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Development and Evaluation of Anti-Gout Jam Formulation from Jamaican Cherry (*Muntingia calabura)* and Stevia (*Stevia rebaudiana* Bertoni): Antioxidant Activity and Uric Acid Reduction Potential

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Abstract

This study examines the potential of Jamaican cherry (JC) and stevia, a natural sweetener, as an anti-gout jam. It aims to evaluate the effects of JC leaf and stevia extracts on the jam's chemical, physical, and organoleptic qualities, finding the optimal formulation and ascertaining whether feeding JC jam lowers mice's blood uric acid levels. A complete block design with two factors was applied. The two factors were JC leaf extract (A1: 30%, A2: 50%, A3: 70%) and stevia extract (B1: 1%, B2: 2%, B3 3%). The findings indicate that, while there was no significant shift in the jam's viscosity, sugar reduction, color, flavor, aroma, or spreadability, adding more JC leaf extract did affect its pH and moisture content. Similarly, stevia extract did not affect flavor, color, spreadability, viscosity, and sugar reduction, but it significantly impacted pH, moisture content, and aroma. The ideal jam formulation was a blend of 70% JC leaf extract (A3) and 3% stevia extract (B3), with a preference score of 4.66 (neutral), a viscosity of 387.50 cP, a pH of 4.16, a moisture content of 59.38%, and a sugar reduction of 1.85%. According to the results of the in vitro test, the JC jam successfully lowered uric acid levels to normal conditions at 4.92 mg/dL.

Keywords: *gout; jam; jamaican cherry; stevia.*

1. INTRODUCTION

Healthy lifestyles are becoming less prioritized as human activity increases and times change. Fast food habits that include the use of preservatives can lead to various health issues. Among these, foods high in protein and those containing alcohol can increase blood uric acid levels. Purine, a component of protein, is metabolized by the kidneys to produce uric acid, which can lead to gouty arthritis, also known as gout. The kidneys regulate the body's ability to maintain stable levels of uric acid. Uric acid will build up in the tissues and joints and cause severe pain if the levels are too high and the kidneys are unable to control their stability. Long-term exposure to uric acid crystals can lead to the formation of kidney stones (Hananto & Setiadi, 2024; Johnson et al., 2023).

Nowadays, there are many medications and artificial sweeteners on the market that contain extra chemicals that are bad for the body. Since these medications and sweeteners have several adverse effects, a safer alternative for treating gout is needed. This alternative is the use of Jamaican cherry (*Muntingia calabura*) fruits and leaves. The flavonoids, tannins, triterpenes, saponins, and polyphenols found in Jamaican cherry (JC) fruit and leaves themselves exhibit antioxidant properties. By blocking the xanthine oxidase enzyme, which acts as a catalyst in the oxidation process of hypoxanthine to xanthine and subsequently to uric acid, flavonoids themselves can lower blood uric acid levels (Meiliza, 2013). It has been demonstrated that leaf decoction and JC fruit juice, as investigated by Meiliza (2013), lower uric acid levels (Ilkafah, 2018a). According to Kholifaturrokhmah and Purnawati (2016) the normal ranges for uric acid levels in men are 3.4–7.0 mg/dL and in women, 2.4–6.0 mg/dL.

People often use JC fruits and their leaves, which have a bitter flavor, either by eating them or by boiling them. For this reason, it is vital to have other processed goods that people enjoy, such as jam. In pre-diabetes, hyperuricemia is one of the metabolic abnormalities linked to hyperinsulinemia, which is why Siregar and Nurkhalis (2015) found a positive correlation between blood sugar levels and uric acid levels.

According to Nasrul and Sofitri (2012) insulin resistance and the hyperinsulinemia system mediate the link between uric acid and reduced sugar tolerance. With the contribution of oxygen and water, insulin resistance, hypoxia, and cell death can alter xanthine, which will then transform into uric acid and peroxide. The oxygen-free radical peroxide itself has the ability to alter the nitric oxide (NO) balance, which is crucial for maintaining the equilibrium of vascular tone. Furthermore, oxidative stress in metabolic syndrome is associated with elevated uric acid levels. As a result, pre-diabetic hyperinsulinemia will make the body reabsorb more, which will raise uric acid levels. Blood sugar levels may fluctuate after consuming fast food that is high in fat, sugar, or protein. Depending on the variables that affect blood sugar levels, alternative solutions are needed as a sugar substitute, including the use of natural ingredients like stevia.

An all-natural sweetener, stevia leaves (*Stevia rebaudiana* Bertoni) are 300 times sweeter than sucrose. The properties of stevia include antimicrobial, antifungal, antibacterial, antiviral, and anti-inflammatory properties. As a natural plant product, stevia's leaves yield the diterpene glycosides (stevioside and rebaudioside), which have been extensively tested on animals and used by humans without causing any adverse effects, as a sweetener to replace sucrose (cane sugar) and are advised for people with diabetes and those following a diet (Buchori, 2007). Based on the explanation above, to add additional value to JC leaves and fruits, their effect on uric acid must be investigated. This study aims to evaluate the effect of JC leaves and stevia extracts on the chemical, physical, and organoleptic quality of jam, to find the optimal formulation, and to determine whether giving JC jam can reduce uric acid levels in the blood of mice. The study will ensure that they have functional value as an anti-gout that can be tested in vivo and that individuals with high blood sugar levels can safely consume them.

2. MATERIAL AND METHODS

2.1 Equipment and Materials

Spoons, pans, scales, basins, knives, blenders, measurement cups, droppers, funnels, measuring flasks, test tubes, and cups were among the equipment used in the study. JC fruits and leaves, stevia leaves, sugar, citric acid, PB-acetate, arsenomolybdate reagent, Nelson reagent, white mice, chicken liver, and allopurinol were the components employed in this investigation.

2.2 Study Area and Period

This research was conducted at the Pilot Plan and Laboratory of the Faculty of Agricultural Technology, Institut Pertanian Stiper, with a research period of five months (March – July 2019).

2.3 Experimental Design

The addition of cherry leaf extract was based on a total weight of 200 grams of material. This means that the amount of cherry leaf extract added to each treatment was:

A1 (30%) = 60 grams of extract
A2 (50%) = 100 grams of extract
A3 (70%) = 160 grams of extract
The second factor was the amount of stevia addition, namely:
B1 = 1 %
B2 = 2 %
B3 = 3 %

2.4 Methods

The production of JC leaf extract is made from fresh leaves weighed according to treatments of 30%, 50%, and 70% of the total weight of the material. The JC leaves are ground, then 200 mL of

water is added, and the mixture is ground again. The ground mixture is then filtered. Stevia extract is made from stevia powder, which is mixed with water in a ratio of 1:3 (w/v), and then filtered using a vacuum filter.

Jam production begins with 200 grams of cherries as the main ingredient. The cherries are first washed to remove dirt and contaminants. Next, the leaf extract is added according to the treatment. The mixture of cherries and leaf extract is then blended to obtain a smooth consistency. Then, 20 grams of sugar and 10 mL of citric acid are added to the mixture, serving as additional sweeteners and acidity regulators. The next step involves adding stevia extract as an additional natural sweetener, as specified in the treatment. The mixture is then cooked until it thickens, forming the characteristic texture of jam. The final product, cherry jam, is packaged in sterile bottles to ensure quality and maintain its shelf life.

This study evaluated the following parameters: viscosity, pH, moisture content, reducing sugar content, organoleptic properties (taste, color, spreadability, and aromas), and an in vivo test using white mice (*Mus musculus*). The organoleptic evaluation was conducted using the Seven Hedonic Scale Different Test. A total of 20 semi-professional panelists-college students aged 17 to 25 years-participated in the sensory evaluation. Data analysis was performed using Analysis of Variance (ANOVA) to identify significant differences among treatment groups. When significant differences were found, Duncan Multiple Range Test (DMRT) was applied as a post-hoc test at the 5% significance level.

3. RESULTS AND DISCUSSION

3.1 Antioxidants in Jamaican Cherry Fruits and Leaves

It is well known that uric acid, a potent antioxidant in humans, can scavenge free radicals such as peroxynitrite, which may lead to oxidant imbalances and oxidative stress (Singh et al., 2022). JC fruits and leaves may be a source of antioxidants, which could help avoid these issues. The antioxidant activity of the JC fruits and leaves used in this study was analyzed, and the results are shown in Table 1, with values of 64.37% and 69.97%, respectively.

Table 1. Antioxidant activity of cherries and cherry leaves

Analysis	Fruits	Leaves
Antioxidant activity	64,37%	69,97%

Given this antioxidant content, it is anticipated that JC fruits and their leaves may be effective in treating gout. JC leaves' anti-inflammatory qualities can lessen joint discomfort by preventing inflammation in those locations. The total phenol content of JC fruit is 21.32 mg GAE/g, but the total phenol content of its leaf extract is 1.163 mg QE/g (Noorhamdani, 2014). Kholifaturrokhmah & Purnawat (2016) states that the flavonoids in JC fruit contain quercetin. Quercetin can lower blood uric acid levels on its own. By blocking the activity of the enzyme xanthine oxidase, which synthesizes uric acid, quercetin lowers uric acid levels.

3.2 Viscosity of Jamaican Cherry Jam

Viscosity analysis is the method of determining a liquid's thickness. Table 2 shows the results of a measurement of the JC jam's viscosity. The final JC jam's viscosity was not considerably impacted by the quantity of JC leaves used as an additive, according to the treatment given. In order to make jam, JC leaves are first produced from their extracted, to which the same amount of water is added. This ensures that the JC extract has a low level of dissolved solids. When up to 70% leaf extract was added, the jam's viscosity remained unchanged. Apriani (2013) asserts that the moisture content of a material also influences its viscosity.

Fruit jam is defined by the National Standardization Agency (1995) in SNI-01-3745-1995 as a semi-wet food made from fruit pulp that has been processed with a mixture of sugar that contains at least 45% by weight of fruit juice and 55% by weight of sugar. In contrast, just 10% sugar was used

in this JC jam study; instead, stevia juice was employed. When jam is made without sugar, the gel will be weaker (Winarno, 2008).

Table 2. Mean Viscosity of JC Jam (cP).

Jamaican cherry leaf extract	Stevia Extract			Mean
	B1 (1%)	B2 (2%)	B3 (3%)	
A1 (30%)	225.00	345.00	325.00	298.33
A2 (50%)	267.50	366.25	363.75	332.50
A3 (70%)	332.75	377.50	387.50	365.92
Mean	275.08	362.92	358.75	298.33

3.3 pH Jamaican Cherry Jam

Table 3 indicates that the mean pH value tends to decrease as the concentration of JC leaf extract arises. The decline is attributed to the presence of flavonoid concentration in the leaf extract. These findings support the idea by Alvianti and Fitri (2018) that higher concentrations of JC extract result in more acidic formulations. It is well known that the flavonoids included in JC leaves raise the acidity of solutions.

The average pH value increased to 4.98%, 4.95%, and 4.64%, respectively, with the addition of 1%, 2%, and 3% stevia extract. The finding is consistent with Buchori's (2007) research, which found that the pH of the jam decreases with increasing stevia extract concentration. Because both JC leaves and stevia extract contain flavonoid components, their pH values interact. Flavonoids are the largest class of slightly acidic phenol chemicals (Alvianti & Fitri, 2018). According to the average results, the pH level becomes more acidic or lower as the amount of stevia and Jamaican cherry extracts increases.

Table 3. Mean pH of JC Jam.

JC leaf extract	Stevia Extract			Mean
	B1 (1%)	B2 (2%)	B3 (3%)	
A1 (30%)	5.00a	4.94a	4.82a	4.92p
A2 (50%)	4.95a	4.93a	4.94a	4.94q
A3 (70%)	5.00a	4.99b	4.16b	4.71p
Mean	4.98p	4.95p	4.64p	

Notes: Means followed by the same letter in the same column indicate no significant difference with the Duncan test at 5% level.

3.4 Moisture Content of Jamaican Cherry Jam

Moisture content is the percentage of water that is present in a material. According to Harefa and Pato (2017) water has a significant impact on the taste, texture, and presentation of food. Table 3 shows the findings of the examination of the water content of JC jam.

Table 4. Moisture Content of JC Jam (Percentage).

Jamaican cherry leaf extract	Stevia Extract			Mean
	B1 (1%)	B2 (2%)	B3 (3%)	
A1 (30%)	54.17 c	55.99 c	54.88 c	55.01 p
A2 (50%)	56.26 bc	55.57 c	53.21 c	55.01 p
A3 (70%)	54.78 c	62.88 c	59.38 b	59.01 q
Mean	55.07 c	58.15 p	55.82 p	

Notes: Means followed by the same letter in the same column indicate no significant difference with the Duncan test at 5% level.

Table 4 shows that the moisture content of the jam product is affected by the addition of JC leaf extract at 30%, 50%, and 70%. Since JC leaf extract has a high moisture content, increasing its

proportion results in a higher moisture content in the jam. The finding is supported by Ahmad et al. (2018), who reported a 5.26% rise in moisture content as the concentration of JC leaf extract increased. The moisture content of JC jam is affected by the addition of stevia extract. To prevent dissolved particles from influencing the jam's moisture content, stevia extract was filtered before processing.

The addition of stevia and JC leaf extracts suggests that the two ingredients interact and significantly affect the jam's moisture content. A study by Laswati (2018) found that both liquid extracts contain the main ingredient of JC, with a water content of 80.43%. This result is consistent with the assertion by Murtadha et al. (2012) that moisture content is influenced by fruit maturity. Wirawan and Mushollaeni (2008) state that there is a correlation between cooking duration and moisture content, with the cooking process contributing to both the increase and decrease of moisture levels. Based on Table 4, the A3B2 treatment had the highest average moisture content, whereas the A2B3 treatment had the lowest. This difference is likely due to the lack of a standardized cooking time, as the endpoint of cooking was determined by visual appearance, specifically the thickening of the food.

3.5 Reduce Sugar Content

Sugars that can act as reducing agents are known as reducing sugars. The existence of free ketone or aldehyde groups is the cause of this. Metal oxidizers, such as $Cu(II)$ compounds, serve as oxidizing agents or reductants in these reactions. Glucose, mannose, fructose, lactose, maltose, and other sugars are examples of reducing sugars (Fadhilah et al., 2024). In contrast, sucrose is classified as a non-reducing sugar (Andragogi et al., 2018).

Table 5 presents the analysis of the reduced sugar content of JC jam. The results show that variation in the addition of JC and stevia extracts did not have a significant effect on lowering sugar levels. This is attributed to the absence of sugar content in JC extract. These findings are consistent with the study by Laswati et al. (2018), which also reported a lack of sugar content in JC leaves.

Table 5. Mean of JC Jam Sugar Reduction (Percentage).

Jamaican cherry leaf extract	Stevia Extract			Mean
	B1 (1%)	B2 (2%)	B3 (3%)	
A1 (30%)	2.15	2.18	2.37	2.24
A2 (50%)	1.66	2.25	2.41	2.11
A3 (70%)	2.69	2.51	1.85	2.35
Mean	2.17	2.31	2.21	

Furthermore, based on Table 5, the addition of stevia extract itself did not affect the reducing sugar levels, which may be related to non-enzymatic browning reactions, such as the Maillard reaction. The Maillard reaction can reduce the concentration of reducing sugars as they are converted into new brown compounds called melanoidins (Rosida, 2011). Melanoidins are substances formed during food processing and preservation through reactions between reducing sugars and proteins or amino acids in the later stage of the Maillard reaction (Wang et al., 2011)

3.6 Organoleptic Test

To evaluate the color, aroma, spreadability, and flavor of JC jam, an organoleptic test was performed. After completing a questionnaire, participants were given a score: 1 for Very Dislike, 2 for Somewhat Dislike, 3 for Dislike, 4 for Neutral, 5 for Somewhat Like, 6 for Like, and 7 for Very Like. Table 5 presents the total organoleptic test findings. Meanwhile, Table 6 presents the interaction of the organoleptic test for two factors and three levels.

Based on Table 6, the addition of JC extract did not have a significant effect on the jam's color preference. This intense green color of the JC extract may have contributed to a lower level of acceptance by the panelists. Furthermore, the addition of stevia extract also had no significant effect on the panelists' preference for jam color. The finding is likely due to the small amount of stevia extract used, which did not noticeably alter the appearance of the jam.

Table 6. Overall test of JC jam.

Experimental treatment	Color	Aroma	Spreadability	Flavor	Mean	Description
Jamaican cherry extract						
A1 (30%)	4.48	4.36	4.49	4.38	4.42	Neutral
A2 (50%)	4.33	4.30	4.48	4.45	4.38	Neutral
A3 (70%)	4.48	4.44	4.36	4.67	4.48	Neutral
Stevia extract						
B1 (1%)	4.53	4.25q	4.39	4.35	4.37	Neutral
B2 (2%)	4.38	4.43p	4.52	4.58	4.47	Neutral
B3 (3%)	4.38	4.42p	4.43	4.57	4.44	Neutral

Notes: Means followed by the same letter in the same column indicate no significant difference with the Duncan test at 5% level.

Table 7. Overall test of JC jam.

Experimental treatment	Color	Aroma	Spreadability	Flavor	Total	Mean
A1B1	4.32 c	4.08 d	4.45	4.50 ab	17.35	4.34
A2B1	4.52 abc	4.35 bc	4.53	4.45 ab	17.85	4.46
A3B1	4.73 a	4.33 bc	4.20	4.10 b	17.36	4.34
A1B2	4.42 abc	4.5 ab	4.55	4.43 b	17.90	4.48
A2B2	4.35 c	4.4 ab	4.58	4.68 ab	18.01	4.50
A3B2	4.37 bc	4.4 ab	4.43	4.63 a	17.83	4.46
A1B3	4.70 ab	4.5 ab	4.48	4.20 b	17.88	4.47
A2B3	4.10 d	4.15 c	4.35	4.23 ab	16.83	4.21
A3B3	4.32 c	4.60 a	4.45	5.28 a	18.65	4.66

Notes: Means followed by the same letter in the same column indicate no significant difference with the Duncan test at 5% level.

