Integrated Fermentation and Supercritical CO_2 Extraction for Lipid Recovery from Spent Coffee Grounds

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Abstract

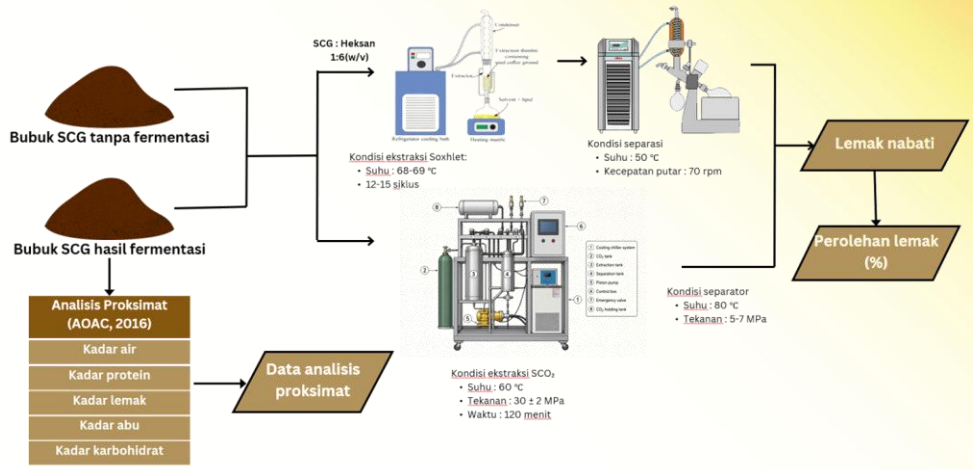
This study presents an eco-friendly approach to valorizing spent coffee grounds (SCG) by combining Fusarium subglutinans fermentation with supercritical carbon dioxide (SCO2) extraction to enhance vegetable fat recovery. Submerged fermentation (36 hours, 25 °C, pH 4.85, 0.26 vvm) effectively disrupted the SCG matrix, increasing the fat yield by 79.5% (from 9.96% to 17.9% w/w). Subsequent SCO_2 extraction (120 min; 60 °C and 30 MPa) achieved a 59.4% recovery ratio while completely eliminating the need for toxic solvents and lengthy separation steps. The extracted lipids demonstrated superior quality for potential biochemical and energetic applications, featuring a higher heating value (HHV) of 41.37 MJ/kg and an antioxidant inhibition capacity of 79.86%. These findings confirm that integrating fungal pre-treatment with SCO_2 extraction provides a highly efficient, sustainable alternative to conventional Soxhlet methods for high-value lipid recovery.

Keywords: Spent coffee grounds (SCG), Fusarium subglutinans, fermentation, SCO_2 extraction

Introduction

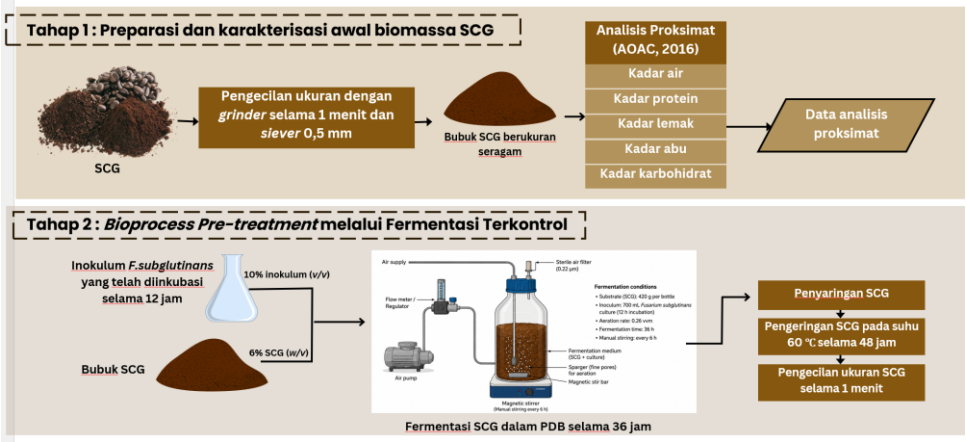
The rapid growth of the instant coffee industry generates abundant spent coffee ground (SCG) waste containing 10-20% valuable lipids trapped within a complex lignocellulosic matrix. To overcome the inefficiency of conventional extraction methods, submerged fermentation with Fusarium subglutinans is used as a pre-treatment to produce hydrolytic enzymes that degrade this structural barrier. This enzymatic breakdown facilitates highly efficient lipid recovery using supercritical carbon dioxide (SCO2) extraction, which selectively isolates the lipids without leaving harmful solvent residues. By evaluating the extracted lipids for density, higher heating value, and inhibition capacity, this integrated approach successfully converts organic SCG waste into high-quality, renewable resources that support a circular economy.

Research Method



Picture 1. Research flowchart and equipment set-up

The methodology began with the preparation of spent coffee grounds (SCG), which were ground, sieved to a uniform 0.5 mm size, and dried at 60 °C to maximize surface area for solvent accessibility. Concurrently, a Fusarium subglutinans inoculum was cultured and incubated in broth for 12 hours before being used to inoculate the SCG for a 36-hour aerated fermentation process. Throughout this fermentation period, the system was actively monitored for pH, cell density, and starch concentration. Following fermentation, the biomass was filtered, dried, and subjected to proximate analysis—alongside unfermented SCG—to determine moisture, protein, lipid, ash, and carbohydrate contents. The fermented biomass then underwent supercritical carbon dioxide (SCO2) extraction at 60 °C and 30 MPa for 120 minutes to isolate the lipids. These extracted lipids were subsequently characterized by evaluating their density, antioxidant capacity via the DPPH method, Higher Heating Value using a bomb calorimeter, and fatty acid composition via GC-FID. Finally, the experimental data were statistically evaluated using a Two-Way ANOVA and Tukey's post hoc test.



Discussion & Result

	Main finding
1	79.5% increase in lipid yield after fungal fermentation
2	Reduction in carbohydrate and increase in lipid content
3	59.4% lipid recovery using SCO_2 compared with Soxhlet
4	Improved DPPH inhibition capacity (72.0% to 79.9%)
5	52.2% unsaturated fatty acids

Conclusion

This study demonstrated that fermentation of spent coffee grounds (SCG) using Fusarium subglutinans increased the lipid yield obtained through supercritical CO_2 (SCO_2) extraction from 9.96% to 17.9% (w/w), representing a 79.5% improvement. Although Soxhlet extraction produced a significantly higher lipid yield ($p < 0.05$), SCO_2 achieved a lipid recovery of 59.4% compared to Soxhlet extraction, with the advantages of shorter extraction time and no need for additional solvent separation.Fermentation also improved lipid quality, increasing the higher heating value (HHV) from 41 to 41.37 MJ/kg and the inhibition capacity from 72.01% to 79.86%. Meanwhile, lipid density slightly decreased from 917.5 to 914.5 kg/m³.Further improvements could be achieved by removing lignin before fermentation to enhance enzymatic degradation of cellulose and hemicellulose. In addition, further extraction experiments with at least three replicates are recommended to improve the reliability of the lipid yield results obtained using SCO_2 extraction.