

## ENHANCING COFFEE AROMAS AND FLAVOR: FERMENTING WITH *LACTOBACILLUS PLANTARUM* FOR AN IMPROVED COFFEE BREW

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### ABSTRACT

Civet coffee (Kopi Luwak) is renowned for its unique flavor and aroma profile, which are attributed to enzymatic and microbial transformations occurring during digestion in the civets' gastrointestinal tracts. However, ethical concerns, sustainability issues, and inconsistent quality due to uncontrolled animal digestion pose significant drawbacks to its production. Given these disadvantages, this research aims to develop a specialty coffee that replicates the unique characteristics of civet coffee without involving animal exploitation and ethical concerns. As part of the study, several bacterial strains were isolated from civets' feces transported from Dak Lak, Vietnam. After identification and biochemical testing, they were assumed to belong to *Lactobacillus plantarum*, a species of lactic acid bacteria commonly found in various fermented foods, including dairy products, pickles, and sourdough. Depulped coffee cherries were then fermented with those bacterial strains as starter cultures in optimized conditions. Following fermentation, the chemical composition of the coffee bean was analyzed using gas chromatography-mass spectrometry (GC-MS). The results indicated the changes in the chemical compound profile and flavors, highlighting differences between the original and fermented coffee beans. These findings suggest that microbial fermentation could serve as a viable alternative to traditional civet coffee production, offering a more ethical and sustainable approach while maintaining desirable flavor characteristics.

**Keywords:** Specialty coffee, Kopi Luwak, *Lactobacillus plantarum*, microbial fermentation, coffee fermentation, biochemical transformation.

### 1. INTRODUCTION

Coffee is among the most economically valuable agricultural commodities globally and is widely consumed not only for its caffeine content but also for its distinctive aroma and flavor, which play a central role in consumer appeal [1, 2]. Among specialty coffees, civet coffee (also known as Kopi Luwak) is regarded one of the rarest and most expensive coffees in the world due to its unique flavor, which is believed to be enhanced through the digestive

process of the Asian palm civet (*Paradoxurus hermaphroditus*). The biochemical reactions occurring during digestion, including the breakdown of proteins and lipids by digestive enzymes, are thought to be responsible for creating the distinct flavor of civet coffee compared to conventional coffees [3]. However, traditional civet coffee production presents numerous challenges such as high cost, difficulty in quality control, food safety concerns, and ethical issues related to animal welfare due to the captivity and exploitation of civets. Forced feeding and confinement raise serious ethical concerns, while also potentially impacting consumer health and the sustainability of food systems [1]. Furthermore, natural digestion is difficult to control and lacks consistency, posing challenges to product standardization and limiting scalability for industrial applications. To address these limitations, recent studies have focused on developing microbial fermentation techniques to simulate the natural digestion process and improve the sensory attributes of coffee while overcoming the drawbacks of traditional production [4]. Among these, lactic acid bacteria (LAB), particularly *Lactobacillus plantarum*, have demonstrated potential in enhancing the aroma and flavor of coffee during fermentation. *L. plantarum* is a well-characterized strain commonly found in various fermented foods such as yogurt, pickles, and sourdough bread, and has been recognized as safe for consumption [2, 5]. *L. plantarum* secretes multiple extracellular enzymes, including protease, esterase, and  $\beta$ -glucosidase, which facilitate the breakdown of proteins and other compounds, contributing to flavor development in fermented foods[6-8]. Importantly, *L. plantarum* strains isolated from the digestive tract of wild animals have received increasing attention for their potential to mimic natural digestive environments, thereby enhancing the efficiency and sensory quality of fermented coffee products. These findings suggest the feasibility of developing a microbial fermentation model using *L. plantarum* as a substitute for animal digestion in the production of civet-like coffee with improved reproducibility and ethical viability [5].