Since JC is intensely green and stevia extract is blackish-brown, it can be argued that the addition of both extracts alters the jam's color. These findings are consistent with a study by Islamika et al. (2023), which reported that JC leaf extract has a blackish-brown color, and with Joshi et al. (2022), who found that stevia extract is dark brown in color. The panelists preferred the brown hue of the JC jam, which resulted from the mixing and heating process. The most favorable jam was obtained by experimental treatment A3B3, which had the highest mean score of 4.66. The mean scores for color, flavor, spreadability, and aroma were 4.32, 4.60, 4.45, and 5.28, respectively. A3B3 did not score the highest on the color test, but it was the panelists' top preference in terms of flavor and aroma. The spreadability test revealed no significant differences among the nine experimental treatments, indicating similar preferences.

The aroma of the JC jam was not significantly affected by the addition of Jamaican leaf extract. The result may be due to the fact that panelists did not enjoy the leafy aroma imparted by the extract. However, the aroma was significantly influenced by the use of stevia extract, possibly due to its distinctive and pleasant aroma. This is because panelists may be drawn to the unique and pleasant aroma of stevia extract. As shown in Table 5, the addition of 3% stevia extract resulted in the highest average aroma score. According to Hidayanto et al (2017) a richer aroma correlates with a higher concentration of stevia. The interaction between Jamaican leaf and stevia extracts contributed to a unique aroma, combining the aroma of stevia with that of JC leaf extract, which resembles the sweet, fruity aroma of the JC fruit itself.

The jam's spreadability was not significantly affected by the addition of JC leaf extract. It is possible because panelists perceived the leaf extract as having high moisture content, which they did not favor. Similarly, the addition of stevia extract did not significantly affect the jam's spreadability. This could be due to the filtration process during stevia extract preparation, which removes most dissolved particles. As such, incorporating up to 3% stevia extract did not noticeably impact the jam's spreadability.

The flavor of the jam was also unaffected by the addition of JC leaf extract. This may be attributed to the astringent and bitter taste of the extract, which the panelists found unappealing. Furthermore, the addition of stevia extract did not significantly influence flavor preference, likely because panelists did not favor its overly sweet taste. However, the overall taste of JC jam was influenced by the combination of stevia and JC leaf extracts. Increasing the concentrations of both extracts enhanced the panelists' preference for the jam's flavor. While stevia provides sweetness, JC extract is naturally astringent and bitter. The combination created a balance between sweetness and bitterness that panelists found appealing. Among the tested formulations, as shown in Table 6, the A3B3 treatment received the highest preference across all organoleptic tests.

3.7 In Vivo Test of Jamaican Cherry Jam as an Anti-Gout Agent

Figure 1 presents the result of the in vivo test on JC jam for its anti-uric acid activity. The x-axis shows the uric acid levels of the treated mice, while the y-axis shows the treatment given to the mice. The table shows that before treatment, the rats had uric acid levels of 1.18 mg/dl. After treatment with chicken liver, the rats' uric acid levels were 8.56 mg/dl, and after treatment with cherry jam, the rats' uric acid levels were 4.92 mg/dl.

According to Kholifaturrokhmah and Purnawati (2016), the normal range of uric acid levels is 3.4–7.0 mg/dL in men and 2.4–6.0 mg/dL in women. The in vivo experiment demonstrated that the administration of JC jam was effective in reducing uric acid levels to 4.92 mg/dL, which falls within the normal physiological range. This indicates that the jam can be considered a functional food for preventing gout.

Although not as potent as the chemical drug allopurinol, JC jam is considered a much safer natural alternative. This aligns with the findings of Ilkafah et al. (2018b), who stated that traditional medicines are generally safer due to their natural origin and milder effects compared to synthetic drugs. Allopurinol primarily functions to lower elevated blood uric acid levels in gout patients, but does not address the pain or inflammation during acute gout attacks, necessitating the use of additional analgesic medications (Arthritis Australia, n.d.). In contrast, JC leaves have demonstrated effectiveness in managing both uric acid levels and joint discomfort.
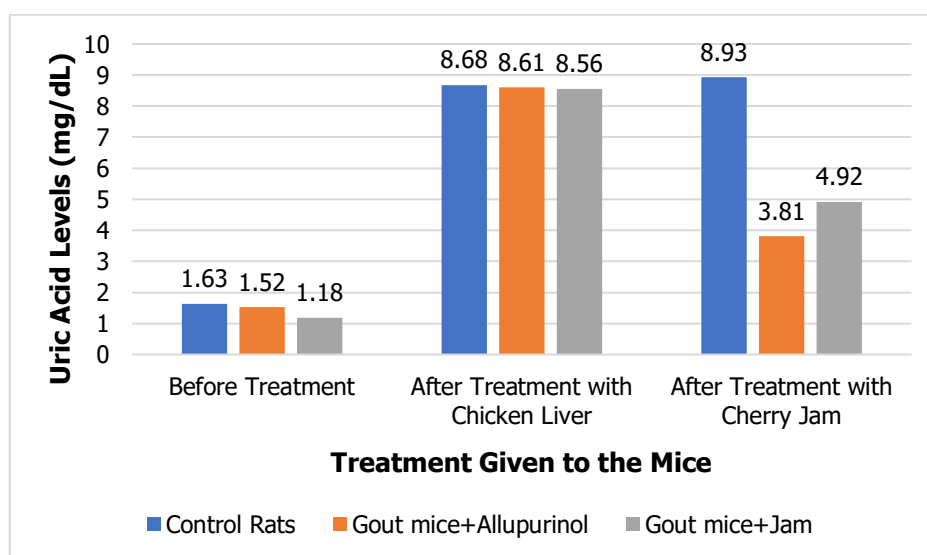

Figure 1. In vivo test results of JC jam as an anti-gout

4. CONCLUSIONS

The JC leaf extract used had a significant effect on the jam's pH and moisture content. However, it did not significantly affect viscosity, reducing sugar content, or organoleptic characteristics (color, scent, taste, and spreadability). Similarly, the addition of stevia extract did not affect the viscosity, reducing sugar content, color, spreadability, or taste of the jam. Meanwhile, it did have a notable impact on pH, moisture content, and aroma. The highest overall acceptability was observed in the A3B3 treatment, with an average of 4.66, corresponding to a neutral description. This formulation consisted of 70% JC leaf extract (A3) and 3% stevia extract (B3), supported by a viscosity of 387.50 cP, a pH of 4.16, a moisture content of 59.38%, and a reducing sugar content of 1.85%. Furthermore, in vivo testing revealed that JC jam was capable of lowering uric acid levels to within the normal range (4.92 mg/dL), indicating its potential for gout prevention.

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The Effect of Aeration on the Composting Process of Distillation Waste from Kaffir Lime Leaves

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Abstract

The extraction process of kaffir lime (Citrus hystrix) leaves is aimed at obtaining its essential oil. However, the residual waste in the form of distilled kaffir lime leaves has not yet been optimally utilised. This residue holds potential as a composting raw material of compost. This study employed naturally occurring mixed-culture microorganism, assessed compost quality based on C/N ratio, temperature changes, yield, visual appearance, and organoleptic characteristics, providing insights into its potential as a sustainable soil amendment. The composting process was conducted using a bin composting method with a chamber volume of 125 cm³. The primary variable investigated was aeration, with two conditions: aerobic and anaerobic. Composting was carried out for a duration of 8 weeks, after which the yield, C/N ratio, organoleptic, and visual characteristics were assessed. The results indicated that anaerobic composting produced a slightly higher yield. In the eighth week, the yield of anaerobic composting was recorded at 2.1%, whereas aerobic composting yielded 1.8%. Both treatments produced compost with C/N ratios that conformed to the Indonesian National Standard (SNI), measured at 15.86 and 16.42 for aerobic and anaerobic processes, respectively.

Keywords: *aeration; composting; kaffir lime leaves; waste.*

1. INTRODUCTION

Kaffir lime (*Citrus hystrix*) is a plant species commonly found across Indonesia. It is primarily utilised for the extraction of its essential oil, which is known to possess antimicrobial properties (Febrianti and Ariani, 2020). Currently, steam distillation is the standard method for extracting the essential oil from kaffir lime leaves and stems (Astriani et al., 2021). The distillation process yields three products: essential oil, hydrosol, and solid waste consisting largely of residual leaves and stems (Khasanah et al., 2021). While the essential oil yield is modest typically ranging from 1.4% to 1.6%, depending on factors like sun exposure the solid residue, which constitutes the bulk of material after distillation, remains largely underutilized (Budiarto and Sholikin, 2022). Therefore, further research is required to explore the potential of using this solid waste effectively.

One such potential utilisation is composting. Composting is a biological decomposition process whereby microorganisms break down organic matter such as cellulose, hemicellulose, and lignin into humus-like material commonly referred to as compost (Ekawandani and Kusuma, 2019). The residual kaffir lime leaves and stems are rich in organic matter, primarily carbon and nitrogen, making them suitable substrates for composting. Compost serves as a soil conditioner and improves soil fertility (Chaniago and Inriyani, 2019). When applied to soil, it enhances structure, improves water retention and porosity, and thereby reduces reliance on chemical fertilizers (Ho et al., 2022).

Previous research involving the composting of post-distillation biomass includes a study by Salim and Sriharti (2008) titled "The Utilisation of Patchouli Leaf Residue as Compost". That study demonstrated that the physical quality of the resulting compost met the Indonesian National Standard (SNI). However, it utilised an activator, whereas the present study adopts naturally occurring mixed-culture microorganisms to assess the influence of any residual antimicrobial compounds within the kaffir lime leaves and stems post-distillation.

Aeration is particularly important in composting because it ensures an adequate oxygen supply for aerobic microorganisms, which are more efficient at breaking down organic material. It also helps dissipate excess heat and manage moisture levels, creating optimal environmental conditions for microbial activity while preventing anaerobic zones (Bhave and Kulkarni, 2019). Inadequate aeration and thus poor oxygen transfer are a primary driver of odorous gas production during composting (Zhu et al., 2021), whereas maintaining aerobic conditions through proper aeration mitigates unpleasant odors associated with anaerobic decomposition (Elsabbagh et al., 2025). Moreover, effective aeration is essential for reducing methane emissions, as it limits anaerobic decomposition pathways (Nordahl et al., 2023).

Several factors influence the composting process, including the carbon-to-nitrogen (C/N) ratio and oxygen availability (Williams, 2004). An initial C/N ratio that is too high (>30:1) can prolong the decomposition process, while a ratio that is too low may lead to putrefaction. Oxygen levels are associated with the aeration process; in anaerobic composting, oxygen levels are expected to be zero (van der Wurff et al., 2020). Research by Dimawarnita et al. (2023) showed that compost produced under aerated conditions had a lower C/N ratio than compost produced without aeration.

However, limited research has been conducted on the composting of kaffir lime distillation residues, particularly using natural mixed-culture microorganisms without commercial activators. This is important because residual antimicrobial compounds in the distillation waste could potentially affect the composting process. Therefore, the objective of this study was to evaluate the effect of aeration on the composting process of kaffir lime (*Citrus hystrix*) distillation waste by comparing aerobic and anaerobic conditions using natural mixed-culture microorganisms. The study assessed compost quality based on C/N ratio, temperature changes, yield, visual appearance, and organoleptic characteristics, providing insights into its potential as a sustainable soil amendment.

2. MATERIAL AND METHODS

2.1 Equipment

The equipment employed in this study included a thermometer, composting bin, and a moisture balance. Thermometer and moisture balance are used as tools to measure the humidity and temperature of the compost. Composting bin is used as a place where the composting process take place.

2.2 Materials

The materials utilised were water and distilled kaffir lime leaves and stems. The distilled kaffir lime stems is cut into 20 cm long to standardize sizes. While the kaffir lime leaves is not cut.

2.3 Experiment Design

The experiment employed a completely randomized design (CRD) with two treatments: Aerobic composting – composting with aeration using perforated bamboo pipes to provide oxygen, and Anaerobic composting – composting without aeration, with the compost bin fully sealed to prevent air entry.

2.3.1 Composting Bin Preparation

The composters used were rectangular in shape, constructed from wood and bamboo. Each composter was equipped with a removable lid. The dimensions of each unit were 2 m in length, 0.5 m in width, and 0.5 m in height. Each composter was divided into four chambers, each measuring 0.5 m × 0.5 m × 0.5 m.
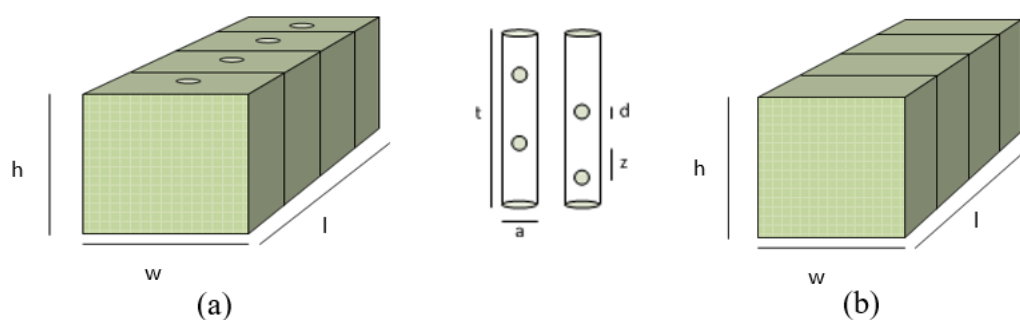
Figure 1. Composting bin a) Aerob, b) Anaerob
h = 0.5 m; w = 0.5 m; l = 2 m; t = 75 cm; d = 10 cm; z = 20 cm; a = ±12 cm

The anaerobic composter had no aeration channels to prevent the intrusion of air from the external environment. Conversely, the aerobic composter featured perforated bamboo pipes for aeration. Each chamber contained one such pipe, placed vertically in the centre. The pipes were perforated with four holes, each 10 cm in diameter, spaced 20 cm apart.

2.3.2 Raw Material Preparation

The post-distillation kaffir lime stems were cut into pieces measuring 10–20 cm. Moisture content was adjusted to achieve a humidity level between 40% and 65%. The ratio of leaves to stems used as raw material was 3:1 by weight.

2.3.3 Composting Process

The composting process began with mixing 15 kg of kaffir lime leaves and 5 kg of stems, resulting in a total of 20 kg of raw material. These were mixed thoroughly and placed into the composters. In the aerobic composter, aeration pipes were inserted at the centre of each chamber.

For the aerobic composting treatment, aeration pipes were inserted vertically at the center of each chamber to facilitate airflow and oxygen supply. The compost temperature, pH, and moisture content were measured daily. The temperature was allowed to rise naturally but maintained below 65°C during the first four days to prevent excessive heat buildup. If the temperature exceeded this threshold, the aerobic composter was opened and the material was turned to release heat and improve aeration. Water was added as needed to maintain moisture levels within the 35–65% range. Additionally, the aerobic compost was turned at least once a week to ensure adequate oxygen distribution and uniform decomposition.

In the anaerobic composting treatment, the bins were fully sealed without aeration pipes to prevent air entry. The compost material was not turned at all throughout the process. Water was only added when the internal temperature exceeded 65°C, helping to regulate heat and maintain microbial activity under oxygen-limited conditions.

For both treatments, water was added at a minimum interval of one week, if needed. The composting process was carried out for a total duration of 8 weeks. Samples for C/N ratio analysis were collected every two weeks, specifically at weeks 0, 2, 4, 6, and 8, by taking representative material from one chamber in each treatment.

2.3.4 Compost Testing

This study was a quantitative experimental study with a descriptive approach. Quantitative data were obtained through direct measurement of compost parameters such as temperature, pH, moisture content, and C/N ratio, while descriptive data were collected through organoleptic and visual assessments. The aim was to quantitatively compare compost quality between two treatments and describe the physical characteristics of the resulting compost. The conclusion was drawn by assessing whether the compost met SNI quality parameters, comparing the final C/N ratio, yield, and organoleptic results between treatments, and identifying which treatment produced higher quality

compost and whether aeration significantly influenced the process. Below is the explanation of each parameters:

A. Temperature, pH, and Humidity testing

Measurements of pH and moisture were performed using a soil meter, which was inserted into the central part of the compost pile. These parameters: temperature, pH, and moisture were recorded daily for the duration of the 8 week composting process.

B. C/N ratio testing

C/N ratio analysis was conducted at the Agricultural Technology Assessment Centre (BPTP) in East Java. The carbon content was determined using the dry ashing method at a temperature of up to 600°C. The total nitrogen content of the compost samples was determined using the Kjeldahl method, a standard and widely used technique for measuring nitrogen in organic materials.

C. Visual Testing

According to the standard (Indonesian National Standard, 2004) compost should be dark and soil-like in colour. Visual observations were made by comparing the compost to soil. For baseline comparison, a sample of normal, untreated soil was used as a reference. This soil was collected from the same location where the compost is expected to be applied. The physical appearance, color, and odor of the compost were compared directly to this normal soil during the organoleptic and visual assessments. No statistical tests were applied to the soil sample because it was used solely as a qualitative reference point.

D. Organoleptic Testing

Five kilograms of compost were sieved using a 1-mesh screen (2 mm). The sieved compost was then used for organoleptic testing. According to the standard (Indonesian National Standard, 2004) compost should exhibit a typical earthy or fermented odour. Twenty respondents were engaged to assess the smell by comparing the compost odour to that of local soil from the Department of Chemical Engineering, Universitas Brawijaya.

