Development of an Integrated Technology Package for Paddy Straw Management

ABSTRACT

Addressing the concern of stubble burning, the study conducted under this thesis envisages on recycling and reuse of Paddy Straw (PS) to assign a commercial utility to this under-utilized biomass. In this context, a multipronged strategy towards zero waste management of PS by developing value-added products (mushrooms, bioformulations (biopesticides/biofertilizers), nanosilica, and enzymes) was attempted.

Valorization of PS using various de-oiled cakes (DEOCs), depicted that supplementation of 5% soybean cake (SC) gave maximum yield of 1014 g kg^{-1} *P. ostreatus* fruiting bodies, furnishing an increase of 18.14 % over PS control. Principal component analysis (PCA) performed by analysing the correlation amongst nutritional parameters depicted a total variation of 78.2%. Energy Dispersive X-Ray (EDX) analysis indicated significant increase of minerals in the fruiting bodies and high content of silica (19-20%) in the spent. The cultivation of *T. asperellum* on spent divulged the fact that the fungal growth was comparatively high in spent ($14.73*10^{11}$) over raw PS ($4.2*10^{3}$). *T. asperellum* grown on spent showed 66.26% inhibition of *Fusarium oxysporum* compared to the non-supplemented PS spent (54.26%).

In the next part, the Spent Mushroom Substrate (SMS) of *P. ostreatus* was utilized for the development of microbial bioformulations, for plant nutrient and disease management in wilt (*F. oxysporum*) susceptible tomato plant F1 Hybrid King 180. SMS (PS+5% SC) supported the growth of *T. asperellum* (TA) to an extent of $12.37x10^{13}$ conidia/g substrate. GC-MS analysis of SMS detected several bioactive metabolites known for plant health management. Bioformulations were developed employing Press Mud (PM) and Talcum Powder (TP) as carrier materials. Among the different bioformulations tested in pots study; SMS (PS+5% SC) SiTAPM, collectively named as TF-I, provided improved levels of morpho-biochemical and nutritional parameters, A significant ($p<0.05$) reduction in the Disease Severity Index (84.34% to 21.23%), was also observed over the pathogen affected plant. The fruits and leaves garnered under TF-I displayed Total Polyphenol Content (TPC) of 74.5 and 126.9 mg/g gallic acid, respectively, with 83.73% DPPH and 72.25% FRAP activity, indicating the elicitation of antioxidant properties. EDX analyses showed 21.53% Silica (Si) in SMS, and plant mapping investigation indicated a substantial accumulation of Si, which is well conceded to promote growth, disease resistance, and antioxidant parameters. The developed bioformulation was delivered to farmers in villages of Uttar Pradesh and a survey study was conducted, which delivered positive outcomes and keen interest towards the implementation of the technology.

An *in-silico* approach was also employed to assess the prospective role of bioactives of *Trichoderma* spp. in combating the *Fusarium* wilt causing enzymes Polygalacturonase (PG2) and tomatinase. The findings of the study revealed that Trichodermamide B produced by *T. harzianum* and Viridin, Virone, and Trichosetin produced by *T. virens* emerged as the potential inhibitors of the phytopathogen’s enzymes. MD simulations and MMPBSA confirmed the structural rigidity and stability of the docked complex.

The silica rich straw was further explored for the synthesis of nanosilica (SiNPs) employing the sol-gel method, via integrating the aqueous extract of *Sapindus mukorossi* as surfactant. EDS and FTIR spectra confirmed the predominant peaks of Si and O. FE-SEM confirmed the spheroid morphology of SiNPs with an average particle size of 20.34 ± 2.64 nm as determined by TEM. DLS studies revealed the stability of SiNPs with zeta potential of -14.37 mV and PDI of 0.198, implying its monodispersed nature. BET surface area of SiNPs was recorded as 746.32 m^2/g with a cumulative pore volume of 2.059 cm^3/g. The employment of SiNPs as a carrier material for clove oil (CO), depicted 62.64% encapsulation of CO in SiNPs under UV analysis. The antifungal efficacy of CO-SiNPs against *F. oxysporum* exhibited minimum inhibitory concentration (MIC) of 125 mg/L. The application of SiNPs in photocatalytic degradation of methylene blue reflected that 66.26 % of the dye was degraded in the first 10 mins, and the degradation reflected a first-order kinetics with a half-life of 6.79 mins.

In another objective of this study, PS was explored for lignocellulolytic enzymes under Solid State Fermentation by *Trichoderma* spp. Response Surface Methodology (RSM) optimization of PS in combination with de-oiled neem cake (NC) depicted that PS:NC in 8:3 ratio, provided maximum xylanase activity of 693.56 U/g on the 5^{th} day, with cellulase and laccase activity of 126 U/g and 28.12 U/g, respectively. OHR-LCMS study of the partially purified enzyme revealed the presence of β-xylanase and α-L-arabinofuranosidase. Enzymatic saccharification of various substrates enhanced the release of reducing sugars demonstrating its applicability in the biofuel domain. LC-MS, ICMPS, and EDX profiling of the residual spent unravelled the manifestation of bioactives, minerals, and silica, playing an essential role as biopesticide and biofertilizer. Life Cycle Assessment (LCA) for the SSF process, depicted adverse impacts due to electricity consumption (92.84%) and use of ammonium sulphate salt (6.17%). Nonetheless, employing renewable energy and reducing salt consumption could help minimize these impacts.

The findings of the study asserted that PS can be substantially utilized for the development of value-added products. The study also promises new ventures for development of PS based small scale industries, as a source of revenue generation.