INTISARI

Limbah cangkang pupa Black Soldier Fly (BSF) kaya akan kitosan dan melanin, namun belum banyak dimanfaatkan sebagai bahan baku bernilai tambah. Di sisi lain, diperlukan kemasan pangan yang aman, biodegradable, dan memiliki aktivitas antibakteri untuk menekan kontaminasi mikroba. Penelitian ini bertujuan mengekstraksi kitosan dan melanin dari cangkang pupa BSF menggunakan metode konvensional dan *microwave-assisted extraction (MAE),* kemudian memformulasikan film komposit PVA/kitosan/melanin sebagai bahan *antibacterial food packaging* serta mengkaji sifat fisik, kimia, biodegradabilitas, dan aktivitas antibakterinya.

Ekstraksi kitosan dan melanin dilakukan melalui tahapan demineralisasi, deproteinasi, dan deasetilasi. Karakterisasi kitosan dan melanin mencakup FTIR, XRD, SEM-EDS, dan *Particle Size Analysis (PSA).* Optimasi ekstraksi melanin dilakukan menggunakan *Response Surface Methodology (RSM)* dengan desain Box–Behnken. Film PVA/kitosan/melanin disintesis dengan variasi konsentrasi melanin 0; 0,5; 1,0; dan 2,0% (b/b), kemudian diuji ketebalan, kadar air, kelarutan, *swelling ratio*, sifat mekanik, biodegradabilitas dalam tanah kompos, serta aktivitas antibakteri terhadap *Escherichia coli (E. coli)* dan *Staphylococcus aureus (S. aureus)* menggunakan uji difusi cakram dan metode perendaman (OD_{600}).

Hasil menunjukkan bahwa MAE meningkatkan efisiensi penghilangan kotoran dan mempersingkat waktu setiap tahap ekstraksi menjadi sekitar 8 menit, dengan derajat deasetilasi kitosan yang sebanding dengan metode konvensional (±76%). *Yield* kitosan yang diperoleh adalah 3,28 ± 0,35% (konvensional) dan 3,89 ± 2,35% (MAE), sedangkan *yield* melanin 0,2 ± 0,03% (konvensional) dan 0,41 ± 0,10% (MAE). Melalui optimasi RSM, diperoleh kondisi optimum ekstraksi melanin pada konsentrasi basa 12,93 M dan rasio padat:cair 1:22,68 dengan *yield* terprediksi 8,24%. Spektra FTIR mengonfirmasi bahwa kitosan hasil ekstraksi memiliki gugus fungsi serupa dengan kitosan komersial, sedangkan melanin menunjukkan karakteristik eumelanin. Data XRD menunjukkan kitosan konvensional memiliki kristalinitas tertinggi (37,76%), sementara SEM-EDS dan PSA mengindikasikan morfologi berpori dan distribusi ukuran partikel nano–mikro yang mendukung pembentukan film dan interaksi dengan matriks polimer.

Penambahan melanin pada film PVA/kitosan meningkatkan ketebalan (0,18 ± 0,01 – 0,23 ± 0,01 mm), menurunkan kadar air (11,93 ± 0,17 – 11,31 ± 0,26%), kelarutan (31,53 ± 1,69 – 24,85 ± 2,39%), dan swelling ratio (145,52 ± 4,76 – 105,12 ± 7,29%), serta memperbaiki sifat mekanik. Kekuatan tarik meningkat dari 16,16 ± 2,51 menjadi 28,81 ± 1,87 MPa dan elongasi dari 18,14 ± 12,88 menjadi 22,42 ± 0,23%, sehingga memenuhi standar SNI dan JIS untuk material bioplastik. Uji biodegradabilitas menunjukkan kehilangan massa 43,74–48,31% dalam 35 hari, dengan model kinetika eksponensial yang mengindikasikan melanin memperlambat laju degradasi namun tetap mempertahankan sifat dapat terurai. Uji antibakteri memperlihatkan bahwa peningkatan konsentrasi melanin memperbesar zona hambat dan faktor penghambatan pertumbuhan bakteri, dengan efektivitas lebih tinggi terhadap *S. aureus* (Imax ≈ 81,81) dibandingkan *E. coli* (Imax ≈ 32,79) berdasarkan pemodelan modifikasi Michaelis–Menten.