3. RESULTS AND DISCUSSION

3.1 Temperature Changes during Composting

Throughout the composting process, temperature fluctuations served as indicators of microbial activity, thereby reflecting the different composting phases. The initial phase observed was the mesophilic phase, which lasted less than a day for both aerobic and anaerobic treatments. In aerobic composting, the temperature rose from 36°C to 49°C on the first day, whereas in anaerobic composting, it increased from 33°C to 50°C, indicating the commencement of the thermophilic phase. The thermophilic phase duration differed between treatments: aerobic composting remained in this phase for 3 days (from day 1 to day 3), while the anaerobic process maintained thermophilic conditions for 15 days. The shorter thermophilic phase in aerobic composting is attributed to aeration through periodic turning, which resulted in more heat loss to the surroundings. In contrast, the anaerobic compost retained heat more effectively due to the absence of turning.
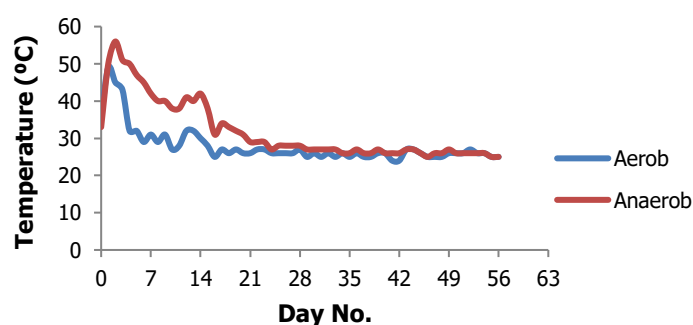

Figure 2. Temperature change in compost

Typically, the thermophilic phase in composting lasts for around 30 days due to sustained microbial activity that rapidly degrades organic matter. However, in this study, the presence of residual antimicrobial compounds in the kaffir lime leaves and stems likely inhibited the growth and activity of beneficial microorganisms. These bioactive compounds, such as essential oils, may have interfered with microbial metabolism, reducing their population and enzymatic activity. As a result, the thermophilic microorganisms were unable to maintain high metabolic rates for a prolonged period, causing an accelerated decline in microbial activity and a premature end to the thermophilic phase. This indicates that the chemical composition of composting materials can significantly influence the duration and stability of the composting process.

Subsequently, the composting process entered the second mesophilic or cooling phase. This phase began on day 4 for the aerobic compost and was characterised by a fluctuating temperature range of 26–32°C. In the anaerobic compost, the second mesophilic phase began on day 16, with temperatures fluctuating between 25–31°C. Although substrate decomposition continued in this phase, it occurred at a slower rate due to reduced substrate availability compared to earlier stages.

The composting process did not achieve the maturation phase. Although ambient temperatures were reached by the final week, the compost still contained undecomposed material. The decline in microbial activity was caused by inadequate composting conditions, including low initial C/N ratios favouring anaerobic decomposition, and excessive mass reduction, which diminished the effectiveness of microbial breakdown.

According to Wang et al. (2024) in small-scale composting systems, the side walls of a composting reactor significantly contribute to heat loss through conduction and convection, due to their high surface area to volume ratio. Forced convection such as that induced by fans or turning accelerates heat dissipation by promoting airflow across surfaces. In contrast, radiative heat loss remains minimal because of the small temperature differential between the compost surface and ambient air.

3.2 C/N ratio

As referenced by (Indonesian National Standardization Agency (2004) the carbon-to-nitrogen (C/N) ratio is a key indicator of compost quality. During the 8-week composting period, C/N ratios were analysed biweekly. The C/N ratio trends for both aerobic and anaerobic treatments are illustrated in Figure 3.
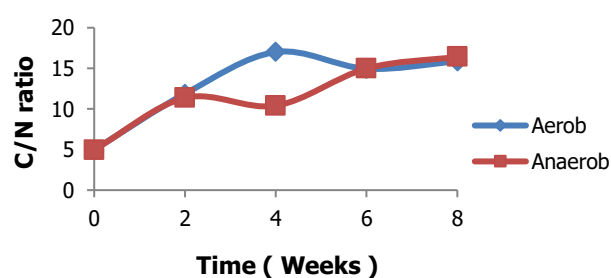
Figure 3. Compost Ratio C/N

The figure reveals that both aerobic and anaerobic composting processes exhibited fluctuating C/N ratios. The raw materials kaffir lime leaves and stems, had a relatively low initial C/N ratio of 4.98:1. According to Al Arni & Elwaheidi (2021) low C/N ratios (<20:1) lead microorganisms to convert a higher proportion of nitrogen into ammonia, particularly under anaerobic conditions. This ammonia generation results in unpleasant odours. As a weak base, ammonia formation is indicated by an increase in compost pH above.

During composting, pH fluctuated, reflecting the nature of the substrate conversion process. Measurements were taken at two points: Point A (the centre of the compost pile) and Point B (approximately 20 cm from the centre). The pH profiles over the 8-week period are shown in Figure 4.

At week 2, both aerobic and anaerobic composts exhibited increased C/N ratios. This indicates that nitrogen was more extensively converted than carbon during early decomposition, resulting in ammonia production and increased pH levels. In aerobic compost at the centre (Point A), pH reached 8, while in anaerobic compost it reached 9.

By week 4, the C/N ratio of aerobic composting increased. This is because at this stage there tends to be only the conversion of nitrogen to ammonia which causes the nitrogen content to decrease. Therefore, the C/N ratio increases. This decrease in nitrogen content is due to the formation of ammonia which will then be released into the air. The formation of ammonia this week is marked by a change in pH reaching 8 at the midpoint of the compost material pile, as shown in Figure 4 (a).

Figure 4. pH change of compost by (a) aerob, (b) anaerob

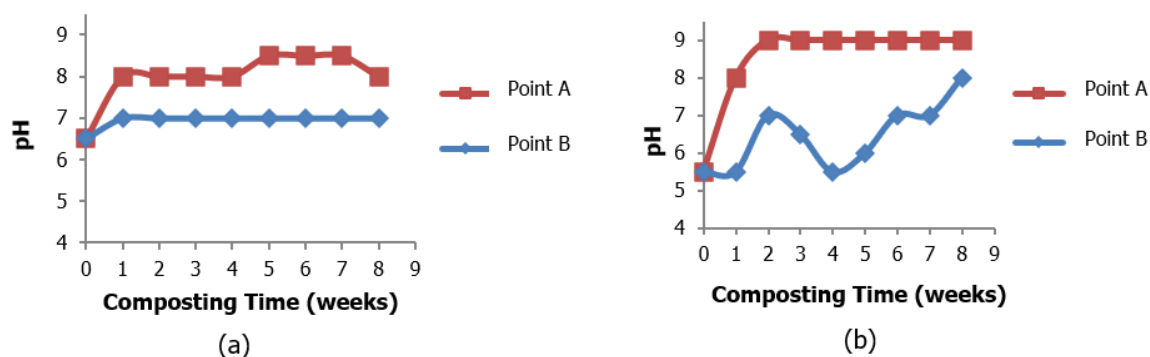The decrease in nitrogen levels observed during composting can be attributed to the volatilization of ammonia produced during protein degradation. High temperature and alkaline conditions promote the release of ammonia gas into the atmosphere, resulting in nitrogen loss. Simultaneously, the growth of microorganisms relies on carbon as an energy source, leading to the preferential consumption of simple carbon compounds and the persistence of more complex forms like cellulose and lignin. These processes collectively contribute to an elevated C/N ratio over time, reflecting both nitrogen depletion and the slower breakdown of remaining carbon-rich materials.

In the 4th week of anaerobic composting, there was a decrease in the C/N ratio. Based on the graph in Figure 4 (b), it is known that there is a difference in pH at the midpoint of the compost material pile with the point located at a radius of ± 20 cm from the midpoint. The pH at the midpoint (point A) reaches 9. This indicates the formation of ammonia from the nitrogen conversion process. Ammonia at that point accumulates more than that released into the air, so the pH at the midpoint of the compost material pile is quite high. In addition, it is possible that ammonia gas (NH_3) changes form into NH_4OH because it binds to water. This condition is possible because in anaerobic composting, the water content given is> 65%, so the amount of water in the compost material pile is quite high. Although ammonia is formed at this phase, the existing nitrogen does not decrease, because ammonia is not released into the air.

The pH of anaerobic composting in the 4th week at a point with a radius of ± 20 cm (point B) from the center point (point A) showed an acidic condition of 5.5. This is in accordance with (Rynk et al., 1992) which states that, in anaerobic conditions, decomposed carbon tends to form intermediate compounds in the form of organic acids. There is a difference in the decomposition process at points A and B, where at point A the nitrogen component tends to be decomposed, while at point B the carbon component tends to be decomposed. This is because point B in the composter is closer to the environment, so that its condition is quite influenced by the surrounding environment. Although composting occurs anaerobically, there is still a limited amount of oxygen. Because point B is closer to the environment, the amount of oxygen at point B is greater than at point A, so that carbon decomposition can occur at point B. The organic acids formed can be further decomposed if there is oxygen into methane compounds, so that some of the carbon at point B will be reduced.

Based on the C/N ratio value which decreased to 10.4 then it can be seen that the carbon conversion at this stage is greater than the nitrogen conversion. In the 8th week of composting, the C/N ratio of both aerobic and anaerobic composting experienced a slight increase and tended to be constant. The decrease in nitrogen levels in both composting was the cause of the increase in the C/N ratio. This condition was caused by the decreasing microbial activity. in the composting process. Based on the explanation of the previous sub-chapter, the longer the composting process is carried out, the greater the shrinkage of the compost material mass, so that the environmental influence is also quite large. This results in the failure to achieve the appropriate composting conditions and the decomposition process by microbes slowing down. After composting was carried out for 8 weeks, the final C/N ratio was obtained as follows.

Table 1. C /N ratio of compost at week 8

Composting	Carbon	Nitrogen	C/N ratio
Aerobic	37,60%	2,37%	15.86
Anaerobic	35,64%	2,175%	16.42
SNI Standard	9,8-32%	Min 0,4%	10-20

From Table 1, it is known that the C/N ratio of compost has met the standard (Indonesian National Standard, 2004). This indicates that, chemically, the compost produced in both treatments achieved the minimum requirements for maturity and stability. However, the results indicate that the final compost had an organic carbon content higher than the maximum limit specified by the Indonesian National Standard (SNI 19-7030-2004), which requires carbon levels to range between 9.8% and 32%. This elevated carbon level suggests that the degradation of carbon-rich compounds such as cellulose, hemicellulose, and lignin was incomplete during the composting process. In this study, the raw material distillation waste of kaffir lime leaves and stems contained a substantial amount of structural plant material and essential oils, both of which are highly resistafint to microbial breakdown. Furthermore, the limited aeration and relatively small composting mass may have reduced microbial activity and slowed down decomposition, preventing adequate conversion of organic carbon into more stable forms like humus. As a result, excess carbon remained in the final compost, indicating that the process did not fully achieve maturity. These findings highlight the need for pre-treatment methods, such as size reduction or co-composting with nitrogen-rich substrates, to improve degradation efficiency and bring the carbon content within the required standard.

3.3 Physical Quality of Compost Produced

Based on the results of the organoleptic and visual assessments, 65% of respondents stated that the anaerobic compost possessed an earthy smell. The characteristic smell of soil arises from the combination of organic matter, minerals, and microbial activity (Margolang et al., 2015). In contrast, responses regarding the aerobic compost were more varied, with the highest proportion (38%) indicating that it did not resemble the smell of soil. Thus, the anaerobic compost was found to have a more soil-like odour than its aerobic counterpart.

In terms of visual similarity to soil, 55% of respondents stated that the anaerobic compost had a colour resembling dark brown to black soil. Meanwhile, 35% noted a very strong resemblance, and the remainder responded neutrally. In contrast, responses regarding the colour of aerobic compost were more inconsistent; 45% claimed it did not resemble soil colour, while 35% observed a similarity. These differences are likely due to the varying visual perceptions of each respondent. Nevertheless, it can be concluded that anaerobic compost is more similar in colour to soil compared to aerobic compost.

As for texture, 50% of respondents found the anaerobic compost to resemble the texture of soil, 21% indicated it was very similar, 17% were neutral, and 12% did not perceive any similarity. Although responses on anaerobic compost texture were somewhat inconsistent, more than half perceived it as having a soil-like texture.

For aerobic compost, the organoleptic responses on texture were similarly mixed: 30% stated it resembled soil, 25% stated it did not, 20% were neutral, 20% found it very similar, and the remainder

claimed it was not similar at all. Despite this variation, anaerobic compost was deemed more similar in texture to soil, as over 50% of respondents indicated a likeness.

The inconsistent results may have been influenced by the screening process, in which both composts were sieved using a 10-mesh screen (equivalent to 2 mm), leading to similar particle sizes in both compost samples. The screening process also showed that anaerobic compost yielded a higher amount of fine compost. From 5 kg of each compost type, 105 grams of anaerobic compost and 90 grams of aerobic compost were recovered with a maximum size of 2 mm.

Based on Table 2, it is known that the compost yield for both aerobic and anaerobic is very small. This is caused by the composting process that runs very slowly starting in the third week. The very slow composting process is caused by the very large environmental influences.

Table 2. Mass of compost after processing screening process

	Aerobic	Anaerobic
Initial mass (kg)	5	5
Mass after sieving (kg)	0.09	0.105
Yield (%)	1.8	2.1

Despite this, the overall yields were still very low - 1,8% for aerobic and 2,1 for anaerobic composting. This is attributed to the extremely slow composting process, which only began to progress in the third week. One of the main contributing factors was the significant environmental influence due to the small amount of raw material used. Additionally, manual monitoring of composting conditions in the composter further amplified environmental impacts, limiting optimal control over the process. The anaerobic composting process also demonstrated greater instability, resulting in more variable outcomes.

4. CONCLUSIONS

Based on the research findings and discussion, distilled kaffir lime leaves and stems cannot be directly used as composting substrates using natural mixed-culture microorganisms without prior treatment. Although both aerobic and anaerobic composting processes produced compost with C/N ratios that met the Indonesian National Standard (SNI), these results alone are not indicative of successful composting. This is due to the very low compost yields: 1.8% for aerobic composting and 2.1% for anaerobic composting.

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Utilization of Nyamplung Oil as an Active Ingredient in an Antioxidant Facial Clay Mask

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Abstract

Nyamplung oil has active components that are beneficial to skin health due to its high antioxidant content. Nyamplung oil serves as an active element in clay masks. This study uses nyamplung oil, which is high in antioxidants, to harness the renewing and skin regenerating qualities of this natural component. The study involved creating a clay mask with various concentrations of nyamplung oil (4%, 6%, 8%) and xanthan gum (0.6% and 0.8%), and then analyzing its antioxidant activity. The clay mask formulated with 6% nyamplung oil and 0.8% xanthan gum demonstrated strong antioxidant activity (IC$_{50}$ = 88.29), with a drying time of 5.6 minutes, a pH of 5.56, and a viscosity of 92.2 cP. Conclusion: The results demonstrate that nyamplung oil is a potent natural antioxidant suitable for cosmetic applications. The clay mask formulation with 6% nyamplung oil and 0.8% xanthan gum showed excellent physicochemical properties and very strong antioxidant activity, indicating its potential as an effective facial skin care product.

Keywords: *antioxidant; clay mask; nyamplung oil; skin; health*

1. INTRODUCTION

Nyamplung plant *(Calophyllum inophyllum)* is a plant that grows well in sandy or coastal areas with a pH of 4 - 7.4. The potential for nyamplung based on its standing area reaches 480.000 ha, with an area of 255.300 ha which is spread from Sumatra to Papua (Syakir and Karmawati, 2013). Nyamplung seed kernels contain 75% oil and 71% unsaturated fatty acids. Nyamplung oil can be obtained by mechanical extraction or chemical extraction (Heriyanto et al., 2011; Leksono et al., 2014). The oil from the nyamplung plant is thick, greenish brown in color, and has a strong scent akin to caramel (Leksono et al., 2014). Windyarini et al. (2018) reported that nyamplung oil contains 35.75% oleic acid, 29.05% linoleic acid, 17.95% stearic acid, and 15.17% palmitic acid. According to the test results for its phytochemical components, nyamplung oil contains steroid, flavonoid, saponin, and triterpenoid components. The liquid fraction comprises steroids, flavonoids, and saponins, but the solid fraction contains just flavonoids. Nyamplung oil inhibits *Staphylococcus aureus* with a diameter of 6.75 mm. Nyamplung oil or tamanu oil contains 41-52% saturated fatty acids, including 25-35% stearic acid, 16.5 ± 1.59% palmitic acid, and 18-22% unsaturated fatty acids (Liu et al., 2015). According to studies Amelia et al. (2024) nyamplung oil is very vulnerable to *Propionibacterium acnes* bacteria and contains terpenoids, quinones, flavonoids, phenols, and steroids. Nyamplung oil includes hymecromone, a derivative of coumarin. Nyamplung has an antioxidant type of fenol.

Although nyamplung oil contains active ingredients such as coumarin and hymecromone that are beneficial for skin health, their specific mechanisms have not been fully explained. These chemicals coumarin and hymecromone, have the potential to significantly boost the added value of nyamplung oil itself. Nyamplung oil has the potential to be a highly profitable cosmetic ingredient if used properly. One example is the presence of *Propionibacterium acnes*, which can be employed as the primary ingredient in clay mask products. With additional study and development, the potential of the active ingredients in nyamplung oil can be completely realized, resulting in more effective and high-quality skin care products. The presence of *Propionibacterium acnes* in nyamplung oil suggests that it could be employed as a clay mask product in the cosmetics business.

Clay masks are commonly formulated with ingredients such as bentonite and kaolin. These masks offer numerous benefits for the skin, including removing dirt and impurities, effectively cleansing the skin, and providing protection against the sun's rays (Fadhilah et al. 2022). Using facial masks can also help reduce the amount of UV light that reaches the skin. Premature aging is caused by frequent excessive activity under the sun, with UV rays causing the formation of free radicals. Nyamplung oil has a high antioxidant content, making it suitable for use as a cosmetic active ingredient, namely in clay masks.

