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Study of decaffeination and business risk feasibility: Arabica and Robusta Arjuno coffee beans by anaerobic fermentation using *Rhizopus oligosporus*

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Abstract

Indonesia is the fourth largest coffee producer in the world. However, coffee is generally sold in its original form, even though the diversification products of coffee, such as decaffeinated coffee, have a higher selling price. One of the coffee-producing areas in Indonesia is Malang-East Java which has superior coffee commodities and does not yet have diversified products, such as Arjuno coffee (Arabica and Robusta) originating from the Mount Arjuno area. In this work, the decaffeination of Arabica and Robusta Arjuno coffee was conducted through anaerobic fermentation by *Rhizopus oligosporus*. An analysis of the business feasibility and production risk was also carried out. The results showed that caffeine content in the coffee significantly decreased with fermentation time. The caffeine content in Arabica and Robusta Arjuno coffee beans after 72 hrs of fermentation declined by 19.9% and 57.8% to 2.3% and 1.7%, respectively. Fermentation did not significantly change the physical of the beans but enriched the taste of coffee, where the flavor was strongly affected by the fermentation time. The analysis of the business feasibility and production risk showed that the decaffeinated Arabica and Robusta Arjuno coffee business provides a profit seven times higher than the existing coffee business.

1. Introduction

Coffee is one of the most popular beverages globally, prized for its aroma and caffeine content. Indonesia is the fourth largest producer in the world (International Coffee Organization, 2023). Coffee production in Indonesia reached 741.61 thousand tons in 2019. East Java has the highest coffee production rate, around 11.7% of Indonesia's total production. Among the regions in East Java, Malang became the highest coffee-producing region, with a total production of 11,429 tons in 2016 which increased by 3.5% in 2018 (Badan Pusat Statistik (BPS) Malang, 2019). One of Malang's superior coffees is Arjuno coffee which originates from the Arjuno Mountain area. The most common variety in this area is Arabica coffee, while the rest are Robusta coffee (Wijayani *et al*., 2021). Compared to Robusta coffee, Arabica coffee is relatively more expensive due to it is more difficult to cultivate. During the years 2018-2021, the price of Robusta coffee is relatively stable, while Arabica coffee tends to rise (Supriyati, 2021). The organoleptic character of Robusta coffee is considered lower than Arabica coffee (Galanakis, 2017).

Several works have shown the positive effects of drinking coffee regularly on various aspects of health, such as psychoactive responses, neurological, metabolism, and liver function. Several studies in Japan even linked drinking coffee with a reduced risk of death (Galanakis, 2017). Otherwise, other studies reported that consuming large amounts of coffee and caffeine can harm pregnancy, increase blood flow to the heart, and cause liver fibrosis and metabolic diseases such as type 2 diabetes (Cornelis, 2019). Another negative effect is that it can cause insomnia, anxiety, stress, lethargy, and loss of enthusiasm for activities when not consuming coffee (Hartati and Syamsiah, 2010; Suartiningsih *et al*., 2018).

Caffeine ($C_8H_{10}N_4O_2$, molar mass 194.19 g/mol) is known as 1H-Purine-2,6-dione, 3,7-dihydro-1,3,7-trimethyl- or 1,3,7-trimethyl-2, 6-dioxopurine is a methylxanthine alkaloid found in several parts of the

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plant, such as nuts, seeds, and leaves. One of the well-known sources of caffeine is coffee beans and commercial products containing caffeine, such as tea, energy drinks, and chocolate (Zabot, 2019). One cup of instant coffee size 6 oz or 180 mL generally contains 100 mg of caffeine (Weinberg and Bealer, 2010). If a person consumes 2-3 cups of coffee daily, he has consumed as much as 200-300 mg of caffeine. Based on the Standar Nasional Indonesia (SNI) (Indonesia National Standard) SNI-01-7152-2006, the highest limit of caffeine consumed in food or beverages is 150 mg/day (Badan Standarisasi Nasional, 2006).

In the last 5 years, in Indonesia, there has been an increase in exports and imports of decaffeinated coffee, which indicates an increase in consumer demand. Currently, there are three conventional methods commonly used to reduce caffeine content in coffee beans, namely supercritical carbon dioxide extraction, solvent extraction, and water extraction. These methods are considered not environmentally friendly, have a negative impact on health since using an organic solvent, and can remove most of the flavor-forming compounds in coffee (Pereira *et al*., 2021). In contrast, decaffeination by fermentation is considered safer, simpler, requires relatively low energy, and can improve the taste and aroma of coffee. According to the SCA value for coffee flavor, the fermentation decaffeination process can increase by 1 - 5 points of the final SCA value (Cardoso *et al*., 2021). According to the work of Kristiyanto *et al*. (2013), the fermentation of coffee beans can reduce the level of caffeine and organic acids in coffee beans.

