# RINGKASAN

Tingginya tingkat persaingan di pasar kopi global mendorong produsen untuk menghasilkan produk yang tidak hanya memiliki karakteristik unik, tetapi juga memenuhi standar mutu tinggi dan prinsip keberlanjutan. Salah satu pendekatan yang mulai banyak diterapkan dalam rangka peningkatan kualitas sensori adalah fermentasi terkontrol menggunakan kultur *starter*, yang terbukti mampu mengoptimalkan pembentukan senyawa volatil yang berkontribusi terhadap aroma dan cita rasa kopi. Mengingat bahwa proses fermentasi dapat memodifikasi sifat fisik dan kimia biji kopi, maka diperlukan suatu metode analisis yang efisien, cepat, serta aplikatif untuk memantau perubahan mutu yang terjadi selama proses tersebut. Penelitian ini bertujuan untuk 1) menganalisis kualitas fisik biji kopi robusta terfermentasi, menggunakan metode *image processing*, 2) mengembangkan model *machine learning* untuk mengklasifikasikan biji kopi fermentasi berdasarkan karakteristik biji kopi, 3) menentukan model *machine learning* terbaik untuk mengklasifikasi biji kopi robusta fermentasi.

Penelitian dilaksanakan di Pusat Riset Teknologi Tepat Guna Badan Riset dan Inovasi Nasional, Kabupaten Subang, Jawa Barat. Penelitian dilakukan pada bulan Oktober 2024 sampai Februari 2025. Fermentasi dilakukan menggunakan percobaan dua faktor, meliputi waktu fermentasi (T) dan jenis media fermentasi (F). Variabel yang digunakan pada penelitian ini terdiri dari 13 parameter yaitu *area, major axis, minor axis, perimeter, circularity, energy, contrast, entropy, homogeneity, correlation, red, green, blue*. Varibael tersebut diperoleh menggunakan metode *image processing*. Analisis data menggunakan metode statistik Kruskal Wallis untuk mengetahui pengaruh perlakuan dan menggunakan 3 model *machine learning* yaitu *support vector machine* (SVM), *random forest* (RF), dan *k-nearest neighbor* (KNN) untuk mengklasifikasikan kualitas biji kopi.

Hasil penelitian menunjukkan perubahan fisik biji kopi fermentasi yang signifikan antar perlakuan dan waktu. Semua model berhasil mengklasifikasikan sampel berdasarkan perlakuan. Model SVM secara konsisten menunjukan performa terbaik dengan nilai akurasi mencapai 80,9 % (24 jam); 88,7 % (48 jam); dan 78,0 % (72 jam). RF menempati posisi kedua dengan akurasi 79,9 % (24 jam); 87,4 % (48 jam); dan 74,9 % (72 jam). Sedangkan KNN memiliki performa terendah dengan nilai akurasi 66,2 % (24 jam); 75,9 % (48 jam); dan 64,4 % (72 jam). Temuan ini menegaskan bahwa SVM lebih efektif dalam mengenali pola fitur citra biji kopi meski karakteristik fisik berubah seiring lamanya fermentasi.

## *SUMMARY*

*The intensifying competition in the global coffee market compels producers to deliver products that are not only characterized by unique attributes but also meet high-quality standards and adhere to principles of sustainability. One of the emerging approaches aimed at enhancing sensory quality is controlled fermentation using starter cultures, which has been shown to effectively optimize the formation of volatile compounds that contribute to coffee's aroma and flavor profile. Considering that the fermentation process can alter the physical and chemical properties of coffee beans, there is a need for an analytical method that is efficient, rapid, and practical to monitor the quality changes occurring during fermentation. Accordingly, this study aims to: (1) analyze the physical quality of fermented robusta coffee beans using image processing techniques, (2) develop machine learning models to classify fermented coffee beans based on their physical characteristics, and (3) determine the most accurate machine learning model for classifying fermented robusta coffee beans.*

*The research was conducted at the Center for Appropriate Technology Research, National Research and Innovation Agency (BRIN), Subang District, West Java, Indonesia, from October 2024 to February 2025. Fermentation was designed using a two-factor experiment, involving fermentation time (T) and type of fermentation media (F). The variables examined in this study comprised 13 image parameters: area, major axis, minor axis, perimeter, circularity, energy, contrast, entropy, homogeneity, correlation, red, green, and blue. These parameters were derived through image processing techniques. The data analysis employed the Kruskal-Wallis statistical method to assess treatment effects, alongside three machine learning algorithms, namely are support vector machine (SVM), random forest (RF), and k-nearest neighbor (KNN), to classify coffee bean quality.*

*The results of the study showed that the physical characteristics of fermented coffee beans differed significantly across treatments and fermentation durations. All models successfully classified the samples according to the treatments. The SVM model consistently demonstrated the best performance, with accuracy values of 80.9% (24 hours); 88.7% (48 hours); and 78.0% (72 hours). RF model ranked second, with accuracy values of 79.9% (24 hours); 87.4% (48 hours); and 74.9% (72 hours). Meanwhile, KNN model showed the lowest performance, with accuracy scores of 66.2% (24 hours); 75.9% (48 hours); and 64.4% (72 hours). These findings confirm that SVM is more effective in recognizing feature patterns in coffee bean images, even as their physical characteristics change over the course of fermentation.*