Antioxidants are chemicals that can stabilize free radicals. Antioxidants compensate the deficiency of electrons caused by free radical exposure, avoiding chain reactions. As a result, skin care products, especially anti-aging solutions, rely heavily on antioxidants to protect the skin from free radical damage (Lushaini et al., 2015; Rumagit et al., 2015). Antioxidants can be obtained from nyamplung, which is known to have high antioxidant activity. Because of the high antioxidant content of the clay, it has the potential to be used as a clay mask product. According to Safrina et al. (2020) found that nyamplung oil had an IC_{50} of 1.28-24.18 µg/mL. High antioxidants will help facial skin care in rejuvenating the skin. Skin irritation will occur if the mask continues to produce a stinging effect after it has been removed. This sensation stimulates skin movement, with clay masks capable of reducing dirt and blackheads when removed from the face. The effect of using a mask is that the skin becomes smoother and more radiant.

The objective of this research is to develop a clay-based facial mask formulation containing nyamplung oil as a natural antioxidant active ingredient. Specifically, this study aims to assess the antioxidant activity of the formulation and its potential efficacy in protecting facial skin against oxidative damage. Nyamplung oil in clay mask formulations for skin treatment has various hurdles, but it also presents an appealing competitive niche in the skin care business. Key problems include stable product formulation, component compatibility, and the efficacy and safety of nyamplung oil for skin, all of which necessitate comprehensive clinical and allergy research. Furthermore, regulatory compliance and product certification are both time-consuming and expensive challenges. On the other side, the competitive landscape creates chances for distinctive product creation, particularly given the growing customer preference for natural and ecologically friendly components. Product differentiation through branding, as well as customer education on the specific benefits of nyamplung oil, are effective marketing methods. However, competing with established conventional items and maintaining competitive pricing present additional hurdles. Opportunities for additional research and development, as well as suitable market segmentation, present enormous growth opportunities. With the appropriate strategy, nyamplung oil can emerge as a standout innovation ingredient in the skin care business.

2. MATERIAL AND METHODS

2.1 Materials

The materials used in this study included nyamplung oil, cosmetic-grade bentonite clay, cosmetic-grade kaolin clay, food-grade xanthan gum (Fufeng), vegetable glycerin, food-grade titanium dioxide, sodium lauryl sulfate, distilled water, and fragrance.

2.2 Tools

The instruments used in this study included Pyrex glassware, a digital pH meter (TS), digital scales (DJ303A), a Brookfield viscometer, and an acid chamber

2.3 Method

The formulation of the clay mask in this study involved incorporating varying concentrations of nyamplung oil (4%, 6%, and 8%) and xanthan gum (0.6% and 0.8%), followed by an evaluation of the antioxidant activity of each formulation. The formulation clay mask is shown in Table 1.

Table 1. Formulation of clay mask

Material	(%)					
	A1	A2	A3	A4	A5	A6
Nyamplung oil	4	6	8	4	6	8
Bentonit	1	1	1	1	1	1
Xanthan gum	0.6	0.6	0.6	0.8	0.8	0.8
Kaolin	34	34	34	34	34	34
Gliserin	2	2	2	2	2	2
Sodium Lauryl Sulphate	1	1	1	1	1	1
TiO_2	0.5	0.5	0.5	0.5	0.5	0.5
Fragrance	10	10	10	10	10	10
Aquadest	100	100	100	100	100	100

Table 1 presents the ingredients used to formulate the clay mask. The important ingredients to made clay mask are bentonite, xanthan gum, glycerin, and active ingredients. Table 1 presents the six clay mask formulations developed in this study. Each formulation varied in the concentration of nyamplung oil (4%, 6%, and 8%) and xanthan gum (0.6% and 0.8%), while the other components such as bentonite, kaolin, glycerin, sodium lauryl sulfate, titanium dioxide, fragrance, and distilled water were kept constant. These variations were intended to determine the optimal composition for antioxidant activity and desirable physicochemical properties of the clay mask.

Bentonite is left wet, then xanthan gum is added and briskly mixed until completely dissolved. Kaolin is added gradually while stirring, followed by TiO_2 and glycerin, which are mixed until homogeneous (Solution A), then sodium lauryl sulfate is dissolved in distilled water (Solution B). Solutions A and B are slowly put into the mortar while stirring, followed by nyamplung oil. To evaluate the quality and performance of the clay mask formulations, several tests were conducted, including pH measurement, viscosity analysis, homogeneity assessment, spreadability test, drying time measurement, and antioxidant activity analysis using the DPPH method. These tests were used to determine the optimal formulation with desirable physicochemical characteristics and strong antioxidant potential. The analysis method for this research is:

a. pH

The pH test is used to determine whether the product has skin-acceptable properties. This needs to be considered because the skin is extremely sensitive to pH levels. The formulation's pH is determined by diluting a 0.5 gram Clay Mask sample in 50 mL of distilled water. The diluted sample is then measured with a pH meter.

b. Viscosity

A viscosity test is performed to determine whether the clay mask formulation produced can match the required specifications. The obtained viscosity value will influence the spreadability. The viscosity test is performed using a Brookfield viscometer with spindle number 4.

c. Homogeneity Test

The homogeneity test is performed by weighing 0.5 grams of formulation, placing it on a glass object, and covering it with a glass object cover. Homogeneity is observed by determining if the formulation is homogeneous or not. The formulation is considered homogenous if the particles are evenly dispersed, the color is consistent, and there are no lumps.

d. Spreadly Test

The spreadability test determines if the formulation can be applied equally to the face or not. This can be accomplished by weighing 1 gram of the formulation, depositing it on a glass plate, applying a load of 100 grams for 1 minute, and measuring the diameter of the mask that is distributed.

e. Drying Time Test

The drying time test involves applying 1 gram to the skin's surface and then calculating the rate at which the formulation is applied till it dries. The resulting time represents the rate at which the formulation dries. A good formulation drying time is between 15 and 30 minutes.

f. Antioxidant Test

Using the DPPH technique, an antioxidant activity test was performed. 5 mg of DPPH crystals were dissolved in 50 mL (1000 ppm) to perform the DPPH technique. After diluting the sample to achieve concentrations of 100, 80, 60, 40, and 20 ppm, 2 mL of DPPH solution was added, and the mixture was incubated for 30 minutes. The effectiveness of radical scavenging is shown by the degree of color reduction in the solution. After 30 minutes of incubation, absorbance was measured using a spectrophotometer set to 517 nm wavelength. The degree of color change in the solution shows how well the radicals were absorbed. Free radical scavenging activity was calculated as the percentage reduction in DPPH coloration using the following equation.

$$\% \text{ DPPH} = \frac{A - A_0}{A_0} \times 100\%$$

Description:
A_0 = absorbance of the negative control/absorbance of the DPPH solution without sample
A = absorbance of the sample.

The IC_{50} value was obtained using the linear regression equation, in which the y-value was set at 50, resulting in the following equation

$$X = \frac{50 - b}{a}$$

3. RESULTS AND DISCUSSION

According to Amelia et al (2024) nyamplung oil has potential for ingredient cosmetics because effective as an antibacterial *Propionibacterium acnes* and has coumarin as an antioxidant (Amelia et al. 2024). The clay masks contain substances like bentonite and kaolin. Clay masks provide various skin benefits, including the ability to absorb oil, help with acne and blackheads, moisturize the skin nicely, and protect the skin from sun exposure. UV radiation can cause premature aging, thus using beauty masks can help prevent it. Premature aging is induced by excessive sun exposure, which produces free radicals. Nyamplung oil has highly strong antioxidants, thus it can be employed as an active cosmetic ingredient. The figure of the clay mask in this research is shown in Figure 1.

Figure 1. Clay mask with nyamplung oil

Clay mask characterisation was carried out to discover the material's basic components. In this study, pH, viscosity, homogeneity, spreadability, drying time, and antioxidant tests were performed to determine the optimal treatment. This characterisation is a critical foundation for developing an efficient product handling strategy that takes into consideration the chemical composition.

a. **pH**

According to study, the pH of a clay mask containing the active component nyamplung oil ranges between 5.5 and 5.8. The pH value obtained does not differ much between treatments. Figure 2 shows a graph of the test findings.

According to the study's findings, the pH value of the clay mask containing the active component nyamplung oil was consistent with the skin pH, which ranged between 5.5 and 5.8. The findings of this study are consistent with (Wananggari dan Oktavilantika 2024) research on clay masks with pandan leaf extract ranging from 4.5 to 6.5. This is consistent with the skin pH range of 4.5 to 7, implying that nyamplung oil preparations can be used in cosmetics (Liu et al. 2012). Normal human skin has a pH range of 4.5–6.5. An excessively high or low pH value can lead to skin dryness.
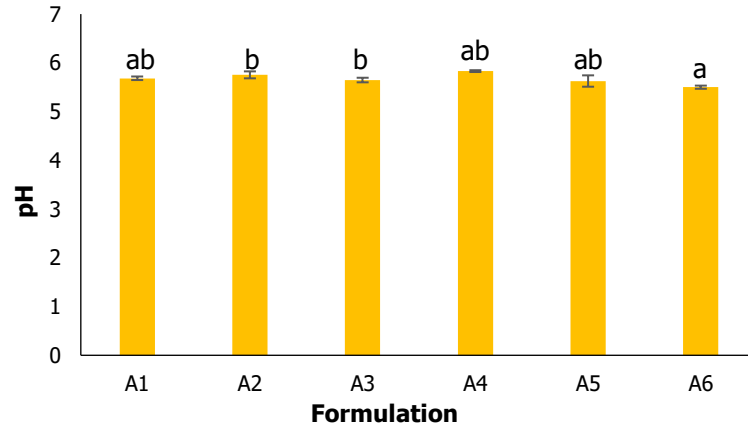
Figure 2. pH of clay mask with nyamplung oil

b. **Spread**

The study's findings indicated that the spreadability of clay masks based on nyamplung oil ranged from 3.63 to 3.76. Figure 3 displays the findings of the investigation. Good spreadability requires a distance of 2 to 5 cm (Santoso et al. 2018). Every formula satisfies the criteria for acceptable spreadability of clay mask preparations, according to the figure of the spreadability test results. The concentration in each formulation is the cause of the variations that arise. Each formulation's spreadability fluctuates while being different ingredients. This happens as different ingredients nyamplung oil. Because oil softens the texture of the mask by acting as an emollient. which impacts each formula's spreadability. The result is shown in Figure 3.

The results of this study are in line with (Fadhilah et al. 2022) the spreadability of clay masks produced from mangosteen peel extraction fluctuated, which is because the differences that occur in each formula occur due to the concentration of mangosteen peel extract in each formula. During storage, the spreadability of each formula increased and decreased. This occurs due to changes in temperature and humidity during storage which affect the spreadability of each formula.

Figure 3. Spreadly clay mask with nyamplung oil

c. Viscosity

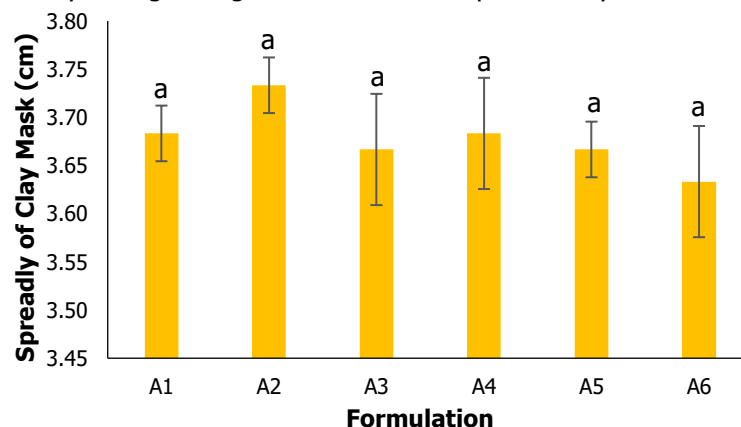The viscosity value requirements for mask preparations are 4000 - 40000 cPs (Syamsidi et al. 2021). The result of viscosity in Figure 4.
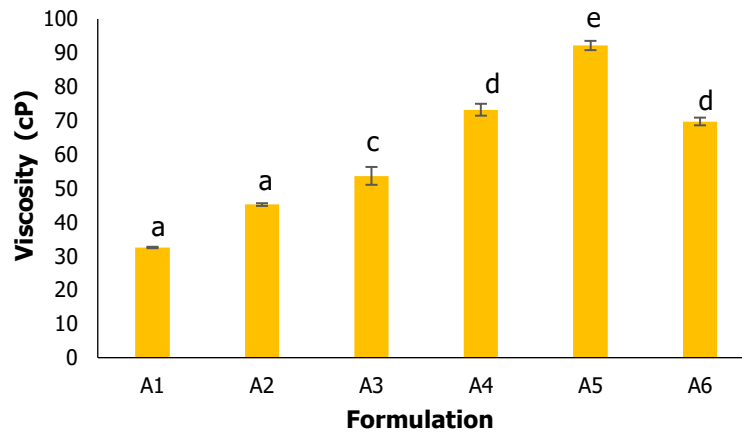

Figure 4. Viscosity clay mask nyamplung oil

The resulting mask's spreadability is also influenced by the viscosity value. An ideal clay mask should be easy to spread but should not readily disappear during use since mask preparations with high viscosity will be difficult to spread and mask preparations with low viscosity will be easily lost during use. The final product has a viscosity value between 32.53 to 92.17 cP. With the exception of treatments A4 and A6, where there was no discernible variation, the viscosity generated in this investigation varied greatly. The clay mask's spreadability may have an impact on this.

d. Adhesive

The overall adhesion at 30 minutes was determined by the adhesion test results. In contrast to the study conducted by (Zainal et al. 2023), which yielded an average adhesion of 0.77–4.81 seconds, this adhesion is quite high. The result of adding more kaolin basis is a clay mask that is tight and sticky; conversely, adding less kaolin base results in a clay mask that is less robust. The large weight pulling the glass plate has an impact on this as well. The adhesion strength increases with the applied load, as a heavier load makes it easier to separate the glass plates. According to (Dipahayu et al. 2021) he range of good adhesion is greater than one second. The results of the adhesion test are presented in Figure 5.

The adhesion test aims to determine how long it takes for the preparation to attach to the skin. According to (Pratimasari et al. 2015), topical treatments must adhere for at least four seconds. Accordingly, the clay mask used in this investigation satisfied the requirements for mask adhesion. The result adhesive clay mask nyamplung oil is shown in Figure 5.
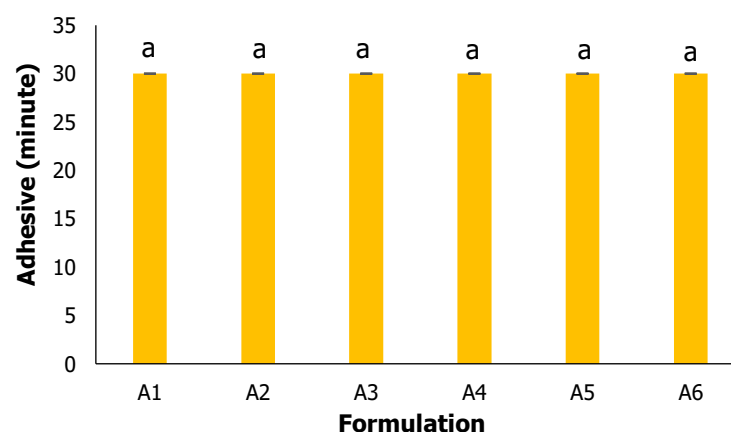

Figure 5. Adhesiveness Profile of Clay Mask Formulations

e. Drying Time

The drying time of the nyamplung oil-based clay mask ranged from 5.4 to 6.5 minutes. Based on the test results, sample A5 was significantly different from other samples; treatment A5 had a drying time of 5.4 minutes faster than the drying time of other treatments. The results of the drying time test can be seen in Figure 6.
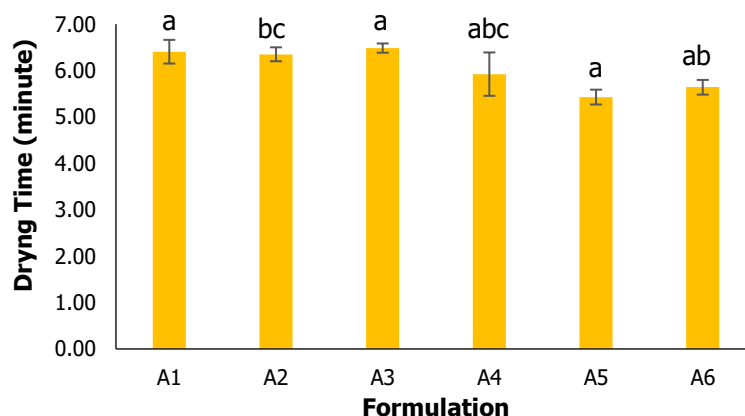

Figure 6. Drying Time Profile of Clay Mask Formulations

The drying time did not meet the standard range for clay masks. According to Sari et al. (2024) the good drying time for a clay mask is between 10-25 minutes. In this study, the drying time for the clay mask was faster than the specified standard, which was influenced by the viscosity of the clay mask produced. According to Indriastuti et al. (2022) thicker preparations can speed up the drying time of a mask, which dries quickly, can speed up the peeling time, and the active substances delivered are not optimal.

f. Antioxidant

Antioxidant testing was performed on the best sample based on viscosity and drying time on sample A5. This is because drying with a shorter time can maintain antioxidants better (Muñoz-López et al. 2018). Antioxidant activity was tested at concentrations of 20, 40, 60, and 80 ppm. The nyamplung oil antioxidant test was carried out using the DPPH method. The antioxidant absorbance of the nyamplung clay mask shows a strong concentration-dependent increase, indicating that higher sample concentrations produce higher antioxidant activity. As the concentration rises from approximately 20 to 80 (units not specified), the absorbance increases consistently from around 13 to 46. The IC_{50} value represents the concentration of the sample required to inhibit 50% of free radicals. To determine the IC_{50} from the linear regression equation obtained in the antioxidant assay, the equation $y = 0.551x + 1.35$ was used, where y represents absorbance and x represents sample concentration. The IC_{50} value is the concentration of the test compound that can reduce free radicals by 50 %. A compound is declared to have very strong antioxidant activity if the IC_{50} value is <10 µg/ mL, strong if the IC_{50} value is between 50 and 100 µg/mL, weak if the IC_{50} value is between 100 and 250 µg/mL, and inactive if the IC_{50} value is above 250 µg/mL (Phongpaichit et al. 2007). The IC_{50} value obtained in this investigation is in the high range of 88,29. Indicating that it is a strong antioxidant is a powerful antioxidant. Figure 7 shows the findings of the IC_{50} analysis.
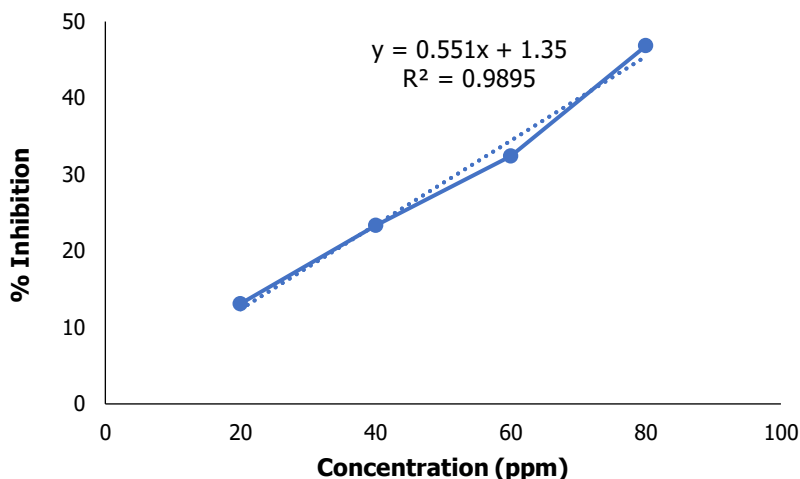
Figure 7. Antioxidant Activity of Clay Mask Formulations

4. CONCLUSIONS

The clay mask formulation containing 6% nyamplung oil and 0.8% xanthan gum (A5 treatment) demonstrated strong antioxidant activity with an IC_{50} value of 88,29. The product exhibited a relatively fast drying time of 5.6 minutes and had a skin-friendly pH of 5.56. In addition, its viscosity of 92.17 cP indicated a stable consistency and ease of application.