In this study, we conducted the isolation and identification of *Lactobacillus plantarum* strains from civet feces collected in the Dak Lak region of Vietnam. These isolated strains were then preliminarily selected for use in the fermentation of de-pulped Robusta coffee beans. The main objective of this study was to evaluate the impact of fermentation using these bacterial strains on coffee bean composition, microstructure, and sensory properties. This approach aims to contribute to the production of civet-like coffee that is efficient, sustainable, and independent of animal exploitation, aligning with current trends in industrial biotechnology and food ethics.

## 2. MATERIALS AND METHODS

### 2.1. Sample collection and conditioning

Civet feces samples were collected from a garden in Dak Lak province, Vietnam. The samples were placed in sterile, clean plastic bags immediately after collection and transported to the laboratory under refrigerated conditions (at 7 °C) within 10 hours to ensure microbial viability.

### 2.2. Bacteria isolation

Approximately 3.00 g of the civet feces sample was aseptically transferred into a sterile tube containing 10.0 mL of 0.9% (w/v) sterilized saline solution. The mixture was homogenized by vortexing for 1 minute. Serial decimal dilutions ( $10^{-1}$  to  $10^{-9}$ ) were prepared by transferring 1.0 mL of the homogenate into 9.0 mL of sterile saline solution in successive sterile Eppendorf tubes. Subsequently, 100  $\mu$ l of each dilution plated onto sterilized MRS agar plates (De Man, Rogosa and Sharpe; Oxoid CM0361B) supplemented with  $\text{CaCO}_3$  using a

sterile spreader [9]. The inoculated plates were incubated at 37 °C for 48 hours. Colonies forming clear zones around them, indicative of CaCO<sub>3</sub> dissolution, were considered potential organic acid-producing strains. After incubation, pure cultures were maintained under refrigerated conditions (7 °C). In this way a stock of presumably lactic bacteria colonies were obtained for being used in subsequent analyses.

### **2.3. Bacterial identification**

#### *2.3.1. Morphological evaluation, Gram stain and catalase activity*

Prior to the genotyping, bacteria isolates were phenotyped. Initial phenotyping was based upon colony and cell morphology, cell motility, Gram stain, catalase reactions after growth on MRS agar for 48 h.

#### *2.3.2. Molecular identification*

The selected isolate was identified using a molecular technique based on 16s rDNA sequences. Genomic DNA was extracted using a standard isoamyl alcohol–chloroform protocol. The 16S rRNA gene was amplified using universal primers (e.g., 27F and 1492R) via PCR. PCR products were confirmed through gel electrophoresis and subsequently purified for sequencing. The obtained 16S rRNA gene sequences were aligned and compared against the NCBI GenBank database using the BLAST tool to determine the closest phylogenetic relatives and to identify bacterial species.

### **2.4. Robusta coffee fermentation and roasting methods**

Robusta coffee cherries harvested from Dak Lak were sorted to remove damaged or defective fruits, then classified by ripeness (ripe, underripe, overripe, etc.). The cherries were thoroughly washed with clean water and allowed to drain before being pulped. The pulping process separated the beans from the fruit using a mechanical pulper, after which only the beans were used for fermentation. A total of 600 grams of Robusta coffee beans were fermented with 10<sup>7</sup> CFU/mL of *Lactobacillus plantarum* per strain in a 3.5 L fermenter for 72 hours under environmental temperature. The bacterial cultures were prepared in MRS medium with a ratio of 1:2 (v/w). For every 1 kg of coffee beans, 500 mL of MRS medium was used [10]. In addition, two control samples were included: the Water sample (coffee beans supplemented with sterile water only, without bacteria) and the MRS sample (coffee beans supplemented with sterile MRS medium only, without bacteria). After fermentation, the coffee beans were washed and subjected to a four-stage drying process as follows: Stage 1 lasted for 4 hours at 45 °C, stage 2 lasted for 2 hours at 65 °C, stage 3 lasted for 5 hours at 40°C. The drying process continued until the moisture content of the beans decreased to below 13%.

The dried beans were then hulled to remove the parchment layer. The resulting green coffee beans were dark roasted and ground into powder for further analysis.