Decaffeination of coffee by fermentation can use yeast (*Saccharomyces cerevisiae*), fungi (*Aspergillus*, *Penicillium*, and *Rhizopus* spp.), and bacteria (*Pseudomonas* sp.) (Mazzafera, 2002). Among these, *Rhizopus* spp. is one of the potential microorganisms since it is recognized as safe by the United States Food and Drug Administration (FDA) and can degrade caffeine as well as tannins in coffee pulp (Londoño-Hernandez *et al*., 2020). According to Lee *et al*. (2016a), *Rhizopus oligosporus* can improve the characteristics of aroma and flavor-forming compounds contained in coffee beans.

Coffee decaffeination through fermentation can occur aerobically and anaerobically. Both conditions have advantages and disadvantages associated with the reduction of caffeine and coffee sensory results. Aerobic coffee fermentation can reduce caffeine content faster than anaerobic fermentation because most of the catabolic activity of caffeine by microbes occurs aerobically. The weakness of this fermentation process is the presence of high-end products in the form of ethanol that can reduce the taste and aroma of coffee. In contrast, anaerobic coffee fermentation only slightly reduces the caffeine content in coffee, but the resulting coffee has a more stable taste and aroma (Gummadi *et al*., 2012).

In the coffee bean fermentation process, caffeine decomposes into uric acid, 7-methylxanthine, and xanthine (Long and Dodge, 2006). The stages that occur during coffee fermentation are the breakdown of mucilage components, sugar breakdown, and changes in coffee taste due to the production of aroma precursors. This process involves biological, chemical, and physical factors in which temperature and the availability of oxygen have been mentioned as the primary external factors. The physicochemical properties of the peel and mucilage also affect microbial activity during fermentation (Tarigan and Towaha, 2017).

Today, Arabica and Robusta Arjuno coffee has been sold in the form of green beans, roasting beans, and natural coffee beans. Diversification of Arjuno coffee, such as decaffeinated coffee, has not been conducted though it has a higher bargaining value. Therefore, in this study, the effect of fermentation time on decreasing caffeine levels in Arabica and Robusta Arjuno coffee was investigated. Its effect on the changes in pH and physical of the coffee beans and the taste of the coffee was also observed. Fermentation was carried out anaerobically using *R. oligosporus*. The analysis of the business feasibility and production risk of decaffeinated Arabica and Robusta Arjuno coffee was also conducted. This study is expected can support business and ecotourism potential in the Mount Arjuno area.

2. Materials and methods

2.1 Raw materials and preparation of coffee beans

Arabica and Robusta coffee was obtained from the Brawijaya Forest (UB Forest) coffee plantation in Arjuno Mountain, Malang Regency, Indonesia. Coffee beans were sieved to remove impurities such as sand and others prior to use in fermentation.

2.2 Rhizopus oligosporus starter preparation

Rhizopus oligosporus was purchased from the Indonesian Institute of Research (LIPI) under the RAPRIMA brand. A starter of the strain was prepared by dissolving 5 g of glucose in 250 mL of distilled water. Subsequently, 5 g of *R. oligosporus* was added to the glucose solution and stirred until homogeneous.

2.3 Fermentation of coffee beans

Robusta and Arabica coffee beans (250 g) were added into a fermenter (Figure 1) and evenly mixed with the starter suspension, respectively. Fermentation was carried out anaerobically at room temperature. Four

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different fermentation times were investigated (24 hrs, 36 hrs, 48 hrs, and 60 hrs).

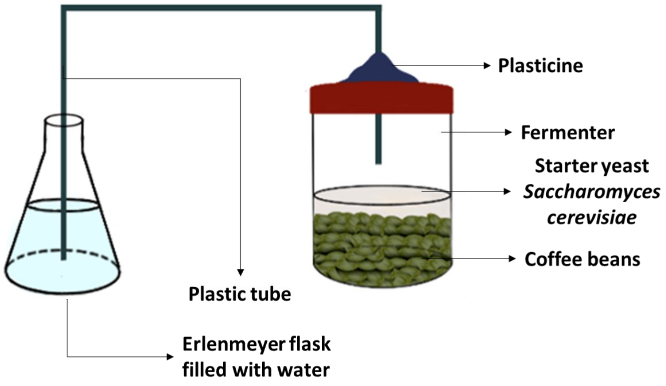

Figure 1. Scheme of laboratory-scale fermenter.

2.4 Extraction of caffeine

The fermented coffee beans were washed with deionized water (DI) until clean and not sleek. Subsequently, the coffee beans were dried using a vacuum oven (Memmert V029, Germany) at 60°C and 197 mbar until their moisture content was 7 to 12%. The beans were then milled using a laboratory-scale grinder (Ariete Grinder Pro 3017, China) and then sieved to obtain a particle size of 20 meshes. To extract caffeine, 0.05 g of coffee powder was added to 25 mL of boiled DI water. The suspension was then heated in a water bath (Memmert One 29, Germany) for 5 mins. The caffeine extract was then separated from the coffee powder by filtration.

2.5 Analytical methods

The suspension (subsection 2.4) was added with 0.08 g sodium carbonate, homogenized, and then filtrated. The filtrate was added with chloroform with a 1:1 (v/v) ratio, homogenized for 10 mins, and the caffeine was subsequently separated using a separatory funnel. Caffeine absorbance was measured using a spectrophotometer (Shimadzu UV 1800, Kyoto, Japan) at a wavelength of 276 nm and then converted to caffeine concentration using a calibration curve.

