistance during the experimental procedure. I also grateful to Mrs. Nirmala Ravimannan for her continuous guidance,

valuable insights and constructive feedback throughout this study.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Author contributions

M.A.Angel: Conceptualization, Methodology, Investigation, Data Analysis, Writing – Original Draft. , R. Nirmala: Supervision, Writing – Review & Editing, Resources. All authors have read and approved the final manuscript.

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