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Community-Based Management on Isolated Islands for Socio-economic Development — A systematic review

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Abstract

This review paper offers a thorough understanding of the literature on research in isolated island communities from the past 10 years. It uses the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. First, the study identified 190 research papers from reputable international publishers, then selected 23 for the final stage. The review highlights the policy implications of community-based management in agriculture (forestry), agroindustry, fisheries, and social science. The review reveals popular research topics discussed in recent studies and provides insight into the methods or approaches used. Our review's results show that specific methods are relevant and are still widely used by 39% of studies. Additionally, future research is expected to explore topics that have not been widely studied, particularly agroindustry. The percentage of agroindustry studies in the CBM review results on isolated islands reflects this situation, representing only 9% of the total, while fisheries represent 52%, social science 22%, and agriculture 17%.

Keywords: *community-based management; economics; isolated islands; social*

1. INTRODUCTION

Poverty is a challenge to the development of isolated community welfare in developing countries. Communities on isolated islands have available resources (natural and social), but studies show that the availability of an island's natural resource potential has not been able to increase the welfare of the people who are still trapped in poverty (Miranti, 2019; Panggarti et al., 2022; Sugiyarto et al., 2019). This situation negatively affects communities in terms of low productivity and community income, resulting in difficulties in accessing health and education services, food insecurity and malnutrition, limited infrastructure, and vulnerability to resource exploitation. Community-based management contributes to reducing poverty, where communities that have strong collective action capabilities can better plan and implement projects. For instance, in Southeast Asia (Beard, 2019; Yasmi et al., 2013), communities with robust collective action were more successful in planning independently, such as in Indonesia (Beard and Dasgupta, 2006; Fahmi et al., 2016) and Thailand (Beard and Phakphian, 2012; Kitipadung and Jaiborisudhi, 2023).

There is still not much discussion about the relationship between socio-economic structural conditions and potential in isolated communities. This paper discusses community-based management for the socio-economic structure of isolated islands in agriculture (forestry), agroindustry, fisheries, and social science. Ibnusina et al. (2023) stated that local wisdom has the potential to transform innovation in coastal communities on isolated islands, such as the Solomon Islands, bringing innovation management to marine products (Trihatmoko et al., 2020), through empowering local workers to improve welfare (Abernethy et al., 2014; Batalofo et al., 2023; Eriksson et al., 2020; Mauli et al., 2023; Rizkina et al., 2025; Schwarz et al., 2017).

Therefore, for a comprehensive study of the development of economies, showing the socio-economic structure of an isolated community, supported by a literature review from Asian countries or developing countries, is necessary. The integration of findings and research gaps are analysed for the

basic sources of this review paper (Castro et al., 2024; Milupi et al., 2017; Pomeroy and Carlos, 1997). Both Milupi et al. (2017) and Pomeroy and Carlos (1997) emphasized the critical role of empowering local communities on isolated islands. The papers also suggested fostering co-management structures involving local governments, NGOs, and community organisations to ensure sustainable socio-economic growth (Milupi et al., 2017; Pomeroy and Carlos, 1997). In addition, Castro et al. (2024) elaborated on digital community management by integrating online platforms with agricultural market linkages, knowledge exchange, and community participation (Karyawati et al., 2020). Insight from Pomeroy and Carlos (1997) is important for resource-based activities (e.g., reforestation and alternative livelihoods), and Milupi et al. (2017) emphasised monitoring aligned with agricultural needs for resource resilience on isolated islands. Research gaps can be supported from the literature review: digital connectivity (Castro et al., 2024), conflict resolution (Milupi et al., 2017; Pomeroy and Carlos, 1997), and equity and inclusivity (Milupi et al., 2017).

This review should help answer potential research questions of the isolated community in socioeconomic conditions while highlighting a deeper understanding of the problem that is useful as a basis for future research. Understanding the socio-economic structural conditions clearly is useful as a first step in answering community problems on isolated islands (Sodjinou, 2024). In addition, this study strengthens how research on small island developing states aligns with sustainable development goals (SDGs). Its findings stressed the importance of cooperation and collaborative efforts. Therefore, this review paper is aligned with the SDG framework to give the paper a stronger direction.

2. MATERIAL AND METHODS

This systematic review was performed using Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA), an evidence-based reporting method comprising a minimum set of elements for meta-analysis and reorganization. PRISMA has been used in several studies, such as Rocha et al. (2021). This method has four processes: (1) defining the research question (RQ), (2) determining the source of articles, (3) conducting a search for articles related to the RQ, and (4) analyzing the search outcomes.

In this review, we highlighted significant research formulations and sought applicable responses. The research questions for this review are shown in Table 1, based on the key direction shown in Figure 1.
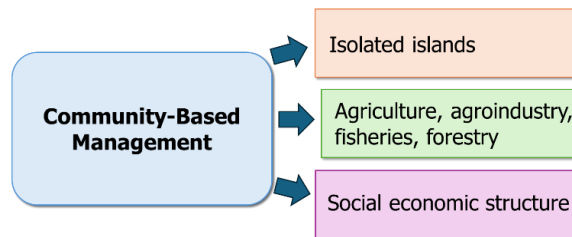
Figure 1. The key directions in the review papers

Table 1. Research questions and justification.

#	Research questions (RQ)	Justification
RQ1	What are the trends and main highlights that summarize the state-of-the-art community-based management (CBM) methods in the academic literature?	This research question aims to investigate and analyze recent trends in CBM methods to evaluate its current state, and then assess how well they are being adopted with recent CBM trends (Kaponda and Chiwaridzo, 2024) and food security (Sari and Masitah, 2021).
RQ2	What about data collection? How is it collected and how is it evaluated?	Our main observations are summarized by the question about the surveyed methods. The answer will be mainly divided into two sections: first, the data-related observations are listed, and next, we elaborate on our observations and highlight the surveyed methods.

#	Research questions (RQ)	Justification
RQ3	Is there a gap between academic research and the practices in the CBM domain?	We not only analyze recent academic works but also pioneering social and commercial CBM projects in an attempt to assess the gap between academic research and society in the domain of communities on isolated islands.
RQ4	What are the possible future directions for CBM development on isolated islands?	In this research question, we aim to compile a list of the insufficiently addressed research areas and techniques. In addition, we aim to list possible novel research directions in the targeted domain.

In this review paper, we used relevant literature that came from literature that was published between 1 January 2014 and 10 January 2025. The journals and conference proceedings were obtained from Elsevier, Science Direct, IOP Science, MDPI, IEEE Xplore, Google Scholar, Wiley, Taylor & Francis, Sage Publishing, and Emerald. A further selection step was applying criteria shown in Table 2. A flowchart of the selection process is shown in Figure 4.

Table 2. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Elsevier, Science Direct, IOP Science, MDPI, IEEE Xplore, Google Scholar, Wiley, Taylor & Francis, Sage Publishing, and Emerald	Books, reviews, short articles, and journal editorial statements,
Published between 1 January 2014 and 10 January 2025	Published outside 1 January 2014 to 10 January 2025
Available in full-text	Unavailable in full-text
Papers written in English	Papers not written in English
Articles must include a certain combination of words, i.e., (community-based management) + (isolated islands/rural area) + (agriculture/agroindustry/fisheries/forestry)+(social economic structure)	Articles did not include a certain combination of words, i.e., (community-based management) + (isolated islands/rural area) + (agriculture/agroindustry/fisheries/forestry) +(social economic structure)

After applying the criteria, 23 articles were included in the review, as shown in Table 3, Figure 2, Figure 3, and Figure 4 (Kuncoro et al., 2023).
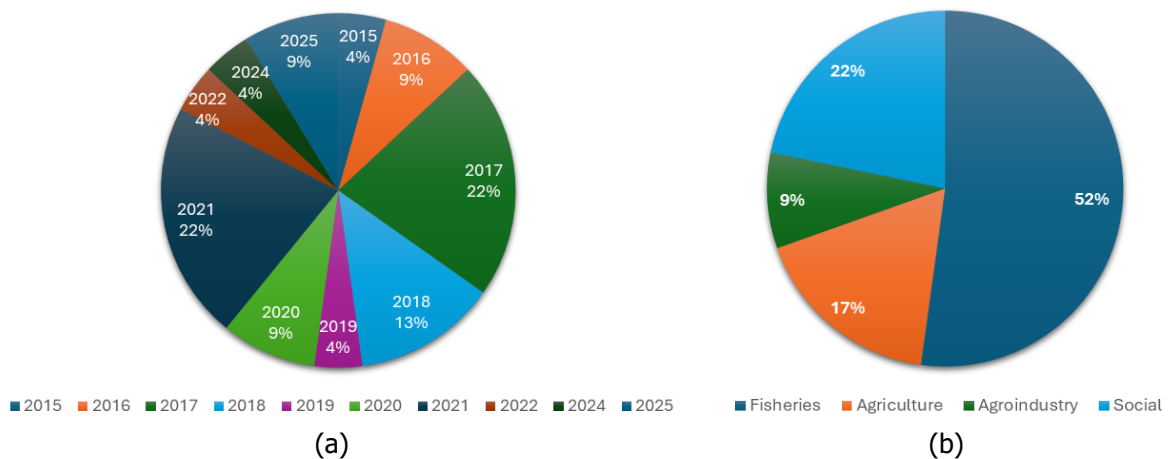
Figure 2. Descriptive statistical analysis based on (a) publication year of the literature studies, and (b) subject keywords of the literature studies

(a)   (b)
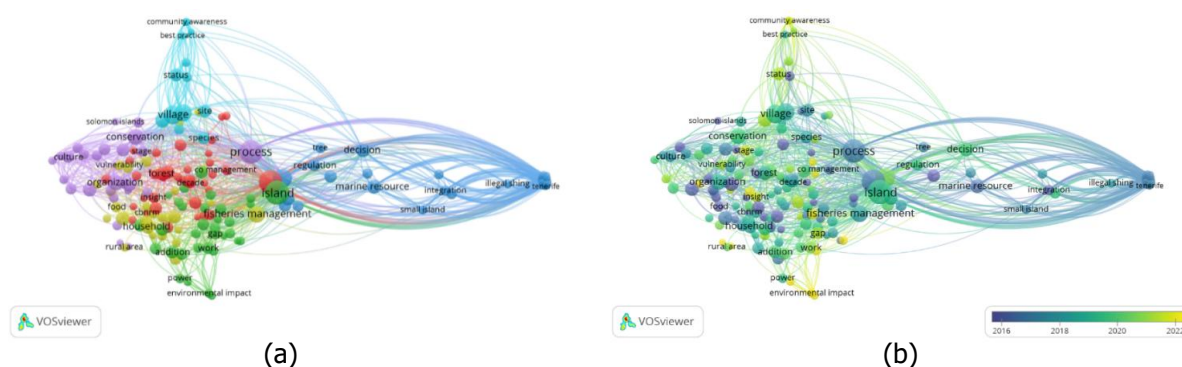
Figure 3. Bibliometric network of literature reviews : (a) based on the related topic and (b) based on the year of publication

Table 3. Selected articles, date of publication, and number of citations

No.	Author	Publication Year	Citation Number	Publisher	Country
1	Wilson et al.	2025	0	Elsevier	United Kingdom
2	Kruse et al.	2025	0	Elsevier	Netherlands
3	Ursić et al.	2024	4	Emerald Group Publishing Ltd.	United Kingdom
4	Reynolds et al.	2022	12	Elsevier	United Kingdom
5	Sok and Yu	2021	9	Elsevier/KeAi Communications Co.	China
6	Murhaini and Achmadi	2021	46	Elsevier	Netherlands
7	Islam, M. S., et al.	2021	13	Emerald Group Publishing Ltd.	United Kingdom
8	Delgado et al.	2021	23	Elsevier	United Kingdom
9	Casola et al.	2021	4	Elsevier	United Kingdom
10	Basel et al.	2020	63	Elsevier	United Kingdom
11	Wahyono and Illiyani	2020	5	IOP Publishing Ltd.	United Kingdom
12	Paulangan et al.	2019	6	IOP Publishing Ltd.	United Kingdom
13	Prieto-Carolino et al.	2018	13	Elsevier	United Kingdom
14	Nwankwo et al.	2018	10	SAGE Publications Inc.	United States
15	Molina	2018	8	Emerald Group Publishing Ltd.	United Kingdom
16	Teniwut et al.	2017	7	IOP Publishing Ltd.	United Kingdom
17	Schwarz et al.	2017	11	South Pacific Commission	Malaysia
18	Romero Manrique de Lara and Corral	2017	24	Elsevier	United Kingdom
19	Prodhan et al.	2017	2	IOS Press BV	Netherlands
20	Corral and Manrique de Lara	2017	20	Elsevier	United Kingdom
21	Remling and Veitayaki	2016	79	Emerald Group Publishing Ltd.	United Kingdom
22	Patankar et al.	2016	10	Elsevier	United Kingdom
23	Suh	2015	15	SAGE Publications Inc.	United Kingdom

Identification of studies via database and registers

Identification

| Record identified from: Elsevier, Science Direct, IOP Science, MDPI, IEEE Xplore, Google Scholar, Wiley, Taylor & Francis, Sage Publishing, and Emerald (n = 190) | → | Records removed before screening due to publication outside the selected periods and not written in English (n = 15) |

Screening

| Records screened (n = 175) | → | Records excluded due to data duplication (n = 6) |

| Records screened (n = 169) | → | Records excluded due to being published ouside 2014 to 2025 (excluded n = 46) |

| Reports assessed for eligibility (n = 123) | → | Records excluded due to not discussing communities on isolated islands (n = 55) |

| Reports assessed for eligibility (n = 68) | → | Records excluded due to not being conducted for agroindustry economic development (n = 45) |

Included

| Studies included in review (n = 23) |

Figure 4. Flowchart of the included studies describing community-based management on isolated islands

3. RESULTS AND DISCUSSION

Studies of community-based management (CBM) continue to develop alongside the increasingly crucial problems of agriculture (forestry), fisheries, agroindustry, and social economics in community life, especially in rural areas and on isolated islands. Additionally, studying management solutions is necessary to maximize the potential and benefits of bioresource business management. Over the past few years, CBM studies have advanced significantly through numerous case studies,

including those on sustainable agriculture (Kaponda and Chiwaridzo, 2024) and food security (Sari and Masitah, 2021). In this publication review on community-based management, we examined 23 papers from 190 papers. Several researchers highlight the sustainability of supporting the lives of people in remote island communities (Wu et al., 2023). Based on the literature study, as shown in Figure 5, a CBM case study outline has been compiled, which is classified based on trends and main highlights, as shown in Table 4.