2.6 Physical test

Arabica and Robusta coffee beans that have been dried to a moisture content of <12% (wb) are subjected to physical tests to determine the quality of the coffee beans. The physical analysis includes the weight of beans/100 seeds, number of beans/10 g, bean size, and coffee bean defects (black beans, half black beans, broken black beans and brown beans) (Badan Strandarisasi Nasional, 2008).

2.7 Measurement of pH inside and pH outside

Measurement of pH outside and inside fermented robusta and arabica coffee was conducted using a pH meter (OHAUS, Starter 300, USA). A 5 g of coffee beans were mixed with 5 mL of distilled water and stirred evenly then the pH outside of the beans was measured. Meanwhile, the pH inside was measured by adding 5 g of coffee powder to 10 mL of distilled water.

2.8 Measurement of reducing sugar

A 4 mL anthrone solution was added to 1 mL of the sample and stirred in a 100°C water bath for 12 mins. The sample was then cooled to room temperature before its absorbance was measured using a UV-Vis spectrophotometer at a wavelength of 630 nm. The concentration of reducing sugar was determined using a calibration curve.

2.9 Measurement of total acidity

The coffee's overall acidity was determined according to the method outlined in Association of Official Analytical Collaboration (AOAC) International (2000). Approximately 1 g of ground coffee was placed in a 250 mL Erlenmeyer flask. Deionized water was added until the total volume reached 100 mL. The resulting suspension was then filtered, and 25 mL of the filtered liquid was transferred into a beaker. It was titrated with 0.1 N NaOH while adding three drops of phenolphthalein until a consistent, faint pink color appeared and remained for more than 10 s. The total acidity was quantified as the volume in mL of 0.1 N NaOH required to achieve neutralization. This process was repeated three times for each sample.

2.10 Sensory evaluation of coffee

A sensory test (cupping test) was conducted on the powder of unfermented and fermented Arabica and Robusta coffee refers to the Specialty Coffee Association (SCA) standard using three expert/trained panelists. The observed parameters refer to the modified SCA model by the CCTC (coffee and cocoa training center), i.e. fragrance, acidity, body (viscosity of the solution), flavor (combination of fragrance and taste), aftertaste (taste left in the mouth), uniformity (uniformity of brew test results from 5 sample cups), balance (an aspect of flavor balance), clean up (general taste impression), and sweetness. The scale of taste parameter is 60 - <70 = good; 70 - <80 = very good; 80 - <90 = superior; 90 - <100 = excellent; 100 = very good. If the total value of the quality score of brewed coffee based on the cupping test was >80, it can be categorized as specialty coffee (SCA, 2015).

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2.11 Analysis of costs, revenues, and profits for coffee agroindustry (existing enterprise) and decaffeinated coffee

The parameters for analyzing the costs, revenues, and profits for coffee agroindustry (existing enterprise) and decaffeinated coffee are summarized in Table 1.

2.12 Analysis of business risk

The method used to analyze the risk of business in this study was House of Risk (HOR). Two HOR models were used i.e. HOR Phase 1 and HOR Phase 2. HOR Phase 1 (HOR 1) is the phase of risk identification and determination of priority risk agents/sources as the basis for developing risk management strategies, while HOR phase 2 (HOR 2) is a priority of mitigation actions by considering the most efficient mitigation costs.

2.12.1 House of risk phase 1

This phase consists of the following:

a. Identification of risk events by mapping the supply chain activities using the Supply Chain Operations Reference (SCOR) method based on five supply chain activities: plan, source, make, delivery, and return.
b. Identification of risk agents.
c. Assessment of the risk impact severity. The severity value used is on a scale of 1-5 in which the severity value is higher if the risk impact severity is higher (Table 2).

Table 2. Scale of severity of risk events (Maharani, 2018).

Score	Criteria	Description
1	Insignificant	Loss of material between 0-10 million rupiah
2	Minor	Loss of material between 10 million - 50 million rupiah
3	Moderate	Loss of material between 50 million -100 million rupiah
4	Mayor	Damage or loss of material between 100 million - 1 billion rupiah
5	Catastrophic	Damage or loss of material reaches more than 1 billion rupiah

d. Assessment of the probability of occurrence of risk agents/sources for each identified risk agent. The occurrence value used is on a scale of 1-5, in which the occurrence value is higher if the frequency of occurrence of risk agents is high (Table 3).

Table 3. Scale of occurrence on risk agents (Maharani, 2018).

Score	Possibility	Frequency of occurrence
5	Almost Certain	more than 5 times per week
4	Likely	3-5 times per week
3	Possible	1-2 times per week
2	Rare	no more than once per 2 weeks
1	Very rare	no more than once per 4 weeks

e. Assessment of the relationship (correlation) between risk events and risk agents by assigning a value of 0, 1, 3, and 9, which respectively show no correlation, low correlation, moderate correlation, and high correlation (Table 4).
f. Calculation of aggregate risk potential of risk agent (ARP) with the equation

Table 1. Parameters used for analyzing the profit of coffee agroindustry (existing enterprise) and decaffeinated coffee.

