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# Editorial

## The Debate Between Plant-Based Dairy And Animal Dairy

**Dr. Rami Al Sidawi** is a sustainability specialist who has successfully completed his PhD in sustainable food systems and food security. He is actively engaged in the sustainability sector, utilizing his expertise to drive positive change and contribute to a more sustainable future.

*In recent years, there has been a significant surge in the popularity of plant-based dairy alternatives.* Driven by concerns for animal welfare, environmental sustainability, and personal health, an increasing number of consumers are opting for non-dairy alternatives like soy milk, almond milk, and oat milk. These plant-based alternatives offer a taste and texture comparable to traditional dairy products while avoiding the negative impacts associated with animal produce. Moreover, numerous companies are investing in the development of innovative plant-based products such as vegan cheese and ice cream [1]

This shift towards plant-based dairy alternatives is not solely attributed to consumer demand but also to the global growth of veganism and vegetarianism. As more individuals embrace a plant-based lifestyle, the market for non-dairy products is projected to continue expanding in the foreseeable future [2].

The environmental consequences of animal dairy production are significant. Cows, during digestion, produce a substantial amount of methane—a potent greenhouse gas. But the feed affects the amount of methane produced (ruminants need more grass than grain). Additionally, the cultivation of feed for cows necessitates substantial land and water resources, leading to deforestation, soil erosion, and water pollution, especially in countries such as Brazil. Animal dairy production also consumes a considerable amount of energy for transporting, processing and refrigeration [3].

Plant-based dairy alternatives have a lower environmental footprint as they require fewer land, water, and energy resources for production. Choosing plant-based dairy can mitigate the negative environmental impact associated with food consumption [4].

The consumption of animal dairy has been associated with various health concerns. One particular concern is the increased risk of developing cardiovascular diseases due to the high levels of saturated fats present in animal dairy products. These fats can elevate cholesterol levels, leading to narrowed arteries and potential heart attacks or strokes. Animal dairy has also been linked to a higher risk of developing type 2 diabetes due to its high lactose content, which


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can cause insulin resistance [4].

Additionally, the utilization of hormones and antibiotics in animal dairy production has raised concerns about their potential impact on human health. Studies indicate that these substances may disrupt normal hormone regulation and contribute to antibiotic resistance, posing further health risks for consumers [5].

Amidst the ongoing debate between plant-based and animal dairy, consumers are carefully considering the advantages and drawbacks of each option. Plant-based dairy alternatives such as soy, almond, and oat milk are gaining popularity due to concerns for animal welfare and environmental impact. These alternatives also provide health benefits for individuals who are lactose intolerant or have allergies to traditional dairy products [5].

However, some consumers argue that these alternatives may not be as nutritionally dense as animal dairy products. Advocates of animal dairy contend that their products offer essential nutrients like calcium and protein, which may not be adequately provided by plant-based options. Additionally, some consumers simply prefer the taste of traditional animal milk products over their plant-based counterparts. Ultimately, consumers must take into account their personal values and health requirements when making choices between plant-based and animal dairy options.

1. Plamada, D., Teleky, B. E., Nemes, S. A., Mitrea, L., Szabo, K., Călinoiu, L. F., ... & Nitescu, M. (2023). Plant-Based Dairy Alternatives—A Future Direction to the Milky Way. Foods, 12(9), 1883.

2. Lehto, E., Korhonen, K., Muilu, T., & Konttinen, H. (2023). How do values relate to the consumption of meat and dairy products and their plant-based alternatives?. Food Quality and Preference, 106, 104804.

3. Moss, R., LeBlanc, J., Gorman, M., Ritchie, C., Duizer, L., & McSweeney, M. B. (2023). A Prospective Review of the Sensory Properties of Plant-Based Dairy and Meat Alternatives with a Focus on Texture. Foods, 12(8), 1709.

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5. Plamada, D., Teleky, B. E., Nemes, S. A., Mitrea, L., Szabo, K., Călinoiu, L. F., ... & Nitescu, M. (2023). Plant-Based Dairy Alternatives—A Future Direction to the Milky Way. Foods, 12(9), 1883.