### **2.5. Moisture and ash content determination**

Moisture was determined according to TCVN no. 7035:2002 [11]. Five grams of samples were weighed in porcelain capsules for each repetition. For 2 h, all samples were heated in an air circulation oven at 103 °C and after this period, the samples were cooled in a desiccator at room temperature, weighed constantly until a constant weight was reached.

The ash was determined using TCVN no. 5253:1990 [12]. Approximately five grams of the coffee sample were accurately weighed into a pre-weighed porcelain crucible. The sample was evenly spread over the bottom of the crucible and gently heated on an electric stove until complete combustion was visually observed. Subsequently, the crucible was transferred to a muffle furnace and ashed at a temperature between 550°C and 600°C for 2 hours and 30 minutes, until the sample was fully ashed, indicated by a white, light gray, or gray residue. After ashing, the crucible was cooled in a desiccator for approximately 40 minutes to room temperature and then weighed.

## **2.6. Analysis of chemical compounds**

### *2.6.1. Sample preparation*

Chemical compounds in coffee were extracted using solvent extraction method. The extraction solvent was prepared by mixing acetonitrile and toluene at a volume ratio of 3:1. For each sample, approximately 0.5 grams of ground roasted coffee were weighed and added to 4.5 mL of deionized water in a 50 mL falcon tube. The mixture was vortexed for 1 minute to ensure uniform dispersion. Subsequently, 5 mL of the prepared extraction solvent was added to the tube. The sample was vortexed again for 1 minute and then centrifuged at 3500 rpm for 5 minutes. After centrifugation, 5 grams of a drying salt mixture (MgSO<sub>4</sub>:NaCl in a 4:1 w/w ratio) were added to the supernatant to facilitate water removal. The tube was centrifuged again under the same conditions. The supernatant was collected and filtered through a 0.22 µm syringe filter. The filtrate was transferred into a 1.5 mL GC vial for subsequent gas chromatography–mass spectrometry (GC-MS) analysis. A blank sample was prepared using the same procedure, the coffee with deionized water. In total, six coffee samples were prepared and labeled numerically from 1 to 6. An additional blank sample, labeled as sample 0, was included as a control.

### *2.6.2. Analysis of chemical compounds using Gas Chromatography-Mass Spectrometry (GC-MS)*

GC-MS analysis was performed using a PerkinElmer Elite-5MS column (30 m × 250 µm × 0.25 µm). Helium was used as the carrier gas at a constant flow rate of 1.2 mL/min under splitless injection mode, with a splitless time of 1.5 minutes. The oven temperature was programmed to rise from the initial temperature to 250 °C at a rate of 11°C/min, held for 10 minutes, then increased to 300 °C at 5 °C/min and held for an additional 8 minutes. Data acquisition was conducted in SCAN mode over a mass range of 50–500 m/z. The identification of chemical compounds was based on the comparison of their mass spectra with those in the NIST 20 library. All analyses were performed in triplicate.

## **3. RESULT AND DISCUSSION**

### **3.1. Isolation of lactic bacteria, morphology, Gram stain and catalase activity**

From the civet feces samples, three bacterial strains were isolated, all forming circular colonies with an opaque white or ivory-white appearance and slightly convex surfaces. Morphological, physiological, and biochemical characteristics of the bacteria were determined by assessing key characteristics including Gram staining, catalase testing, and motility evaluation. The results showed that all isolated strains were Gram-positive, non-motile, and catalase-negative (data not shown) [13].