No.	Parameter	References
1	Cost acceptance (TR)	Sudrajat (2020)
2	Cost revenue/profit	Asnidar and Asrida (2017)
3	R/C Ratio Criteria: R/C > 1, business is feasible to run R/C < 1, business is not feasible to run R/C = 1, business is at break-even point	Asnidar and Asrida (2017)
4	Net Present Value (NPV) Criteria: NPV > 0, investment is feasible to run NPV < 0, investment is not feasible to run NPV = 0, investment is at break-even point	Dwijatenaya *et al*. (2019)
5	Internal Rate of Return (IRR) IRR > i, business is feasible to run IRR < i, business is not feasible to run IRR = 1, business is at break-even point i = prevailing loan interest rate	Mantau (2015)
6	B/C Ratio Criteria: Net B/C > 1, business is feasible to run Net B/C < 1, business is not feasible to run Net B/C = 1, business is at break-even point	Saragi *et al*. (2022)

$$ARP_j = O_{-j}\sum S_i \cdot R_{ij}$$

Where ARP_j = aggregate risk potential of risk agent j, O_j = occurence probability of risk agent j, S_i = severity of risk event I and R_{ij} = the degree of relationship between the risk agent j with the risk event i.

g. Ranking of risk agents ARP values as the basis for determining mitigation actions. After determining the risk priority or Aggregate Risk Potential (ARP), the framework of HOR Phase 1 was constructed as shown in Table 5.

Table 4. Scale evaluation of correlation between risk events and risk agents (Maharani, 2018).

Level	Description
0	No correlation
1	Low correlation
3	Moderate correlation
9	High correlation

2.12.2 House of risk phase 2

HOR Phase 2 has the following steps:

a. Choosing a risk agent with the highest priority level using Pareto charts.
b. Identify relevant actions to mitigate risks. Compile risk mitigation actions or preventive actions (PA_k) based on risk priorities.
c. Determine the relationship between each preventive action (PA_k) with risk agent (A_j) using scale of 0, 1, 3, and 9. These numbers show a relationship that is, respectively, no, low, moderate, and strong relationship between action k and agent j (Table 4).
d. Calculate the total effectiveness (TE_k) of each action as follows:

$$TE_k = \sum ARP_j \times E_{jk}$$

Where TE_k = total effectiveness k mitigation strategy, ARP_j = aggregate Risk Potentials from risk agents j and E_{jk} = relationship between preventive action i and risk agent j

e. Evaluate the degree of difficulty (D_k). Dk is an assessment to determine the level of difficulty of implementing risk mitigation strategies. The degree of difficulty (D_k) scale is shown in Table 6.

Table 6. Assessment of difficulty level (degree of difficulty) (Maharani, 2018).

Value	Description
1	Mitigation actions are very easy to implement
2	Mitigation actions are easy to implement
3	Mitigation actions are quite easy to implement
4	Mitigation actions are difficult to implement
5	Mitigation actions are very difficult to implement

f. Determine the Effectiveness to Difficulty (ETD_k) ratio. This value shows the effectiveness of implementing risk mitigation compared to the level of difficulty. It is calculated as follows:

$$ETD_k = TE_k/D_k$$

Where ETD_k = ratio effectiveness to difficulty, TE_k = total effectiveness, and D_k = degree of difficulty

g. Ranking the ETD_k ratio value to determine the priority of risk mitigation strategies.
h. Selection of prioritized risk mitigation strategies based on the Pareto chart.

The matrix or framework of HOR phase 2 is shown in Table 7.

2.12.3 Pareto charts

A Pareto chart is a static chart consisting of bar and line graphs. The bar graph on the Pareto chart depicts the sequence of risk agents from those with the highest Aggregate Risk Potential (ARP) value to the lowest ARP value. The ARP value is obtained from the results of data analysis at the HOR phase 1. The line graph shows the cumulative ARP value in percentage. The priority risk agent is the one with the highest ARP value. The Pareto chart is used to select priority risk agents that will be continued in the calculation at the HOR phase 2 using the 80/20 principle, where 80% of the problems that occur are caused by 20% of the underlying causes

Table 5. Matrix or Framework of HOR phase 1 (Pujawan and Geraldin, 2009).

Business Process	Risk events (Ei)	Risk agents (Aj)					Severity of risk events i (Si)
		A1	A2	A3	A4	A5	
A	E1	R11	R12	R13	R14	R15	S1
B	E2	R21	R22	R23	R24	R25	S2
C	E3	R31	R32	R33	R34	R35	S3
D	E4	R41	R42	R43	R44	R45	S4
E	E5	R51	R52	R53	R54	R55	S5
Occurrence of agent j		O1	O2	O3	O4	O5	
Aggregate risk potential j		ARP1	ARP2	ARP3	ARP4	ARP5	
Priority rank of agent							

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Table 7. Matrix or framework of HOR phase 2 (Pujawan and Geraldin, 2009).