Figure 5. Research block diagram of the literature reviews

Table 4. Outline of CBM case studies, trends, and main highlights

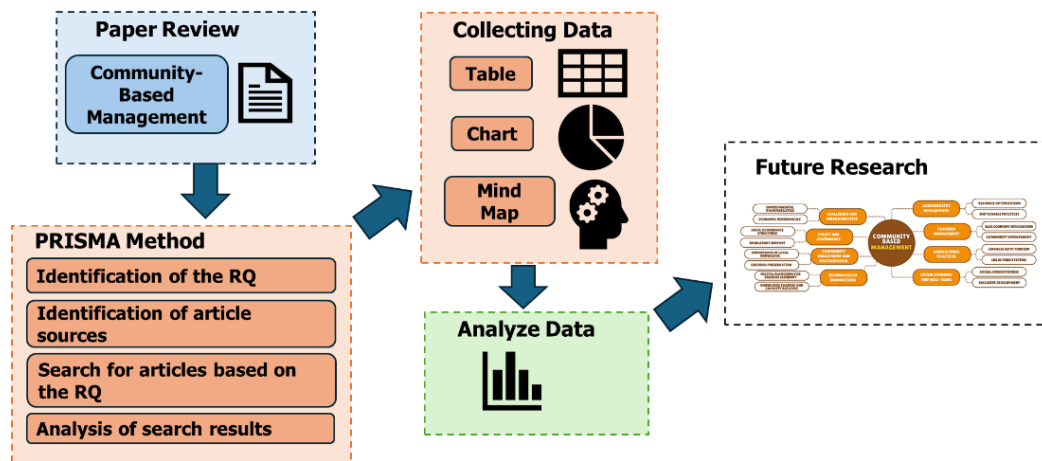| No.	Reference	CBM Case Study	Trend	Main Highlight
1	(Wilson et al., 2025)	Centralized fisheries management in Lake Malawi and Mbenji Island, Malawi	Centralized management	Need for historical awareness in fisheries management
2	(Wahyono and Illiyani, 2020)	Marginalization of coastal communities on the island of Brač, Croatia	Rights of coastal communities	Need for rights-based fisheries management (RBFM)
3	(Ursić et al., 2024)	Female perspective on island development	Significant trend in increasing tourism	Reimagining island development from a female perspective
4	(Teniwut et al., 2017)	Knowledge management capabilities related to marine and fisheries resources in Southeast Maluku, Indonesia	Development of knowledge management capabilities	Three critical factors: technology, organizational structure, organizational culture
5	(Suh, 2015)	Case of the 'Full of Grace Organic Agriculture Producers' cooperative in the Philippines	Community-based organic agriculture (CBOA)	Government's role in promoting organic agriculture
6	(Sok and Yu, 2021)	Co-management of small-scale fishery in Tonle Sap Lake, Cambodia	Co-management of small-scale fisheries	Community participation and satisfaction levels
7	(Schwarz et al., 2017)	Adaptive co-management in small-scale fisheries in the Solomon Islands	Community-based resource management (CBRM)	Importance of local governance, knowledge integration, community participation

No.	Reference	CBM Case Study	Trend	Main Highlight
8	(Romero Manrique de Lara and Corral, 2017)	Artisanal fishing community on the Island of Tenerife, Spain	Socio-economic development of small island fishing communities	Necessity for participatory research and improved communication among stakeholders
9	(Reynolds et al., 2022)	Feasibility of an anaerobic digestion (AD) plant installation in the Orkney Islands, United Kingdom	Waste-to-resource approaches for sustainability	Feasibility of an anaerobic digestion (AD) plant
10	(Remling and Veitayaki, 2016)	Community's proactive resource management on Gau Island, Fiji	Community-based adaptation (CBA)	Importance of local engagement and integrated resource management
11	(Prodhan et al., 2017)	Salinity intrusion affecting agricultural practices in Parulia Union, Bangladesh	Successfully adapted by salinity intrusion due to shrimp farming	Adaptation strategies by farmers
12	(Prieto-Carolino et al., 2018)	Philippine abalone fisheries	Community-based co-management (CBCM)	Fishers' empowerment and collaboration with local government units and stakeholders
13	(Paulangan et al., 2019)	Coral reef management in socio-economic dimensions in Jayapura, Indonesia	Sustainability index values	Need for tailored management strategies
14	(Patankar et al., 2016)	Effectiveness of traditional marine management practices in the Nicobar Islands	Need for compliance in comparing three management regimes	Importance of traditional institutions in managing marine resources sustainably
15	(Nwankwo et al., 2018; Patankar et al., 2016)	Role of community heritage resources in crisis management within rural Nigeria	Community management and identification through heritage	Importance of preserving resources for community unity and conflict resolution
16	(Murhaini and Achmadi, 2021)	Farming management practices of the Dayak people in Kalimantan, Indonesia	Sustainable farming practices	Cultural significance of rice and the social dimensions in agricultural practices
17	(Molina, 2018)	Collective action among stakeholders in the Gigantes Islands, Philippines	Promoting resilience and inclusive development in small island communities	Convergence strategy with implementation of a project
18	(Kruse et al., 2025)	Ecosystem Status Report (ESR) framework in the Bering Sea and Aleutian Islands, the Alaska Region	Necessity of continuous evaluation of crab stocks and ecosystems	Importance of integrating ecosystem considerations into fisheries management
19	Islam, S., et al., 2021)	Maritime transport system for coastal communities of Vancouver Island, Canada	Resilience of maritime supply chains	Importance of developing resilience strategies tailored to specific disruptions

No.	Reference	CBM Case Study	Trend	Main Highlight
20	(Delgado et al., 2021)	Role of managing water supply and participation of rural households on Chiloé Island, Chile	Governance structures and community participation in water management	Conceptual models and frameworks
21	(Corral and Manrique de Lara, 2017)	Artisanal fishing communities on the Island of Tenerife, Canary Islands	Socio-economic development and challenges to local coastal and marine resources	Importance of integrating local fishing communities into decision-making processes
22	(Casola et al., 2021)	Artisanal fishing communities on Andros Island, The Bahamas	Effects of modernization on fishing communities	Effects for both positive and negative outcomes
23	(Basel et al., 2020)	Community-based climate change adaptation planning on Rendova Island, the Solomon Islands	Local knowledge and resource management	Community priorities for adaptation: governance, sustainable livelihoods, resource management

The management of isolated islands through community-based methods is increasingly recognized, as evidenced by research recommendations based on robust and valid methods. Data analysis synthesizes trends and highlights, justifying integrative and adaptive problem-solving. Table 5 and Figure 6 (a) show the types of methods used in CBM research: a mixed methods approach, a qualitative method, and a specific analysis approach. A mixed methods approach combines qualitative and quantitative research techniques in one study to produce a deeper, more comprehensive understanding of the research problem (Sedegah et al., 2023). Several papers in this review study have successfully carried out this approach, providing more in-depth solution recommendations (Prodhan et al., 2017; Sok and Yu, 2021; Teniwut et al., 2017; Wilson et al., 2025). Qualitative methods focus on exploring phenomena in depth by capturing the meaning and experiences of respondents without emphasizing measurement and statistical analysis (quantitative methods) (Sedegah et al., 2023). In this study, the percentage of researchers who used a qualitative method was much higher than the percentage of researchers who used a specific method approach. In the context of CBM on isolated islands, qualitative methods can provide rich contextual insights into community perceptions, values, and practices. In addition, specific analysis approaches can assess case study issues that are more relevant and appropriate to the researcher's needs for justification, such as the participatory technique in Figure 6 (b).
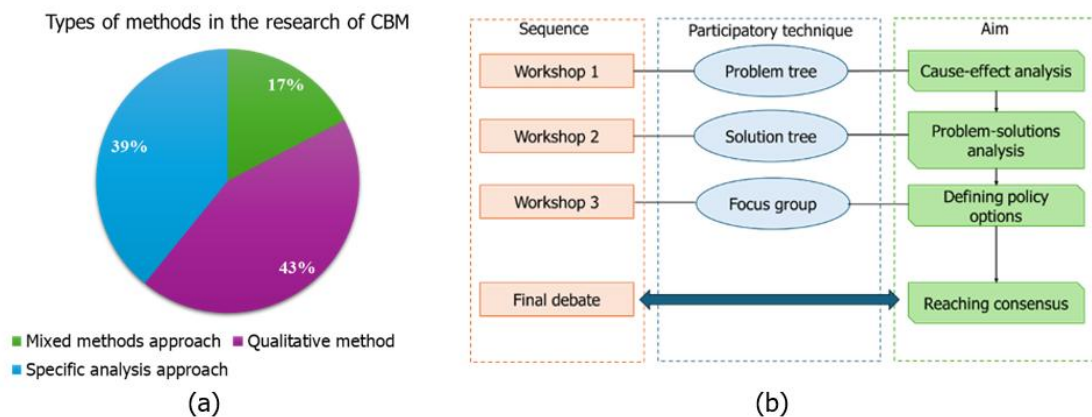

Figure 6. (a) Types of methods used in the research of CBM; (b) Methodological framework of the participatory techniques (Corral and Manrique de Lara, 2017; Romero Manrique de Lara and Corral, 2017)

One of the main highlights from the literature review is the need to integrate local knowledge into natural resource conservation practices. Researchers report the importance of incorporating local knowledge and practices into natural resource management (Basel et al., 2020; Nwankwo et al., 2018; Patankar et al., 2016). This is also supported by the findings of the researchers' study which emphasized the need for open communication through participatory discussions to ensure the success of management strategies (Delgado et al., 2021; Molina, 2018; Wahyono and Illiyani, 2020). On isolated islands, ecosystems are usually fragile due to the impact of external pressures, so natural resource management practices based on local wisdom have the potential to produce management practices that are more appropriate and in line with community values (Casola et al., 2021; Corral and Manrique de Lara, 2017; Kruse et al., 2025).

In addition, studies on trends and main highlights also highlight aspects of agroindustry that have not been widely studied but have a significant impact on communities in isolated islands. This is like the potential for supply chain management for food security and marketing of natural resource products reported by Islam, M.S., et al., (2021) and strengthening upstream to downstream production design in local wisdom-oriented resource management (Prodhan et al., 2017; Remling and Veitayaki, 2016). The potential of supply chain management will be a great start for fast-moving consumer goods (FMCG) businesses (Trihatmoko et al., 2020). Other research also has the potential to improve the welfare of communities on isolated islands, such as tourism development (Ursić et al., 2024) and waste management (Reynolds et al., 2022). The justification for problem-solving in almost every research paper is explained as a specific problem related to a comprehensive understanding of the local context and the synergy of collective actions. Based on the SDG framework, some papers discussed the localization of the SDGs, which involves tailoring the SDGs to island-specific governance, culture, and environment through local engagement. The quality of the evidence can be found in all the research papers that discuss a specific problem trend and elaborate on a fundamental theory to justify problem-solving. The recent trends are classified by methods and justification for problem-solving, as shown in Table 5.

Table 5. Recent trends in methods and justification for problem-solving

No.	Reference	Trend	Method	Justification for problem-solving
1	(Wilson et al., 2025)	Centralized management	Mixed methods approach	The study moves beyond merely technical solutions to include broader social and political considerations
2	(Wahyono and Illiyani, 2020)	Rights of coastal communities	Qualitative method	In-depth understanding of the socio-cultural and regulatory dynamics affecting coastal communities
3	(Ursić et al., 2024)	Significant trend in increasing tourism	Thematic analysis approach	Grounded in existing theoretical frameworks; comprehensive understanding of participants' experiences and perspectives
4	(Teniwut et al., 2017)	Development of knowledge management capabilities	Mixed methods approach	Providing a comprehensive understanding of factors influencing knowledge management
5	(Suh, 2015)	Community-based organic agriculture (CBOA)	Qualitative method	The method is relevant and adaptable to local conditions, maximizing the synergy of collective actions
6	(Sok and Yu, 2021)	Co-management of small-scale fisheries	Mixed methods approach	Allowed for a robust collection of data, providing a well-rounded understanding of issues at hand

No.	Reference	Trend	Method	Justification for problem-solving
7	(Schwarz et al., 2017)	Community-based resource management (CBRM)	Participatory diagnosis, management, monitoring	Management solutions tailored to fit the local governance context and informed by multiple knowledge sources, fostering local ownership and participation
8	(Romero Manrique de Lara and Corral, 2017)	Socio-economic development of small island fishing communities	Qualitative method	Comprehensive problem-solution relationship analysis, fostering a collaborative approach to sustainable fisheries management
9	(Reynolds et al., 2022)	Waste-to-resource approaches for sustainability	Techno-economic analysis	This approach helps in evaluating the feasibility of the investment opportunity and addresses the problem of waste management
10	(Remling and Veitayaki, 2016)	Community-based adaptation (CBA)	Qualitative method	Comprehensive understanding of local contexts and priorities
11	(Prodhan et al., 2017)	Successfully adapted by salinity intrusion due to shrimp farming	Mixed methods approach	The study captures a holistic view of the problem, facilitating development of effective adaptation strategies
12	(Prieto-Carolino et al., 2018)	Community-based co-management (CBCM)	Qualitative method	Comprehensive understanding of issues and to propose solutions, leveraging strengths of community organizing and stakeholder collaboration
13	(Paulangan et al., 2019)	Sustainability index values	RAPSOCIO-ECOSYSTEM method: modified version of Rapid Appraisal for Fisheries Approach (RAPFISH),	Multidimensional framework necessary for addressing the complex issues of coral reef ecosystem management
14	(Patankar et al., 2016)	Need for compliance in comparing three management regimes	Qualitative method	Need to evaluate effectiveness of traditional management systems in the Nicobar Islands
15	(Nwankwo et al., 2018)	Community management and identification through heritage	Descriptive survey research design and ethnographic methods	The study captures both the measurable effect of heritage resources and nuanced, culturally embedded practices
16	(Murhaini and Achmadi, 2021)	Sustainable farming practices	Qualitative method	Particularly effective in problem-solving: helps identify cultural and social factors that influence farming practices
17	(Molina, 2018)	Promoting resilience and inclusive development in small island communities	Institutionalization of a convergence strategy	Collectively contribute to sustainable development and resilience building in the islands

No.	Reference	Trend	Method	Justification for problem-solving
18	(Kruse et al., 2025)	Necessity of continuous evaluation of crab stocks and ecosystems	Ecosystem-based fisheries management (EBFM) approach	Robust framework for addressing multifaceted challenges of fisheries management, ensuring that decisions are informed by a comprehensive understanding
19	(Islam, S., et al., 2021)	Resilience of maritime supply chains	Case study approach for practical reasons; triangulated research design	Detailed understanding of under-researched topics by incorporating multiple sources of evidence
20	(Delgado et al., 2021)	Governance structures and community participation in water management	Mixed methods approach	Collectively enable a transdisciplinary approach, integrating social, ecological, and political perspectives to address complex challenges
21	(Corral and Manrique de Lara, 2017)	Socio-economic development and challenges to local coastal and marine resources	Qualitative method	Collectively enhance decision-making process and empower local communities to participate actively in managing their resources
22	(Casola et al., 2021)	Effects of modernization on artisanal fishing communities	Qualitative method	The study is able to address gaps in previous research that often relied on outsider viewpoints
23	(Basel et al., 2020)	Local knowledge and resource management	Modified Local Early Action Planning (LEAP) methodology and a semi-quantitative vulnerability assessment	The study achieves a comprehensive vulnerability analysis that is both scientifically rigorous and locally relevant, increasing likelihood of identifying effective adaptation priorities

Most researchers use field surveys to collect data. These surveys may include interviews, focus group discussions, household surveys, direct participation, and triangulated research designs. This literature review examined community-based management (CBM) using a case study of an isolated island or rural area. The findings are presented in a three-phase framework research paper pattern, as shown in Figure 8: input, process, and output. Based on the literature review, researchers attempted to bridge the gap between academic theory and community issues and needs by identifying socioeconomic conditions, as demonstrated in Table 7 and Figure 9. Researchers adjust their analyses to the research methods used in the data analysis process. Furthermore, when using a mixed methods approach, researchers conduct qualitative research through interviews and literature studies, as well as statistical tests. For example, Teniwut et al. (2017) performed a hierarchical regression test using SPSS 24 (Teniwut et al., 2017). Additionally, researchers using qualitative methods have valid and reliable data analysis methods that are adjusted to the needs of the research, the conditions of the field, and the characteristics of the data. For example, Murhaini and Achmadi (2021) conducted qualitative research with data analysis using a coding process guided by Kroeber and Kluckhohn's cultural cycle approach (Murhaini and Achmadi, 2021).
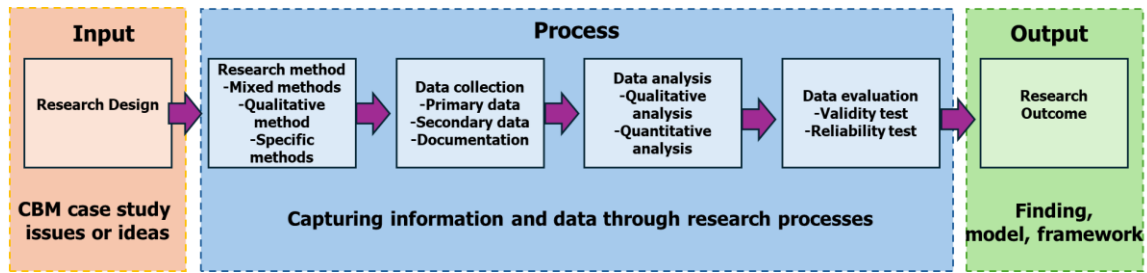
Figure 8. Overview of research framework

Community-based management (CBM) research aims to solve community problems through academic inquiry. Therefore, paying attention to the research framework is important for conducting good research. Based on a literature review, researchers have attempted to bridge the gap between academic theory and community issues and needs by identifying socioeconomic conditions, as illustrated in Table 7 and Figure 9.
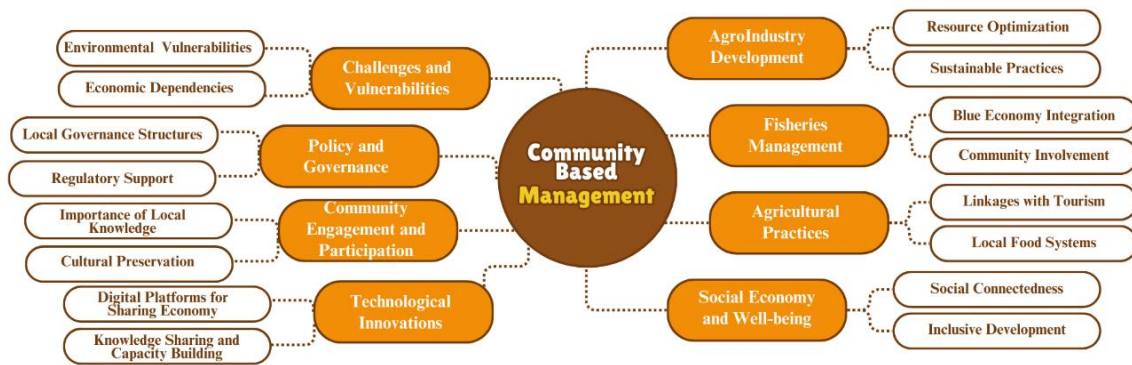

Figure 9. Mind map of community-based management (CBM) based on paper review results

Based on the literature review, researchers attempted to bridge the gap between academic theory and community issues and needs by narrowing their research focus and employing relevant methods. This makes research findings more easily accepted and applied by communities in isolated areas. Examples include the long-term success of the Mbenji Island fisheries (Wilson et al., 2025); a unique cooperative of artisanal producers (Manrique de Lara and Corral, 2017); and community-based knowledge sharing (Teniwut et al., 2017). Table 7 provides a classification of relevant studies for CBM and socio-economic conditions.

