Pengembangan Film Nanokomposit Ramah Lingkungan Berbasis Pullulan dari Ubi Cilembu Terserang Hama Lanas untuk Aplikasi Kemasan Pasca Panen

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Lili Melani[1], Siti Salwa Jamilah[1], Elvi Restiawaty[2], Maya Fitriyanti[1], M. Yusuf Abduh[1]

[1]Sekolah Ilmu dan Teknologi Hayati, [2]Fakultas Teknologi Industri

Abstract

This study developed an environmentally friendly pullulan-based nanocomposite film from weevil-damaged Cilembu sweet potatoes for postharvest packaging. Sweet potato hydrolysate was used as a carbon source for pullulan production by *Aureobasidium pullulans*. The highest pullulan yield (55.4%) was obtained using 110 g/L hydrolysate, an initial pH of 7.5, and 1 g/L yeast extract. The recovered pullulan was combined with bacterial nanocellulose (BNC) and chitosan, and the films were prepared by solvent casting. Incorporating chitosan and BNC improved film strength and flexibility compared with the pullulan control. The best formulation, F3, exhibited a stress at break of 15.1 MPa and a strain at break of 30.6%, whereas the control showed 6.1 MPa and 9.5%, respectively. These results indicate that a moderate BNC concentration promoted effective stress transfer while maintaining polymer-chain mobility, demonstrating the potential of this nanocomposite film as sustainable postharvest packaging.

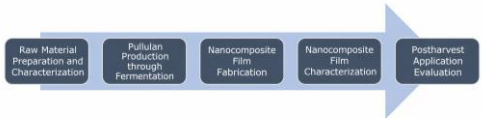
Keyword: BNC; chitosan; nanocomposite film; pullulan; sustainable packaging

Introduction

Postharvest loss remains a major challenge in Indonesia, where 20-50% of horticultural products may deteriorate before reaching consumers because of inadequate handling technologies, biological damage, and tropical conditions. In Cilembu sweet potato, losses begin during cultivation due to sweet potato weevil (*Cyclas formicarius*) infestation. Larval tunnelling causes hidden internal damage, reduces quality and palatability, and may result in yield losses exceeding 50%, leaving large quantities of tubers as biomass waste. Previous research demonstrated that weevil-damaged Cilembu sweet potato can be converted into bacterial nanocellulose (BNC). Despite being unsuitable for consumption, the damaged tubers retain abundant starch and therefore offer a promising carbon source for producing pullulan through *Aureobasidium pullulans* fermentation. Pullulan is transparent, food-safe, odourless, and an effective oxygen barrier; however, its limited mechanical strength and moisture sensitivity restrict its use in postharvest packaging. This research aims to develop an active, biodegradable nanocomposite packaging film based on pullulan derived from damaged Cilembu sweet potato. Specifically, it seeks to produce pullulan by fermentation, fabricate pullulan films reinforced with BNC, incorporate biomass-derived chitosan as an antimicrobial component, evaluate the films' physical, mechanical, and barrier properties, and characterize their chemical structure, crystallinity, and thermal stability using FTIR, XRD, and TGA. This integrated approach valorizes agricultural and agro-industrial residues while supporting a circular bioeconomy and sustainable postharvest management in tropical Indonesia under local conditions.

Research Method

Weevil-damaged Cilembu sweet potatoes are collected, cleaned, and processed to obtain HSP as the primary carbon source for pullulan production. BNC from previous research and chitosan derived from black soldier fly biomass are prepared as the reinforcing and antimicrobial components, respectively. Pullulan is produced through submerged fermentation using A. pullulans at 28-30°C for 72-120 hours under controlled pH and agitation. After fermentation, the cells are removed by centrifugation, and pullulan is recovered from the supernatant through precipitation with cold 95% ethanol, followed by incubation, separation, and freeze-drying. Nanocomposite films are fabricated by solvent casting using pullulan as the polymer matrix, BNC as the nanostructural reinforcement, chitosan as the antimicrobial agent, and glycerol as the plasticizer. The resulting films are conditioned before characterization. Postharvest performance is assessed using a model fruit stored under controlled tropical conditions by monitoring weight loss, colour, texture, and visual quality.