Risk agent (aj)	Preventive action (Sir)					Aggregate risk potentials (ARP)
	PA1	PA2	PA3	PA4	PA5	
A1						ARP1
A2						ARP2
Total efficiency of action	TE1	TE2	TE3	TE4	TE5	
Degree difficulty performing action	D1	D2	D3	D4	D5	
Effectiveness to difficulty ratio	ETD1	ETD2	ETD3	ETD4	ETD5	
Rank of priority	R1	R2	R3	R4	R5	

(Purnomo *et al*., 2021; Anindyanari and Puspitasari, 2023).

3. Results and discussion

3.1 Effect of fermentation time on decreasing caffeine content in coffee beans

The effect of fermentation time on decreasing caffeine levels in coffee beans is shown in Figure 2. The caffeine content in Robusta and Arabica coffee beans decreased with the length of fermentation time. The caffeine content in Robusta and Arabica coffee beans after 72 hrs of fermentation was 1.7% and 2.3%, respectively. In other words, the decline was 57.8% and 19.9%, respectively. According to SNI 01-3542-2004, the quality standard of coffee powder for caffeine content is 0.45 – 2% (Badan Standarisasi Nasional, 2004). It means that the caffeine content in fermented coffee beans obtained in this study met the quality standard of coffee powder.

During coffee fermentation by *R. oligosporus*, several enzymes are produced that play a role in degrading caffeine complex compounds. These enzymes are caffeine demethylase, paraxanthine demethylase, theophylline demethylase, theobromine demethylase, and heteroxanthine demethylase. The degradation pathway of caffeine compounds by *R. oligosporus* with the main metabolite formed is theophylline, theophylline will then undergo a second demethylation to form 3-methylxanthine as shown in Figure 3. In some cases, the caffeine complex compound will also be broken down into theobromine, and paraxanthine. Theobromine and paraxanthine will also undergo a second demethylation to form 7-methylxanthine, 1-methylxanthine, and xanthine. The resulting xanthine compound will be converted into intermediate metabolic products such as uric acid, allantoin, allantoate, ureidoglycate, glyoxylate, CO_2, and NH_3 (Dash and Gummadi, 2006; Olechno *et al*., 2021).

The degradation process of caffeine compounds into uric acid occurs at 12-36 hrs (Figure 2) (Muzaifa *et al*., 2020). The decomposition of caffeine compounds into simpler compounds can cause a decrease in caffeine levels in coffee beans (Gokulakrishnan *et al*., 2005) and a reduction in the size and molecular weight of caffeine. This causes caffeine could diffuse out easily through the cell walls and dissolve in the fermentation media, thereby reducing the caffeine content in the coffee beans (Pérez *et al*., 2022).

Arabica coffee beans fermented for 48 hrs experienced a decrease in caffeine levels and began to be stationary, while Robusta coffee has not shown signs of stationary (Figure 2). This is because the complex compounds in Robusta coffee beans are more than in Arabica coffee beans, Arabica coffee beans require fermentation for about 24-48 hrs to be able to fully break down the complex compounds contained and 48-72 hrs for Robusta coffee beans (Prakash *et al*., 2022). The stationary phase occurs when nutrients such as sugar content in the fermentation medium begin to decrease and begin to form fermentation by-products in the form of organic acids that can reduce the pH of the environment so that the performance of *R. oligosporus* is not optimal. The high level of alcohol produced during the fermentation process can also cause the death of microbes so that they cannot ferment anymore (Kurniawan *et al*., 2014). The longer the fermentation time, the number of microbes will decrease and lead to the death phase of yeast cells (dead phase) due to increasing alcohol accumulation and decreasing substrate (Kurniawan *et al*., 2014; Wibowo *et al*., 2021).

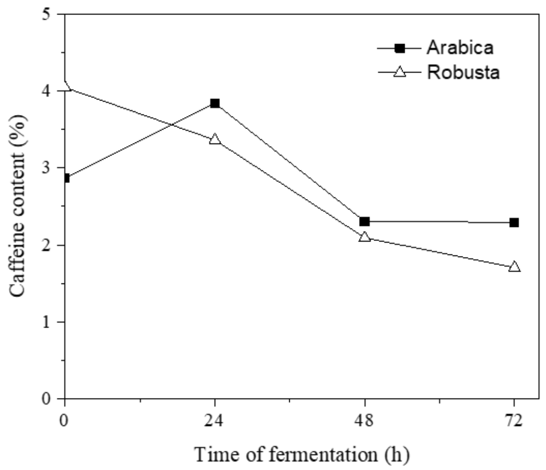

Figure 2. Effect of fermentation time on decreasing caffeine content in Arabica and Robusta Arjuno coffee beans.