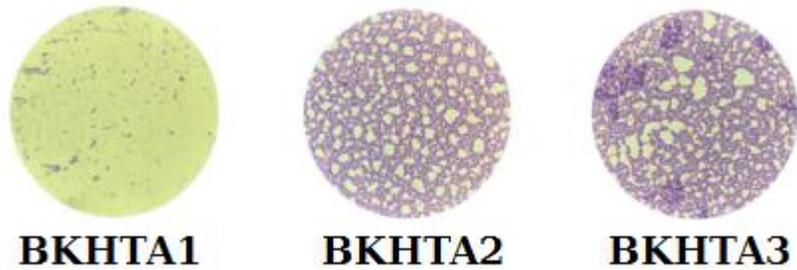


Figure 1. Gram stain of bacteria isolated from the civet feces in MRS broth, focus at 1000x magnification

### 3.2. Molecular identification

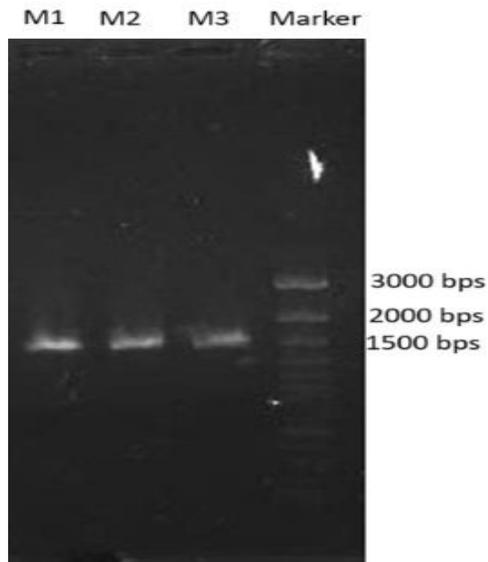


Figure 2. Gel electrophoresis of 16S rRNA gene PCR products from isolated lactic acid bacterial strains. M1, M2 and M3 are bands of BKHTA 1, BKHTA 2, and BKHTA 3 respectively.

Distinct DNA bands are observed in all tested samples, with estimated product sizes of approximately 1,500 base pairs, which is consistent with the expected size of the full-length 16S rRNA gene. The absence of smearing or multiple bands indicates that the amplification was specific, and the DNA samples were not degraded and contaminated. These high-quality PCR products were subsequently used for 16S rRNA sequencing and bacterial identification via BLAST search against the NCBI database. Regarding lactic bacteria, *Lactobacillus plantarum* BKHTA 1, *Lactobacillus plantarum* BKHTA 2 and *Lactobacillus plantarum* BKHTA 3 were detected in the feces samples. Lactic bacteria are responsible for the pH decrease and the production of flavor-active esters which improved the sensory quality of the coffee [14]. In Figure 3, the three studied strains, labeled BKHTA 1, BKHTA 2, and BKHTA 3, cluster together with reference strains of *Lactobacillus plantarum*, including sequences LC547211.1, LC547222.1, and LC546826.1. This suggests that the BKHTA strains are genetically close to *L. plantarum*, and may belong to the same species or at least a closely related taxon.



Figure 3. Phylogenetic tree based on 16S RNA gene sequences from *Lactobacillus* genus. The tree was constructed using the Maximum Likelihood method in MEGA11

### 3.3. Moisture and ash content determination

Moisture content is a critical factor in evaluating the quality and stability of coffee products. It is determined based on the weight loss of the sample during drying, which may result from the evaporation of water or the volatilization of compounds such as carbon dioxide and volatile acids. A higher moisture content generally indicates a lower concentration of nutritional components in coffee, and vice versa. Accurate determination of moisture content is essential not only for quality assessment but also for establishing optimal storage conditions to prevent spoilage and extend shelf life.

Total ash content in coffee mainly consists of minerals and metal elements. According to the Vietnamese National Standard (TCVN 5253:1990), the total ash content in ground coffee must be less than 5%.