Secara keseluruhan, film komposit PVA/kitosan/melanin dari cangkang pupa BSF berpotensi diaplikasikan sebagai bahan kemasan pangan antibakteri yang ramah lingkungan dan mendukung konsep ekonomi sirkular.

ABSTRACT

Black soldier fly (BSF) pupal shells are an abundant biowaste rich in chitosan and melanin but remain largely underutilized as a high-value raw material. At the same time, there is a growing demand for safe, biodegradable food packaging materials with antibacterial activity to reduce microbial contamination. This study aimed to extract chitosan and melanin from BSF pupal shells using conventional and microwave-assisted extraction (MAE), to formulate PVA/chitosan/melanin composite films, and to evaluate their physicochemical properties, biodegradability, and antibacterial performance for application as antibacterial food packaging.

Chitosan and melanin were obtained through a series of demineralization, deproteinization, and deacetylation steps. The extracted materials were characterized by FTIR, XRD, SEM-EDS, and particle size analysis (PSA). Melanin extraction was optimized using Response Surface Methodology (RSM) with a Box–Behnken design. PVA/chitosan/melanin films were prepared by solution casting with melanin loadings of 0%, 0.5%, 1.0%, and 2.0% w/w. Film thickness, moisture content, water solubility, swelling ratio, mechanical properties, soil burial biodegradability, and antibacterial activity against *Escherichia coli (E. coli)* and *Staphylococcus aureus (S. aureus)* were evaluated using disk diffusion and optical density at 600 nm (OD_{600}) assays.

MAE enhanced impurity removal efficiency and reduced extraction time to about 8 minutes per step, while maintaining a comparable degree of deacetylation (~76%) to conventional treatment. The chitosan yields obtained were 3.28 ± 0.35% (conventional) and 3.89 ± 2.35% (MAE), whereas the melanin yields were 0.20 ± 0.03% (conventional) and 0.41 ± 0.10% (MAE). RSM optimization indicated an optimum melanin extraction condition at 12.93 M NaOH and a solid-to-liquid ratio of 1:22.68, with a predicted yield of 8.24%. FTIR confirmed that BSF-derived chitosan exhibited functional groups similar to commercial chitosan, while melanin showed eumelanin-type features. XRD revealed the highest crystallinity for conventional chitosan (37.76%), and SEM-EDS/PSA results indicated porous morphologies with nano- and micro-scale particle sizes, which are favorable for film formation and interfacial interactions.

The incorporation of melanin into the PVA/chitosan film increased its thickness (0.18 ± 0.01–0.23 ± 0.01 mm), reduced moisture content (11.93 ± 0.17–11.31 ± 0.26%), solubility (31.53 ± 1.69–24.85 ± 2.39%), and swelling ratio (145.52 ± 4.76–105.12 ± 7.29%), and improved the mechanical performance. The tensile strength increased from 16.16 ± 2.51 to 28.81 ± 1.87 MPa, while the elongation increased from 18.14 ± 12.88 to 22.42 ± 0.23%, meeting both SNI and JIS standards for bioplastic materials. Biodegradability tests showed a mass loss of 43.74–48.31% within 35 days, with an exponential kinetic model indicating that melanin slightly slows the degradation rate while maintaining biodegradability. Antibacterial assays revealed that higher melanin concentrations enhanced inhibition zones and growth inhibition factors, with greater efficacy against S. aureus (Imax ≈ 81.81) than E. coli (Imax ≈ 32.79), as demonstrated by the modified Michaelis–Menten modeling.

Overall, PVA/chitosan/melanin composite films derived from BSF pupal shells exhibit promising mechanical, barrier, biodegradation, and antibacterial properties, highlighting their potential as eco-friendly antibacterial food packaging while valorizing insect biowaste within a circular economy framework.