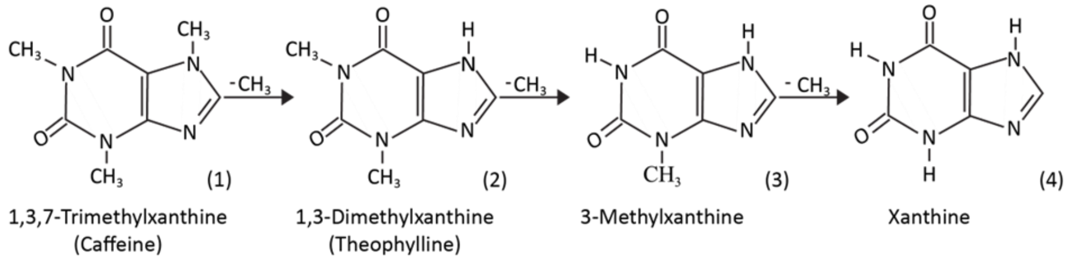

Figure 3. Caffeine degradation pathway by *R. oligosporus* (Dash and Gummadi, 2006).

3.2 Effect of fermentation on the pH of Arjuno coffee beans

As presented in Figures 4 and 5, during fermentation the inside and outside pH of the beans decreased in both varieties. This is because the production of acid increased with the increasing fermentation time (Table 8). As reported by Bangli *et al*. (2018), during coffee fermentation, microbes can produce metabolites such as ethanol and organic acids. Ethanol can be oxidized to acetic acid and then converted to oxalic acid and lactic acid, where oxalic acid is the most abundant produced acid, followed by acetic acid and lactic acid. The decrease in pH inside the beans was probably due to acids diffusing from the outside into the inside of the beans. This might explain why the decrease in pH inside the beans was less significant than outside the beans. The pH of coffee beans before fermentation was around 6 and then decreased to pH 5.5 after 72 hrs of incubation.

Table 8. Total acid content of Arabica and Robusta Arjuno coffee beans during anaerobic fermentation by *R. oligosporus.*

Time (hrs)	Total acid (%)	
	Arabica	Robusta
0	7.60	6.84
24	7.89	8.02
48	8.98	8.53
72	6.79	6.71

3.3 Effect of fermentation on the physical changes of coffee beans

The effect of fermentation on the physical changes of coffee beans in terms of the number of damaged and size changes was summarized in Table 9 and Table 10, respectively. The results showed that the number of damaged Robusta coffee beans increased with the longer fermentation time, while the damage to Arabica coffee did not increase until the end of fermentation (Table 9). In terms of the size change of the beans, the results showed that the size of Arabica and Robusta Arjuno coffee beans did not change significantly after 72 hrs of fermentation (Table 10). These results revealed that fermentation is a promising method for reducing caffeine content in coffee beans without changing the physical properties of the beans. The phenomenon that showed that fermentation did not significantly affect coffee bean size was also observed in the work of Hatiningsih *et al*. (2018). However, it was not fully understood. Worku *et al*. (2022) concluded that changes in the physical features of coffee beans (color, weight, size, shape, and density) are much more affected by geographical topography, particularly the elevation where they grow, than the processing.

3.4 Effect of fermentation on sensory quality of coffee beans

The flavors of Arabica Arjuno and Robusta coffees were assessed by a panel that has a coffee taste test certificate. Unfermented Arabica Arjuno has nutty,

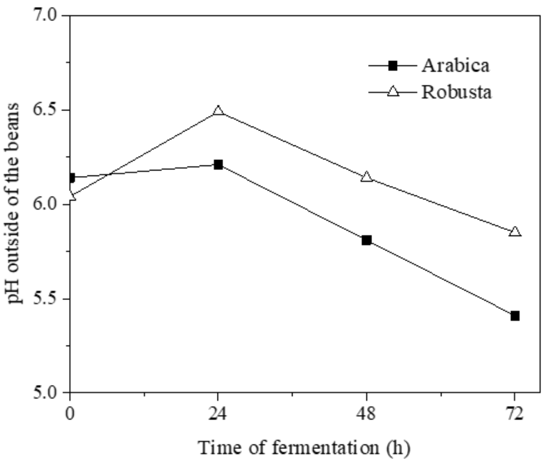

Figure 4. Effect of fermentation on the pH outside of Arabica and Robusta Arjuno coffee beans.

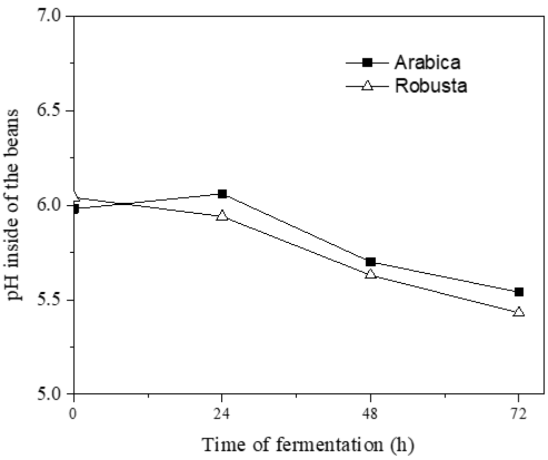

Figure 5. Effect of fermentation on the pH inside of Arabica and Robusta Arjuno coffee beans.

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Table 9. Number of damaged Arabica and Robusta Arjuno coffee beans during anaerobic fermentation by *R. oligosporus*.