Table 1. The moisture and total ash contents of samples

Samples	Moisture (%)	Total ash (%)
BKHTA 1	2.13	4.21
BKHTA 2	1.71	4
BKHTA 3	2.37	3.97
Water	1.68	3.62
MRS	1.61	3.01

Moisture content ranged from 1.61% to 2.37%, with the lowest observed in the sample tested in MRS (1.61%) and the highest in the sample fermented with BKHTA 3 (2.37%). All values were well below the maximum limit of 5% as specified by the Vietnamese National Standard (TCVN), indicating proper drying and good preservation potential. Total ash content

ranged from 3.01% to 4.21%. The highest ash content was recorded in the sample treated with BKHTA 1 (4.21%), while the lowest was found in the sample MRS (3.01%). These values reflect the presence of mineral components and remain within acceptable limits for ground coffee. The variation in moisture and ash content suggests that different LAB strains and fermentation environments influence the chemical composition of the final coffee product. Among the strains, sample BKHTA2 showed a favorable balance of low moisture (1.71%) and acceptable ash content (4.00%), making it a promising candidate for further development. This balance is crucial, as appropriate moisture ensures product stability and flavor retention, while total ash content reflects purity and mineral composition, both of which are key indicators of coffee quality.

### 3.4. Analysis of chemical compounds

*Table 2.* List of chemical compounds identified by GC-MS method in coffee samples fermented with three different lactic acid bacterial strains (BKHTA 1, BKHTA 2, BKHTA 3), nonfermented control, and additional reference samples (MRS medium and water)

No.	Compound	Group	BKHTA 1	BKHTA 2	BKHTA 3	Nonfermented	Water	MRS
1	2,5-Dimethylfuran-3,4(2H,5H)-dione	Furans			x			
2	2,5-Furandione, dihydro-3-methylene-	Furans		x				
3	Furaneol	Furans		x				
4	(R)-6-Methoxy-2,8-dimethyl-2-((4R,8R)-4,8,12-trimethyltridecyl)chroman	Methoxy compounds	x					
5	Phenol, 3-methyl-	Phenolics			x			
6	Hexadecanoic acid, methyl ester	Phenolics						x
7	11,14-Eicosadienoic acid	Phenolics				x		
8	2-Butenedioic acid, dibutyl ester	Phenolics					x	
9	Hexadecanoic acid, ethyl ester	Phenolics						x
10	4-Oxo-5-methoxycarbonylthio-3-thiopentanoic acid, methyl ester	Phenolics				x		
11	l-(+)-Ascorbic acid 2,6-dihexadecanoate	Phenolics				x		
12	trans-9-Octadecenoic acid, pentyl ester	Phenolics				x		
13	Octadecanoic acid, 2-(2-hydroxyethoxy)ethyl ester	Phenolics				x		
14	2-Isoamylpyrazine	Pyrazines			x			
15	n-Pentylpyrazine	Pyrazines		x				
16	Pyrazine, 2-ethyl-5-methyl-	Pyrazines					x	
17	Pyrazine, 2-ethyl-6-methyl-	Pyrazines				x		
18	Pyrazine, 2,3-dimethyl-	Pyrazines				x		
19	Pyrazine, 2-ethyl-3-methyl-	Pyrazines				x		
20	4(H)-Pyridine, N-acetyl-	Pyridines				x		
21	Pyrrole, 4-ethyl-2-methyl-	Pyrroles				x		
22	1,2-Cyclopentanedione, 3-methyl-	Others					x	
23	7,9-Di-tert-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione	Others					x	
24	Mequinol	Phenolics				x		