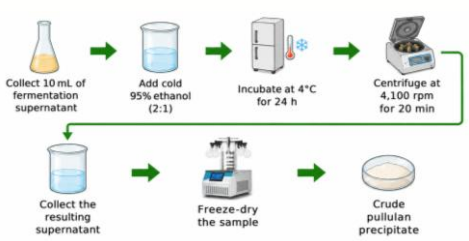
Picture 1. General research procedure



Picture 2. Chitin deacetylation process using BSFL biomass waste to produce chitosan

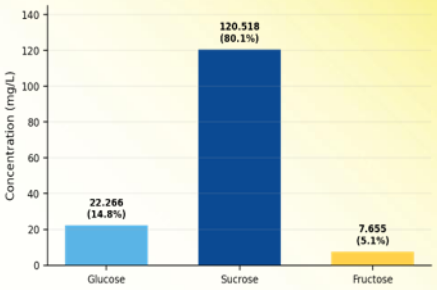
Table 1. RSM matrix for producing pulluan

HSP, %w/v	pH Media	Yeast Extract, %w/v
70	6,5	3
110	6,5	3
70	8,5	3
110	8,5	3
70	7,5	1
110	7,5	1
70	7,5	5
110	7,5	5
90	6,5	1
90	8,5	1
90	6,5	5
90	8,5	5
90	7,5	3
90	7,5	3
90	7,5	3



Picture 3. Procedure for harvesting pullulan

Discussion & Result



Picture 4. Sugar composition of Cilembu sweet potato hydrolysate (HSP)

Table 2. Formulation of film nanocomposite

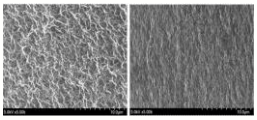
Sample code	Ratio code	Pullulan (wt%)	Chitosan (wt%)	BNC (wt%)
F0	01:00:00	100	0	0
F1	35:15:01	68,63	29,41	1,96
F2	01:01:00	50	50	0
F3	25:25:01	49,02	49,02	1,96
F4	25:25:02	48,08	48,08	3,84
F5	15:35:01	29,41	68,63	1,96

Table 3. Yield of pullulan based on RSM matrix

HSP, %w/v	pH Media	Yeast Extract, %w/v	Pullulan content, % w/w
70	6,5	3	48,1
110	6,5	3	53,8
70	8,5	3	49,3
110	8,5	3	51,1
70	7,5	1	46,1
110	7,5	1	55,4
70	7,5	5	45,7
110	7,5	5	50,3
90	6,5	1	53,6
90	8,5	1	52,3
90	6,5	5	50,4
90	8,5	5	51,8
90	7,5	3	52,4
90	7,5	3	52,5
90	7,5	3	52,7

Table 4. Mechanical properties of film

Sample code	Stress at break, Mpa	Strain at break, %
F0	6,1	9,5
F1	11,3	21,3
F2	8,5	18,2
F3	15,1	30,6
F4	13,8	25,2
F5	11,2	20,9



Picture 5. FE-SEM images for film nanocomposite: F4 (left) and F3 (right)

The mechanical properties of the films were strongly influenced by the proportions of pullulan, chitosan, and bacterial nanocellulose (BNC). The pullulan control, F0, showed the lowest stress at break and strain at break, at 6.1 MPa and 9.5%, respectively. Incorporating chitosan and BNC generally improved both the strength and flexibility of the films. F3 exhibited the best mechanical performance, reaching a stress at break of 15.1 MPa and a strain at break of 30.6%. Compared with F2, F3 showed approximately 78% greater strength and 68% greater elongation.

Conclusion

Damaged Cilembu sweet potato provides a sugar-containing feedstock for pullulan production. Sucrose represented 80.11% of the quantified sugars. The pullulan yield reached 55.4% under: HSP concentration of 110 g/L, pH 7.5, and yeast extract concentration of 1 g/L. Based on the mechanical-property data, the improved film strength indicates that a moderate BNC concentration facilitated effective stress transfer while maintaining sufficient polymer-chain mobility.