	Number of damaged beans per 10 g of beans							
	No fermentation (%)		24 hrs fermentation (%)		48 hrs fermentation (%)		72 hrs fermentation (%)	
	Arabica	Robusta	Arabica	Robusta	Arabica	Robusta	Arabica	Robusta
Black bean	0	0	0	0	0	0	0	0
Half black bean	5	2	5	2	5	5	5	7
Broken black bean	4	0	4	2	4	2	4	7
Brown bean	0	0	0	0	0	0	0	0

Table 10. Size change of Arabica and Robusta Arjuno coffee during anaerobic fermentation by *R. oligosporus*.

Time (h)	Size of Arabica (cm)			Size of Robusta (cm)		
	Long	Wide	Thick	Long	Wide	Thick
0	1.14	0.79	0.52	1.01	0.83	0.51
24	1.36	0.73	0.57	0.91	0.87	0.47
48	1.25	0.88	0.51	1.06	0.86	0.59
72	1.11	0.81	0.45	0.96	0.826	0.52

brown sugar and lemon flavors, while unfermented Robusta Arjuno has earthy, chocolate, and oat flavors. After 24 hrs of fermentation, Arabica Arjuno coffee gave flavors of sweet, dark chocolate, lemon, and caramel, while after 72 hrs it gave flavors of sweet, dark chocolate, lemon, and fruity. For Robusta Arjuno coffee, after 24 hrs of fermentation, the flavor changed to dark chocolate, brown sugar, and oats. However, after 72 hrs, its aroma and taste became sour, over-fermented, and had a slight chocolate taste.

According to Figure 6, the fragrance of Arabica Arjuno coffee increased after 24 hrs of fermentation compared to unfermented coffee. However, prolonging the fermentation time decreased its fragrance quality and aftertaste. Parameters of acidity and balancing increased with the increasing fermentation time. Meanwhile, the parameters of sweetness, uniformity, size, and flavor were not changed significantly.

For Robusta Arjuno coffee, the fragrance and flavor quality increased after 24 hrs of fermentation, however, decreased significantly after 72 hrs of incubation. Prolonging fermentation time increased attribute mouthfeel, however, also increased its acidity and bitter taste. In the parameter of balancing and mouthfeel, the fermented coffee beans gave a higher value than unfermented beans. Meanwhile, the parameters of sweetness and uniformity were not changed significantly (Figure 6).

These results suggest that generally anaerobic fermentation using *R. oligosporus* enriches the flavor of coffee beans, where the quality of flavor is strongly affected by fermentation time. The decrease in the quality of coffee beans in terms of fragrance and flavor after 72 hrs of incubation might be caused by the accumulation of organic acids in the beans as metabolites or caffeine degradation products, which are indicated by a decrease in the pH of the beans (Figure 5). As a result, the taste became sour and might be bitter. This was consistent with a study that showed the increasing acidity and decreasing sensory quality of coffee beans with increasing fermentation time due to catabolic processes of *Saccharomyces cerevisiae*, which were suspected because of the accumulation of acetic acid and ammonia (Sousa *et al*., 2023). According to Lee *et al*. (2016b), the concentration of acetic acid and lactic acid increased in the fermented green coffee beans by *R. oligosporus*, where the accumulation of lactic acid corresponded to the metabolism of sugar. These findings highlight the

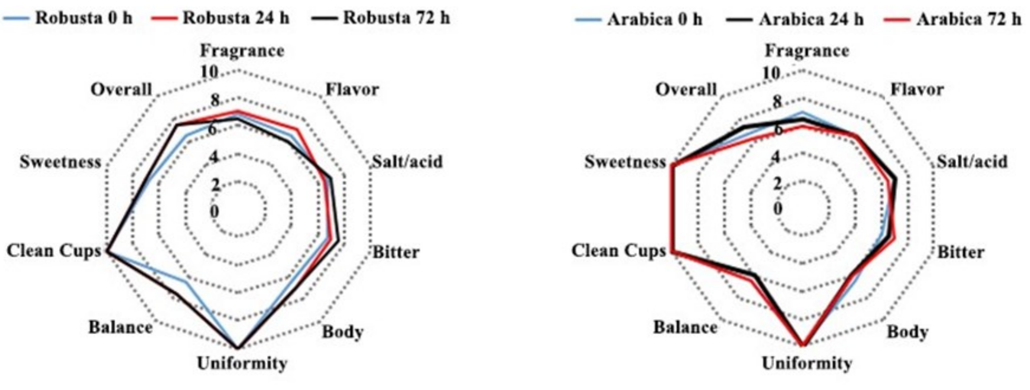

Figure 6. Effect of fermentation on *the* sensory taste of Arabica and Robusta Arjuno coffee.

https://doi.org/10.26656/fr.2017.8(6).171

importance of pH control during the fermentation process to achieve the desired fragrance and flavor.