25	Trimethylaluminum	Others	x					
26	2-Pyrrolidinone	Lactams		x				
27	Diazene, bis(1,1-dimethylethyl)-	Others				x		
28	Isoxazole-4-carbonitrile, 5-amino-3-methyl-	Others					x	
29	Orcinol, 2TMS derivative	Phenolics				x		
30	Ethyl p-hydroxybenzoate	Esters				x		
31	p-Cresol	Phenolics					x	
32	Propane, 2-bromo-2-methyl-	Others					x	
33	Ergosta-5,24(28)-dien-3-ol, (3.beta.)-	Sterols						x
34	2-Phenylpyrido[3,4-d]-1,3-oxazin-4-one	Others				x		
35	Henicosanal	Aldehydes				x		
36	Isopropyl tetradecyl ether	Ethers				x		
37	1H-Pyrrole-2-carboxaldehyde, 1-methyl-	Aldehydes		x	x	x		
38	Phenol, 4-ethenyl-2,6-dimethoxy-	Phenolics		x	x	x		
39	2-Butenedioic acid (Z)-, dibutyl ester	Phenolics			x	x		
40	3,4-Dimethoxycinnamic acid	Phenolics	x		x			x
41	Benzeneacetic acid	Phenolics		x	x			
42	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	Phenolics				x		x
43	Hexahydro-3-(1-methylpropyl)pyrrolo[1,2-a]pyrazine-1,4-dione	Pyrazines			x		x	x
44	13-Docosenamide, (Z)-	Others		x	x			x
45	Pregna-3,5-dien-20-one	Others			x	x	x	
46	2-Cyclopenten-1-one, 3-ethyl-2-hydroxy-	Others	x					x
47	5-Hydroxymethylfurfural	Furans		x	x	x		
48	Ethanone, 1-(2,5-dihydroxyphenyl)-	Others					x	x
49	1,2-Cyclopentanedione	Others	x			x		
50	N-Methyl-3-formyl-2(1H)-pyridone	Others	x				x	
51	Resorcinol, 2-acetyl-	Others	x	x	x			
52	Piracetam	Others			x			x
53	Cyclo(L-prolyl-L-valine)	Peptides		x	x		x	
54	Butyl 9,12-octadecadienoate	Esters			x	x		x
55	5-Pregnen-3.beta.-ol-20-one, formate	Steroids					x	x
56	Indole	Others		x		x		

The symbol “x” indicates the presence of a compound in the sample. The group classification column organizes the detected compounds into functional chemical categories, including phenolics, pyrazines, furans, aldehydes, alcohols, esters, and unclassified structures. This comprehensive dataset serves as the foundation for comparative aroma profiling and fermentation-driven metabolic differentiation among treatments.

A total of 56 chemical compounds were detected in the analyzed coffee samples, distributed across the following chemical groups: alcohol, aldehydes, ester, furans, lactone,

methoxy compound, phenolic compounds, pyrazines, pyridine, pyrrole, sterols, steroids, peptides, triterpenes, and other compounds. Among the fermentation treatments, the coffee sample fermented with BKHTA 1 strain contained 7 compounds, BKHTA 2 exhibited 12 compounds, and BKHTA 3 showed 16 compounds. In comparison, the nonfermented coffee sample contained 26 compounds, while the MRS medium sample and the water-fermented sample contained 11 and 14 compounds, respectively.

Interestingly, two compounds, (R)-6-methoxy-2,8-dimethyl-2-((4R,8R)-4,8,12-trimethyltridecyl)chroman and trimethylaluminum, were detected exclusively in the coffee sample fermented with the BKHTA 1 strain. However, no published literature was found reporting their contribution to coffee flavor or aroma.

In the sample fermented with BKHTA 2, four unique compounds were identified: 2,5-furandione, dihydro-3-methylene-, furaneol, n-pentylpyrazine, and 2-pyrrolidinone. Furaneol, a member of the furanone group, is known to contribute sweet, caramel-like, and fruity aromas to food and beverages [15]. n-Pentylpyrazine, a pyrazine derivative, contributes to the roasted and nutty aroma characteristic of coffee [16]. The BKHTA 3 fermented coffee uniquely contained 2,5-dimethylfuran-3,4(2H,5H)-dione, phenol, 3-methyl-, and 2-isoamylpyrazine. The furanone compound 2,5-dimethylfuran-3,4(2H,5H)-dione contributes sweet and caramel-like notes associated with toasted or baked aromas, as described in studies on Maillard reaction products in coffee (). Phenol, 3-methyl-, a phenolic compound formed from the degradation of chlorogenic acids during roasting, imparts smoky, medicinal, and earthy characteristics commonly found in dark-roasted coffee [17]. Meanwhile, 2-isoamylpyrazine, an alkylpyrazine, is a key odorant in roasted coffee that delivers distinctive nutty and roasted notes [18].