Table 7. Relevance studies from classification for CBM and socio-economic conditions

Reference	Method	Data Collection	Socio-economic Conditions
(Wilson et al., 2025)	Mixed methods approach	Archival research, oral histories, environmental sampling	Long-term success of Mbenji Island fisheries
(Wahyono and Illiyani, 2020)	Qualitative method	Interviews and observations	Not mentioned
(Ursić et al., 2024)	Thematic analysis approach	Interviews with both snowball and convenience sampling	Capital framework to identify socio-cultural, economic
(Teniwut et al., 2017)	Mixed methods approach	In-depth interviews and questionnaires	Community-based knowledge sharing for sustainable economic objectives
(Suh, 2015)	Qualitative method	Not mentioned	Lack of economic incentives for CBOA; suggests policy measures to address this gap

Reference	Method	Data Collection	Socio-economic Conditions
(Sok and Yu, 2021)	Mixed methods approach	Household surveys, key informant interviews, group discussions	Need for improved resource sharing, capacity building, and law enforcement
(Schwarz et al., 2017)	Participatory diagnosis, management, monitoring	Household surveys, focus group discussions (FGDs), secondary literature	Necessity of capacity building among participants to reflect and adapt management practices.
(Romero Manrique de Lara and Corral, 2017)	Qualitative method	Participatory approach	Unique cooperative of artisanal producers proposed to enhance commercialization and reduce operational costs
(Reynolds et al., 2022)	Techno-economic analysis	Online questionnaire	Economic and social benefits of utilizing local waste
(Remling and Veitayaki, 2016)	Qualitative method	Qualitative fieldwork: semi-structured interviews and discussions	Local ownership and self-determination, which are crucial for sustainable change
(Prodhan et al., 2017)	Mixed methods approach	Focus group discussions and key informant interviews	Need for further scientific studies and government support to ensure long-term sustainable solutions for affected communities
(Prieto-Carolino et al., 2018)	Qualitative method	Face-to-face interviews, focus group discussions (FGDs), key informant interviews	Effectiveness of organized fishers in managing abalone resources sustainably
(Paulangan et al., 2019)	RAPSOCIO-ECOSYSTEM method	Field surveys and in-depth discussions	Socio-economic changes contingent upon strong community institutions
(Patankar et al., 2016)	Qualitative method	Measuring fish abundance and biomass, recording all non-cryptic fish species, semi-structured interviews	Not mentioned
(Nwankwo et al., 2018)	Descriptive survey research design and ethnographic methods	Cluster and purposive sampling for interviews; multistage sampling for the quantitative survey	Not mentioned
(Murhaini and Achmadi, 2021)	Qualitative method	Direct observation, interviews, secondary data	Significance of customary values and traditions in the Dayak people's farming management system
(Molina, 2018)	Institutionalization of a convergence strategy	Participatory risk and capacity needs assessments	Not mentioned
(Kruse et al., 2025)	Ecosystem-based fisheries management (EBFM) approach	Annual bottom trawl surveys	Importance of integrating ecosystem and socioeconomic indicators into stock assessments
(Islam, S., et al., 2021)	Case study approach for practical reasons; triangulated research design	Triangulated research design, using interviews, documentation, site visits	Several resilience strategies to mitigate effect of future disruptive events on maritime logistics
(Delgado et al., 2021)	Mixed methods approach	Literature review, semi-structured interviews, rural household survey	Need for a multi-level contextual approach to

Reference	Method	Data Collection	Socio-economic Conditions
			improve rural water governance
(Corral and Manrique de Lara, 2017)	Qualitative method	Stakeholder analysis, semi-structured interviews, focus groups, workshops	Socio-economic development of small-island fishing communities, particularly focusing on artisanal fishing sector
(Casola et al., 2021)	Qualitative method	Interviews using snowball sampling	Modernization and globalization have resulted in overexploitation of natural resources
(Basel et al., 2020)	Modified Local Early Action Planning (LEAP) methodology, semi-quantitative vulnerability assessment	Capturing information, semi-quantitative vulnerability assessment, interviews	Importance of inclusive and participatory processes in developing effective climate adaptation strategies

The number of research articles discussing agroindustry studies on isolated islands is very low. Researchers have found few research articles on the socio-economic development of agroindustry on isolated islands with an in-depth and comprehensive understanding. This lack of articles on agroindustry studies is different from the topics of fisheries, agriculture, and social science, which are not difficult to find. This situation can lead to potential future research on the agroindustry that focuses on upstream and downstream connections being important for people on isolated islands. Researchers have only conducted studies on supply chain management in communities on isolated islands. Krisnaningsih et al. (2024) reported the importance of a decision support system to optimize supply chain conditions on isolated islands. Kusnandar et al. (2019) found that the participation of all actors in the supply chain plays an important role in achieving sustainable change in agroindustrial, with the proposal of Participatory Sustainable Agricultural Development, which can be implemented by involving communities in such development. Therefore, there is little research on agroindustry (lack of empirical support), and the location on an isolated island is an overlooked study area. In addition to fisheries, agriculture, and social science that have been widely studied, CBM for the development of socio-economic agroindustry on an isolated island should potentially become another perspective for comparison in viewing a problem.

Based on the literature review, the potential of agroindustry in community-based management on remote islands is relevant and plays several important roles. First, in terms of economic development, agroindustry can stimulate economic growth on isolated islands by creating jobs and increasing local income. For example, Mardesci et al. (2021) found that developing a coconut-based agroindustry in Indonesia has proven effective in providing jobs and increasing the value of coconut products. Second, in terms of food security, agroindustry can increase food security on remote islands by establishing facilities and improving food processing skills (Rizkina et al., 2025), enabling communities to reduce their dependence on food products from outside the islands, which are often subject to weather and sea conditions. Agroindustry also has the potential to contribute to food availability and economic stability (Abildtrup, et al., 2012; Rizkina et al., 2022). Additionally, in terms of sustainable resource management, agroindustry can utilize local resources efficiently through sustainable practices, such as minimizing waste. For instance, increasing the value of agricultural byproducts can mitigate environmental impact (Murtius, 2024). This aligns with the local wisdom of isolated islands, which helps preserve ecosystems and biodiversity while supporting the local economy. Then, community empowerment and community-based management in the agroindustry sector will involve community contributions to foster a sense of shared ownership and responsibility for resource management. According to Fahmi et al. (2013), community involvement in agroindustry can increase

social cohesion and empower local residents. This is particularly relevant for isolated islands, where strong community ties and collective action can lead to more effective resource management. Finally, technological innovation and the introduction of new technologies can adapt to the community's needs, increasing productivity and efficiency. Examples include the use of digital devices in agricultural practices (Medvedskaya et al., 2021).

Methods as steps or procedures for conducting research, are an important part of research. Based on the literature review of CBM on isolated islands, qualitative methods and specific methods are the most widely used. Mixed methods are the least used, even though it is effective in providing an in-depth and comprehensive understanding compared with other types of methods. Therefore, researchers should be able to use mixed methods to explore problems more deeply through qualitative research and draw valid conclusions and reliable generalizations through quantitative research. Community-based management involves community contributions to foster a sense of shared ownership and responsibility for resource management. The study of community-based management is also still considered to be limited in examining isolated island case studies. Most research only discusses case studies of rural areas, whereas isolated island case studies need to be given attention because some problems are essential. Therefore, future research is expected to pay attention to isolated island case studies to reduce a concern problem, such as poverty, as the number one sustainable development goal (SDG).

The SDG framework adopted the 17 Sustainable Development Goals (SDGs) as part of the 2030 Agenda for Sustainable Development. The SDGs aim to promote human well-being, environmental conservation, and the sustainable management of natural resources. To support these goals, community-based management in isolated communities can be a new research objective. However, little research exists on interdisciplinary discussions of CBM, which are necessary for isolated communities as vulnerable objects. In addition, fisheries are a major focus of CBM-related research because they are fundamental to the economic development of isolated islands. The community depends on fisheries and marine products for food security and business. The same is true for agriculture, which is also a major concern in CBM-related research. However, research gaps can be found in the SDGs on agroindustry, which are under-researched in island contexts. Therefore, this innovative research and robust methodology can provide proper policies and precise practical recommendations, particularly for governments and NGOs working in island contexts.

4. CONCLUSIONS

The study highlights novel contributions to research papers over the past ten years. It shows that CBM applications continue to focus on integrating local wisdom through the participation of all stakeholders, such as community members and government officials. CBM studies primarily employ observation, interviews, focus group discussions, surveys, and literature reviews to collect data. The evaluation of CBM study data should align more closely with the mixed methods approach, which is rarely used. The study also suggests reducing the gap between academic theory and community needs by examining methods that provide a deeper, more comprehensive understanding for future research directions, according to field conditions. Our review's results show that 39% of studies still use specific methods, which is this review's unique contribution. Additionally, future research is expected to explore topics that have not been widely studied, such as agroindustry in isolated island contexts. This finding is reflected in the percentage of CBM review results on isolated islands: agroindustry studies represent only 9%, while fisheries represent 52%, social sciences represent 22%, and agriculture represents 17%. The study suggests that future research based on an in-depth exploration of CBM topics in isolated island contexts can provide specific, practical implications for policymakers through robust methodologies such as mixed-methods approaches in agroindustry. This approach will help policymakers analyze decision-making based on comprehensive data.

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Integrating Co-Creation and Open Innovation for Sustainable Value Creation: Evidence from Muslim-Friendly Restaurants in Tokyo

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Abstract

The growing presence of Muslim residents and visitors in Japan has increased the need for food services that align with Muslim-friendly expectations. However, limited empirical research examines how co-creation and open innovation contribute to sustainable business performance in this niche sector. This study explores these dynamics by analysing insights from five Muslim-friendly restaurants in Tokyo and survey responses from 57 Muslim consumers. The findings show that consumer involvement in open innovation activities meaningfully enhances several dimensions of sustainability, including financial performance, environmental responsibility, and social value creation, thereby strengthening trust and loyalty. Despite these positive outcomes, restaurants continue to face operational constraints—particularly certification challenges and the costs associated with providing fully Muslim-friendly offerings. The study suggests refining the DART (Dialogue, Access, Risk–Benefit Assessment, and Transparency) framework to better reflect co-creation practices in minority-market food services. Overall, the results confirm that open innovation significantly drives sustainable business outcomes (β = 0.675, p < 0.05) and provide strategic guidance for Muslim-friendly restaurants seeking to expand their market reach and enhance long-term sustainability.

Keywords: *co-creation; minority markets; Muslim-friendly food services; open innovation; sustainable business*

1. INTRODUCTION

Food quality has become a significant concern for many, particularly among Muslim communities, as evidenced by the considerable growth of the halal food market, which rose by 6.9% in 2021 and 7.0% in 2022 (DinarStandard, 2022). This growth presents an opportunity for countries that receive large numbers of Muslim tourists to meet the demand for halal food, such as Japan. However, the previous research by Ohgata (2021) stated that the production and business processes present in Japan pose complex challenges, including raw material selection, production facilities, transportation, kitchen usage, storage, placement of sales floors, and certification costs, which have limited product development (Widiastuti et al., 2020) and resulted in a lack of customer trust, loyalty (Quoquab et al., 2019), and satisfaction (Putra et al., 2016).

Japanese restaurants have been encouraged to develop innovative business processes to address these challenges. However, halal business owners struggle to balance open innovation with the challenges of the halal food industry, and providers must utilize co-creation to maintain customer loyalty. Previous research demonstrates a positive correlation between open innovation, co-creation, and business performance, particularly in product development and marketing. Additionally, stakeholder collaboration is a core success factor for businesses to sustain their performance (Jeong et al., 2020).

Although Muslim-friendly food services hold considerable promise in countries where Muslims represent a minority, scholarly evidence on how co-creation and open innovation contribute to

sustainable business performance in this sector remains scarce. Actors within this ecosystem require integrated innovation frameworks; however, practical and strategic challenges frequently lead to fragmented information and limited coordination. In response to these gaps, this study investigates how Muslim-friendly restaurants in Tokyo, Japan's largest metropolitan area, and a key example of a Muslim-minority market, enact open innovation and co-creation to identify mechanisms that can strengthen long-term sustainability within these businesses.

2. MATERIAL AND METHODS

This study investigates how open innovation and co-creation operate in Muslim-friendly foodservice businesses in Tokyo, with a specific emphasis on restaurant operations. Co-creation is approached as a value-generation process grounded in reciprocal interaction between firms and consumers, whereby both parties contribute knowledge, preferences, and experiential insights (Prahalad & Ramaswamy, 2004). This process aligns closely with the principles of open innovation, which encourage organizations to incorporate external ideas and knowledge flows into their internal development activities (Haro et al., 2014). Together, these concepts provide a foundation for understanding how Muslim-friendly restaurants engage multiple stakeholders in shaping product and service improvements.

The study examines open innovation and co-creation as integral components of product and service development, involving contributions from business owners, customers, and relevant external actors—including community groups and governmental institutions. To analyze these interactions, the research draws on the Dialogue, Access, Risk, and Transparency (DART) framework, which provides a structured lens for assessing how co-creation unfolds in practice. The framework enables a dual-perspective analysis, capturing both consumer expectations and restaurant owners' operational considerations as they seek to enhance Muslim-friendly service delivery and strengthen business sustainability.

Understanding the regulatory and operational context of Muslim-friendly food services in Japan is essential for situating the conceptual model. In Japan, the term "Muslim-friendly restaurant" generally refers to establishments that offer food and services aligned with selected Islamic dietary expectations without fully meeting all requirements for formal halal certification. Guidance from organizations such as the Nippon Asia Halal Association (NAHA) highlights several areas relevant to this designation, including the sourcing and handling of ingredients, the use of dedicated or segregated utensils, staff competencies, hygiene management, and overall food safety procedures. Certification bodies further outline expectations regarding the treatment of animals, the avoidance of prohibited ingredients, and management practices to prevent cross-contamination. These criteria shape how businesses interpret and operationalize Muslim-friendly service standards in practice (Kitayama et al., 2018).

To empirically examine the relationships among the study constructs, Partial Least Squares–Structural Equation Modeling (PLS-SEM) was employed using SMARTPLS software. Selected PLS-SEM was suitable for complex models involving multiple latent variables, for its ability to handle non-normal data, and for its strengths in exploratory and predictive analysis—the analytical procedure involved two primary stages. First, the measurement model was assessed to evaluate indicator reliability, construct reliability, and the validity of the latent variables. Convergent validity was examined through the magnitude of item loadings and the average variance extracted (AVE), while discriminant validity was assessed to ensure adequate separation between constructs. Composite reliability was used to evaluate the internal consistency of the constructs.

The second stage involved evaluating the structural model to determine the strength and significance of the hypothesized relationships among the latent variables. The stage included assessing multicollinearity, examining path coefficients and their statistical significance, and evaluating the model's explanatory power using the coefficient of determination (R^2). Model fit and predictive relevance were also reviewed in accordance with established PLS-SEM guidelines. Figure 1 illustrates the analytical framework and hypothesized relationships.
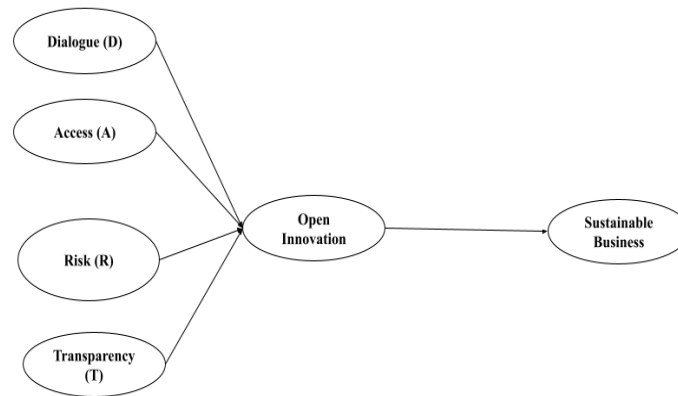
Figure 1. Research Model

The study adopted a combination of snowball and purposive sampling to reach members of the Muslim community in Tokyo, including both producers and consumers engaged with Muslim-friendly restaurant services. Producer-side data were collected through interviews with five restaurant operators: one serving Japanese cuisine, two offering Indonesian cuisine, and two international establishments originating from Bangladesh and Pakistan.

On the consumer side, data collection began with a preliminary survey of 35 individuals to explore their preferences toward Muslim-friendly dining options. The survey used a structured questionnaire completed by 57 Muslim respondents to obtain detailed consumer perceptions. The analytical approach focused on examining the roles of open innovation and co-creation by applying the DART framework alongside a multi-actor network perspective. The operationalization of each construct, including the questionnaire items used, is summarized in Table 1.

Table 1. Scale Measurement of Co-Creation and Open Innovation.