3.5 Effect of fermentation on the reducing sugar

Fermentation is a metabolic process that uses sugars, either in the absence (anaerobic) or presence (aerobic) of oxygen. Microorganisms (yeast, *R. oligosporus*) play a major role in degrading mucilage by producing various enzymes, alcohols, acids, carbonyls, esters, furans, phenols, pyrazines, pyrroles and terpenes during the fermentation process. During coffee fermentation, microorganisms produce diverse metabolites (Lee *et al*., 2016b; Haile and Kang, 2019). Microbial activity and the extent of fermentation determine the concentrations of free sugars (e.g., glucose and fructose) and free amino acids that continue to surround the bean and subsequently contribute to the production of Maillard compounds and volatiles during the roasting process (De Maria *et al*., 1996). Based on Table 11, the reducing sugar in Robusta and Arabica coffee beans decreased with the length of fermentation time. This is due to the sugar that is used as a nutrient (carbon source) by the

Table 11. The reduction of reducing sugar content during fermentation.

Variable		Reducing sugar (%)
Type of coffee	Fermentation time (hrs)	
Robusta	0	5.10
	24	4.72
	48	3.94
	72	2.35
Arabica	0	6.98
	24	6.95
	48	5.36
	72	3.02

Table 12. Comparison of the feasibility of the existing and decaffeination coffee agro-industry for 15 years.

Indicator	Existing coffee agro-industry	Decaffeination coffee agro-industry
Net Present Value	IDR 618,981,089	IDR 4,250,118,331
B/C ratio	1.1	1.9
Internal Rate Return	34%	599%

yeast which at the end of the fermentation produces organic acids and other metabolites (Puspaningrum *et al*., 2022).

3.6 Cost analysis of coffee agroindustry (existing business) and decaffeinated coffee

In this study, the calculation of investment costs, variable costs, fixed costs, and total costs for each coffee processing business, namely the existing and decaffeinated coffee agro-industries was conducted. Feasibility indicators for existing coffee agro-industry and decaffeinated coffee meet the eligibility criteria for each indicator consisting of Net Present Value, B/C ratio, and Internal Rate Return (IRR). As summarized in Table 12, the existing coffee agro-industry and decaffeinated coffee agro-industry have a positive Net Present Value (more than 0), indicating that the business is feasible to continue. The B/C ratio is also more than 1, suggesting that both businesses are efficient and can be continuously implemented. The value of IRR is also greater than the prevailing loan interest rate (14%), so these two agro-industries can provide a good return on investment. When compared, the proposed agro-industry decaffeinated coffee provides a much greater indicator value than the existing agro-industry. Therefore, the decaffeinated coffee business is very feasible and profitable.

3.7 Business risk analysis

In risk analysis, the House of Risk (HOR) approach is used to identify risk sources and prioritise risk mitigation. Of the 85 lists of potential risks that were submitted to the business manager during the interview session. There were 28 risk events, 25 selected risk agents and the coffee business was managed if the potential risk is a risk event, while risk agents if the potential risk is the cause of the risk. After assessing the severity and occurrence, the correlation value between

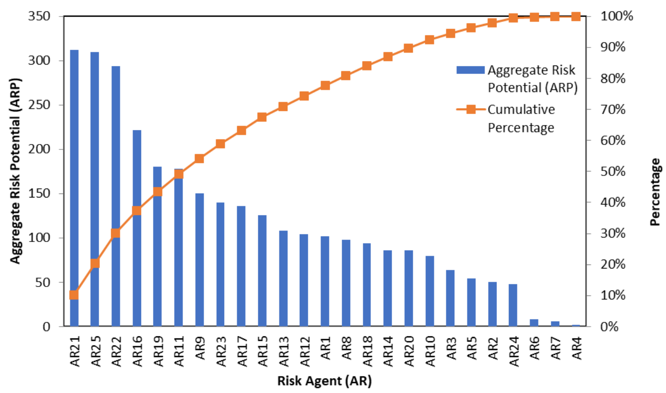

Figure 7. Pareto charts based on cumulative AR.

the risk event and the risk agent is determined. One risk event can affect one or more risk agents. According to Figure 7, 80% of risk events are caused by 13 main risks.

Based on the HOR analysis, from 28 risk events and 25 risk agents, there are 13 most significant risk contributors to the existing coffee agro-industry. The risk contributors are as follows, sorted from the highest risk to the lowest risk: production schedule delay, product delivery delay, change of sales plan, company internal factors, defective products (imperfect results), lack of skills and qualifications in human resources, error item sent by the supplier, checking is done manually before shipping, recording during production (sorting, storage, and packing) and data transfer is done manually, packaging contaminated during the storage process, engine failure, recording of receipts still uses books and notes manually, the historical record of production is not well organized, so it is difficult to understand.

4. Conclusion

Decaffeination of Arabica and Robusta Arjuno coffee beans through anaerobic fermentation by *R. oligosporus* has been demonstrated in this study. Fermentation successfully decreased the content of caffeine in both varieties. During fermentation, the yeast produced organic acids, which contribute to a decrease in the pH of the beans. Assessment of the physical changes of the beans showed that the size of fermented beans did not change significantly. Anaerobic fermentation enriches the flavor of the coffee beans. The analysis of the business feasibility and production risk showed that the business of decaffeinated Arabica and Robusta Arjuno coffee is feasible and profitable.

Conflict of interest

The authors herewith declare no conflict of interest.

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