#### 4. CONCLUSION

The results demonstrate that microbial fermentation, particularly with specific lactic acid bacteria strains, significantly affects the formation of chemical compounds in Robusta coffee. Compared to non-fermented and traditionally roasted samples, the fermented coffee showed a strain-specific profile of aroma-active compounds. In particular, each BKHTA strain led to the formation of distinct compounds, which were not found in other samples. For example, BKHTA 2 produced furaneol and n-pentylpyrazine, which contribute sweet, caramel, and nutty notes to the coffee flavor. BKHTA 3 generated 2,5-dimethylfuran-3,4(2H,5H)-dione and 2-isoamylpyrazine, both associated with roasted and nutty characteristics. These findings highlight the potential of microbial fermentation to modify coffee aroma and flavor in a targeted manner, based on the selected bacteria strains. The DNA gel electrophoresis and 16S rRNA sequencing confirmed the identity and purity of the bacterial strains used for fermentation, ensuring that the observed biochemical changes can be attributed to known microbial species. The consistent band size (~1500 bp) and absence of contamination increase the genetic reliability of the isolates.

Overall, the study supports that fermentation using characterized LAB strains is an effective strategy to diversify and enhance coffee flavor and aroma. Through modulation of both aromatic and non-volatile compounds, this process paves a new way for specialty coffee production with distinctive and strain-driven sensory characteristics.

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## TÓM TẮT

### TĂNG CƯỜNG HƯƠNG VỊ CÀ PHÊ BẰNG PHƯƠNG PHÁP LÊN MEN CÀ PHÊ VỚI *LACTOBACILLUS PLANTARUM*

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Cà phê chồn (Kopi luwak) nổi tiếng nhờ hương vị và mùi thơm đặc trưng, được cho là bắt nguồn từ các quá trình biến đổi enzym và vi sinh diễn ra trong hệ tiêu hóa của loài chồn. Tuy nhiên, việc sản xuất loại cà phê này đang đối mặt với nhiều vấn đề như lo ngại về đạo đức, tính bền vững và chất lượng không đồng đều do quá trình tiêu hóa ở động vật không thể kiểm soát. Trước những hạn chế nêu trên, nghiên cứu này hướng đến việc phát triển một loại cà phê đặc sản có thể tái tạo các đặc điểm đặc trưng của cà phê chồn mà không liên quan đến việc khai thác động vật, từ đó loại bỏ các vấn đề đạo đức. Trong khuôn khổ nghiên cứu, một số chủng vi khuẩn đã được phân lập từ phân chồn được vận chuyển từ Đắk Lắk, Việt Nam. Sau quá trình định danh và thử nghiệm sinh hóa, các chủng này được xác định là thuộc loài *Lactobacillus plantarum* – một loại vi khuẩn lactic thường xuất hiện trong nhiều loại thực phẩm lên men như sữa, dưa muối và bánh mì chua. Quả cà phê đã được loại bỏ vỏ (depulped coffee cherries) sau đó được lên men bằng các chủng vi khuẩn này trong điều kiện tối ưu. Sau quá trình lên men, thành phần hóa học của hạt cà phê được phân tích bằng phương pháp sắc ký khí khối phổ (GC-MS). Kết quả cho thấy sự thay đổi trong hồ sơ hợp chất hóa học và hương vị, phản ánh sự khác biệt giữa hạt cà phê nguyên bản và hạt cà phê sau lên men. Những phát hiện này cho thấy quá trình lên men bằng vi sinh vật có thể là một phương pháp thay thế khả thi cho quy trình sản xuất cà phê chồn truyền thống, mang lại giải pháp bền vững và nhân đạo hơn, đồng thời vẫn duy trì được các đặc tính cảm quan mong muốn.

*Từ khóa:* Cà phê đặc sản, Cà phê chồn (Kopi Luwak), *Lactobacillus plantarum*, lên men vi sinh vật, lên men cà phê, biến đổi sinh hóa.