Construct	Indicators	Measurement items	Source
Dialogue (D)	Customer Engagement	Conduct dialogue sessions with the consumer frequently (D1)	Taghizadeh et al., 2016; Cheng et.al., 2014; So et.al.,2014
	Realize Innovativeness	Use a variety of communication channels to facilitate dialogue with consumers (D2)	
Access (A)	Customer Participation Behavior	Provide consumers with comprehensive information related to the service product (A1)	Taghizadeh et al., 2016: Yi & Gong, 2013; Solakis et al., 2017
		Offer consumers the opportunity to determine how they wish to experience the service product (A2)	
Risk (R)	Risk and Responsibilities	Inform consumers of any potential risks associated with the service product (R1)	Taghizadeh et al., 2016: So et.al.,2014
		Communicate the firm's knowledge and capability limitations to consumers (R2)	
		Assume full responsibility for risks related to the service product (R3)	

Construct	Indicators	Measurement items	Source
Transparency (T)	Sharing Information	Disclose all pricing-related information to consumers (T1)	Taghizadeh et al., 2016: Apenes Solem, 2016
		Foster consumer trust by providing transparent and accurate information (T2)	
Open Innovation Strategy (OI)	Network and Knowledge Management	Obtain innovation opportunities through building a network among other significant players in the ecosystem (OI1)	Felix, 2022
	Business Model	Implement collaboration with external stakeholders (OI2; OI4)	
	Knowledge Base View	Encourage outsiders to supply external innovation (OI3)	
Sustainable Business (SB)	People, Planet, and Profit	Achieve customer satisfaction (SB1)	Nidumolu et al., 2009; Werbach, 2009
		Increase the market performance constantly (SB2)	

The quantitative data were analysed using Partial Least Squares–Structural Equation Modelling (PLS-SEM) to examine the relationships among variables and to identify the significant factors underlying the proposed hypotheses:

H1: Dialogue is positively related to Open Innovation

H2: Access is positively related to Open Innovation

H3: Risk is positively related to Open Innovation

H4: Transparency is positively related to Open Innovation

H5: Open Innovation is positively related to Sustainable Business

3. RESULTS AND DISCUSSION

3.1 Respondent Profile

The study's producer respondents were five Muslim-friendly restaurants in Tokyo, Japan. The restaurants applied codes A, B, C, D, and E for confidentiality purposes. A is a pioneer in halal ramen, while B and C are authentic Indonesian cuisine restaurants. D specializes in authentic Pakistani cuisine, while E offers a variety of Indian and Bengali dishes. Table 2 presents a summary of the restaurant profile, with the representative as the interviewee, as shown below.

Table 2. Characteristic Restaurant Profile and Representatives.

No	Name of The Restaurant	Category	Specific Menu	Interviewee Role	Country of Origin
1	A Restaurant	Japanese Restaurant	Ramen	Halal Advisor	Indonesia
2	B Restaurant	Indonesian Restaurant	Indonesian cuisine, e.g, Rendang, Fried rice, and noodles	Owner	Indonesia

No	Name of The Restaurant	Category	Specific Menu	Interviewee Role	Country of Origin
3	C Restaurant	Indonesian Restaurant	Indonesian cuisine with traditional sambal, e.g, Ketoprak, Gado-gado, and Rendang	Owner	Japan
4	D Restaurant	Pakistan Restaurant	Traditional Pakistani dishes, including curries, biryanis, and beef seekh kebabs	Branch Manager	Pakistan
5	E Restaurant	Bangladesh Restaurant	Indian and Bengali dishes, e.g., biryani, chicken tikka masala, kebab, and tandoori chicken	Owner	Bangladesh

Among the sample, Indonesian students were the most frequent consumers of Muslim-friendly restaurants, with 57 respondents from various backgrounds residing in Japan, including researchers, trainees, and workers, as detailed in Table 3 and indicated by the statistical results. The respondents are predominantly male (71.9%), young adults aged 20 to 34 (70.2%), students (47.4%), and reside in Tokyo (50.9%).

3.2 Statistical Results

Two evaluation procedures in SMARTPLS 4.0: the measurement model and the structural model applied to the questionnaire data.

Table 3. Demographic characteristics (n=57).

Details		Frequency	Percentage (%)
Gender	Male	41	71.9
	Female	16	28.1
Age (years old)	15-19	3	5.3
	20-24	15	26.3
	25-29	18	31.6
	30-34	7	12.3
	35-39	6	10.5
	40 and Above	8	14
Educational Background	Junior High School	0	0
	Senior High School	13	22.8
	Bachelor Degree	21	36.8
	Master Degree	13	22.8
	Doctoral Degree	10	17.5
Occupation	Student	27	47.4
	Lecturer/Researcher	6	10.5
	Trainee	5	8.8
	Permanent Employee	16	28.1
	Others	3	5.3

Details		Frequency	Percentage (%)
Gender	Male	41	71.9
	Female	16	28.1
Domicile Prefecture	Tokyo	29	50.9
	Kanagawa	10	17.5
	Chiba	2	3.5
	Saitama	4	7
	Others	12	21.05
Nationality	Indonesia	46	80.7
	Malaysia	5	8.8
	Bangladesh	3	5.3
	Pakistan	1	1.8
	Nepal	1	1.8
	United States of America	1	1.8

3.2.1 Measurement Model.

The first phase of the analysis examined the measurement model to determine whether the constructs adequately captured the validity and reliability criteria. Convergent validity was assessed by examining the extent to which indicators of the same construct shared variance. In line with established guidelines, an average variance extracted (AVE) exceeding 0.50 was taken as evidence of adequate item convergence (Fornell & Larcker, 1981; Hair et al., 2022). Indicator loadings were reviewed to ensure that items contributed meaningfully to their respective constructs; although loadings above 0.70 are generally preferred, items with moderate loadings may be retained when theoretically justified (Hair et al., 2011; Henseler & Ringle, 2009).

Internal consistency was evaluated using composite reliability, which reflects the overall coherence of the indicators within a construct. Appropriate reliability is typically demonstrated by values ranging from 0.60 to 0.70 in exploratory contexts and above 0.70 in more confirmatory applications. At the same time, very high levels (e.g., approaching 0.95) may suggest redundancy among indicators (Hair et al., 2021). Table 4 presents the outcomes of these assessments.

Table 4. Measurement Model.

Dimensions	Question Items	FL	CR	AVE
Dialogue (D)	D1	0.702	0.783	0.646
	D2	0.894		
Access (A)	A1	0.914	0.835	0.717
	A2	0.775		
Risk (R)	R1	0.728	0.771	0.53
	R2	0.765		
	R3	0.688		
Transparency (T)	T1	0.862	0.868	0.766
	T2	0.888		

Dimensions	Question Items	FL	CR	AVE
Open Innovation (OI)	OI1	0.813	0.87	0.626
	OI2	0.88		
	OI3	0.738		
	OI4	0.725		
Sustainable Business (SB)	SB1	0.904	0.736	0.591
	SB2	0.604		

Table 5. Discriminant Validity Test (Fornell-Larcker Criterion).

Dimensions	D	A	R	T	OI	SB
D	0.804					
A	0.583	0.847				
R	0.198	0.382	0.728			
T	0.114	0.23	0.242	0.875		
OI	0.472	0.432	0.259	0.287	0.791	
SB	0.473	0.449	0.122	0.171	0.675	0.769

The factor loadings are all greater than 0.6, and the CR and AVE values meet the reliability test standards. The Fornell-Larcker Criterion result is also satisfactory for the discriminant validity test, as shown in Table 5.

3.2.2 Structural Measurement Model

Then, after the data has passed the validity and reliability test, the second measurement is an evaluation that aims to determine how well the proposed model fits the data, hypothesis testing, and whether the relationships between the latent variables are statistically significant and theoretically meaningful, including path analysis and explanatory power analysis using R-squared and F-squared.
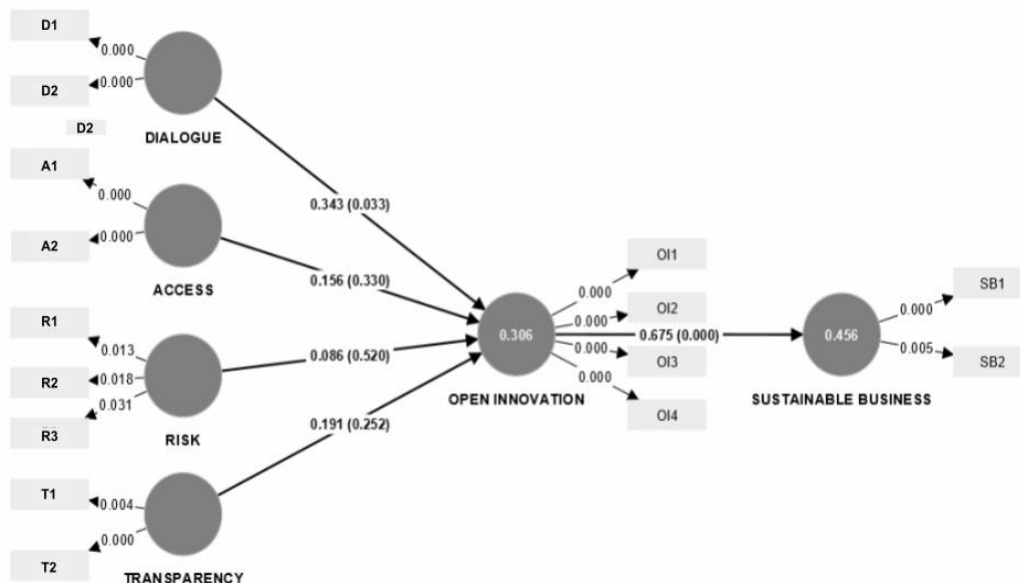

Figure 2. Path Analysis Model

Table 6. Path Analysis.

Path Analysis	Path Coefficient (β)	Mean	Standard deviation	T statistics	P values	Hypothesis remarks
D → OI	0.343	0.327	0.161	2.13	0.033	H1 supported
A → OI	0.156	0.163	0.16	0.973	0.33	H2 rejected
R → OI	0.086	0.115	0.133	0.644	0.52	H3 rejected
T → OI	0.191	0.179	0.167	1.147	0.252	H4 rejected
OI →SB	0.675	0.684	0.074	9.074	0.000	H5 supported

The second stage of the analysis focused on evaluating the structural model to determine the strength and significance of the hypothesized relationships among the latent constructs. Effect sizes were interpreted using guideline ranges commonly applied in PLS-SEM, in which smaller path coefficients indicate weaker influences and larger coefficients denote more substantial impacts (Hair et al., 2013; 2021; 2022). Thresholds were adjusted to match the characteristics of the sample used in this study, in accordance with recommendations for PLS-based modelling (Hair et al., 2022). Figure 2 visually summarizes the outcomes of the path analysis.

The results indicate that Dialogue exerts a significant positive influence on Open Innovation (β = 0.343, $p < 0.05$), with a moderate effect size. Open Innovation also demonstrates a strong, statistically significant effect on Sustainable Business outcomes (β = 0.675, $p < 0.05$). These findings provide empirical support for hypotheses H1 and H5.

In contrast, the pathways from Access to Open Innovation (β = 0.156, $p > 0.05$), Risk to Open Innovation (β = 0.086, $p > 0.05$), and Transparency to Open Innovation (β = 0.191, $p > 0.05$) were not statistically significant, leading to the rejection of hypotheses H2, H3, and H4.

Interpretation of explanatory power followed established benchmarks for R-square values in PLS-SEM (Hair et al., 2011), where values near 0.10 signal weak explanatory ability, values between 0.11 and 0.30 indicate modest explanatory strength, values from 0.30 to 0.50 reflect moderate explanatory power, and values exceeding 0.50 denote strong predictive capability. As shown in Table 5, the combined influence of Dialogue, Access, Risk, and Transparency explains 30.6% of the variance in Open Innovation, representing a moderate level of explanatory power. Additionally, Open Innovation accounts for 45.6% of the variance in Sustainable Business, suggesting a mild degree of predictive strength for this construct.

Table 7. R-square and F-square value.

Path Analysis	F-square	R-square
D → OI	0.111	
A → OI	0.02	
R → OI	0.009	0.306
T → OI	0.048	
OI →SB	0.837	0.456

On the other hand, Table 7 also presents the F-square result. The findings revealed that Dialogue value (F-square = 0.111) was the most significant predictor of Open Innovation, with a medium effect size, compared with other variables such as Access (0.02), Risk (0.009), and Transparency (0.048), which indicated small effect sizes. Additionally, the Open Innovation value (F-square = 0.837) is also a critical predictor of Sustainable Business, with a large effect size.

3.3 Implementation of Co-creation and Open Innovation in Tokyo Halal Food Industry

This study applied the DART model to examine the implementation of co-creation and open innovation among the restaurant respondents in the Tokyo halal food sector. The analysis yielded the following key findings:

Dialogue: All the restaurants engage in frequent conversations with their customers, using both direct communication methods, such as in-person interactions, and indirect methods through social media platforms. One restaurant owner believes in focusing on five-sense communication during the customer's visit to encourage repeat business with the quotes below:

"I concentrate on providing friendly service and offering free mineral drinks to catch up with customers because I believe they will want to revisit our restaurant due to their positive experience." (E Restaurant owner - Bangladesh)

Access: Most restaurants are open to customer insights when creating new menus, and access to the platform is primarily through dialogue, including social media. Some restaurants use vending machines and social media engagement to increase customer accessibility. One of the owners quotes below:

"In our restaurant, we used a vending machine system so that the consumer could easily access their favorite menu with detailed prices and variety. Not only that, the influence of social media such as TikTok and Instagram has helped us to be more popular through the Instagram stories and reviews" (Halal Advisor A Restaurant - Indonesia)

Risk: Most restaurants inform consumers about the consumption risks associated with the menus they offer, while also acknowledging that they still face limitations in providing a full halal standard. Building a trustworthy relationship with consumers is established through the sharing of information regarding halal qualification, such as the use of the halal logo and a Muslim-friendly menu. One of the owners quotes below:

"The most important thing for us is that consumers know that the menu we offer does not contain prohibited ingredients such as alcohol and pork, even if not all of our menu items are halal-certified. We inform them about this, even though I am still confused about the Muslim-friendly requirements and the various types of halal certificates that are quite expensive." (C Restaurant owner - Japan)

Transparency: All respondents claimed to be transparent with their consumers, despite offering some non-halal menu items, by providing ingredient information, detailed pricing, and building trust through the halal certification process. One of the owners quotes below:

"We recognize that our consumers are not only Muslim but also non-Muslim, such as Japanese. Therefore, we offer alcohol and pork-based dishes, but we also inform consumers by displaying the non-halal menu items separately." (E Restaurant owner - Bangladesh)

Open Innovation and Sustainable Business: Establishing positive relationships with customers, the government, and halal institutions was vital to the respondents' efforts to export products beyond their countries, expand their number of branches, and reach more consumers who enjoy their cuisine. Rapid response to new product development was also crucial to the success of some restaurants. The representative's restaurant quotes are below:

"I built a strong partnership with a supplier who supplies specific materials such as traditional flavoring or halal ingredients. It impacts food menu availability, and we are also able to make an online marketplace to provide an Indonesian menu." (C Restaurant owner - Japan)

"Our team was getting trust from consumers and easy access to the relevant supplier, so that we were also able to provide a green halal supermarket" (E Restaurant owner - Bangladesh)

The findings suggest that Dialogue is closely related to open innovation in the Muslim-friendly restaurant sector, involving shared learning and communication that helps build customer loyalty. Access, on the other hand, is not statistically significant in helping producers develop open innovation strategies due to limited consumer involvement in the process. Regarding Risk and Transparency, halal

food restaurants need to provide consumers with comprehensive information about their menu items, including any potential risks of consumption. However, some Muslim-friendly restaurants may not provide such information due to a lack of knowledge or fear of losing customers. It is worth noting that transparency levels vary across different food industries, especially in the restaurant sector. Furthermore, the study confirms that Open Innovation only partially explains the DART components, suggesting that DART may not accurately represent innovation strategies as aligned with previous findings (Pellizzoni and Baldanza, 2019; Mazur and Zaborek, 2014).

Additionally, previous research has demonstrated the positive impact of co-creation-based open innovation strategies on various industries. For example, in the perfume industry, such strategies have contributed to the development of new products (Santos et al., 2017), while in the telecommunication sector, they have resulted in improved market performance (Taghizadeh et al., 2016) Similarly, in the case study of the Korean food industry has experienced enhanced financial sustainability through the implementation of open innovation practices (Jeong et al., 2020). This research has provided new and valuable insights into the food industry's open innovation and its implications for sustainable business practices. All respondents desire this approach due to its positive effects on business profitability, community, and environmental acceptability. Statistical analysis has further supported this claim by indicating a strong relationship between open innovation and sustainable business practices (H5 supported).

The recommendations for potential strategies, based on the research findings, are divided into two categories: Adjustment Strategies and Improvement Strategies. The adjustment strategy suggests that halal food restaurants should focus on delivering high-quality halal food to both Muslim and non-Muslim customers, develop strategies to create halal products that appeal to non-Muslim consumers, and create products that meet the long-term needs of the immigrant community. The improvement strategy suggests that halal food businesses should enhance their service systems and business development, conduct market research and competitor analysis, engage with consumers through dialogue activities, and improve their business support systems, such as promotional media and customer service. Restaurants can make their websites more accessible to foreign tourists and offer additional measures, such as free Wi-Fi or complimentary water refills, to enhance customer convenience.

4. CONCLUSIONS

This study examines how open innovation (OI) relates to sustainable business (SB) practices in the Muslim-friendly food service sector, using an analytical framework derived from prior scholarly work. Drawing on a case study of five Muslim-friendly restaurants in Tokyo, the research examines the OI approaches adopted by these businesses. It evaluates how consumer involvement contributes to sustainability across different dimensions. The results show that co-creation and OI play meaningful roles in advancing financial resilience, promoting environmentally conscious practices, and strengthening social value creation, thereby fostering greater trust and loyalty among customers. Despite these benefits, restaurants' capacity to fully implement Muslim-friendly standards remains limited due to structural constraints, particularly certification costs and the complexity of compliance procedures. The study suggests that several strategic alternatives—such as modifying products to align with customer expectations, targeting new consumer segments, and enhancing quality and service through improved standardization—may offer practical avenues for improving business performance in this context.

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