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# Measuring the economic performance of smallholder organic maize farms; Implications for food safety and security

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**Keywords**

Food safety; maize farming; organic farms; profitability; organic seed cost

The use of chemical inputs in conventional agriculture is associated with some health and environmental issues. This led to a call for more sustainable and environmentally friendly agriculture without health issues. However, there is low participation in organic farming in Nigeria, which could be linked to less knowledge about its profitability. The study investigated smallholder organic maize farming profitability in Northern Nigeria. We employed descriptive statistics, profitability analysis, and a multiple regression model to analyse data collected from 480 maize farmers. The results revealed that organic maize farmers had a gross profit of USD 604.81 per hectare, a 0.46 profit ratio, a 0.54 gross ratio, a 0.32 operating ratio, a benefit-cost ratio of 1.85, and a 0.85 return on capital invested. Thus, organic maize farming is a productive and profitable venture. Organic manure, compost manure, farm size, selling price, cooperative membership, extension contact, access to credit, irrigation, education, and major occupation were factors that enhanced organic maize farming's net profit. However, seed and transportation costs negatively influenced organic maize farming's net profit. Therefore, government and development agencies must intervene to make organic farming more sustainable and profitable by subsidizing seed costs and providing financial assistance to farmers.

## 1. Introduction

Agricultural activities in Nigeria and most developing nations are mainly on a small-scale level. More than 80% of Nigerian farmers are smallholders, who are responsible for over 85% of the food produced locally in the country and contribute to the nation's GDP (Mgbenka & Mbah, 2016; Obetta et al., 2020). Nigerian farmers, just like others in sub-Saharan Africa, practice conventional agriculture where chemical inputs such as chemical fertilizers, pesticides, and herbicides are used. Chemical inputs serve as agents of pollution to the environment and their residual effects on crops also affect the nervous system, respiratory system, and gastrointestinal tract of human beings (Anitha et al., 2009).

Due to the negative impacts, such as the poisoning of about 30 million people, leading to the death of 220,000 people yearly (Muhammad et al. 2016), associated with conventional agriculture, organic farming is gaining recognition and is emerging as an alternative farming system in the 21st century. There is an increase in consumer concerns about the safety and quality of foods, which prompts them to seek organic foods (Vasileva et al., 2019). Organic food is desired by consumers due to environmental production practices, biodiversity conservation, and animal welfare practices that do not harm the environment (Vasileva et al., 2019). Researchers and policymakers are now interested in organic agriculture and organic food. For instance, the International Federation of Organic Agricultural Movements (IFOAM) was created to encourage and develop organic farming. Also, the Association of Organic Agriculture Practitioners of Nigeria (formerly Nigerian Organic Agriculture Network (NOAN)) was created to draw up organic standards for the farming of crops, snails, aquaculture, and livestock for Nigerian local markets.

Organic food is produced without using chemical fertilizers and pesticides and grown without radiation (Pandey et al., 2019). Organic farming practices include composting, green manure, animal manure, cover cropping, nitrogen-fixing, and crop rotation, which enrich soil fertility. It further includes mulching, natural soil amendment, organic pesticide to control pests, organic insecticide to control insects, the use of natural enemies to control weeds, and the planting of pest-resistant plant varieties. It has health and environmental benefits by producing safe food and maintaining soil quality, respectively (Stein-Bachinger et al., 2021). It also provides safer water for the soil, supports animal health and welfare, and combats erosion. Organic farming attracts a high price due to its health and environmental benefits (Suwanmaneepong et al., 2020). Thus, an increase in organic maize production in Nigeria and other countries can enhance economic growth.

Maize is an important cereal grain that serves as food for man, feed for animals, and a means of livelihood for people. Currently, a larger proportion of maize output in Nigeria is from conventional agriculture. Therefore, there is a need to engage in maize farming in such a way that its product is free from health and environmental risks that are associated with the use of chemical inputs. Hence, organic maize farming would be the best choice in this situation as it enhances and promotes a healthy ecosystem and minimizes the adverse effects of chemical usage on natural resources (IFOAM, 2006).

In recent times, food safety concerns and the importance of organic farming are gaining attention and discussion among researchers and stakeholders. However, there is less documented information on how profitable organic agriculture is, especially organic maize farming. In addition, there are diverse reports on the profitability of organic agriculture. A few studies have revealed that conventional farming has a higher profit than organic farming (Dobbs & Smolik, 1996; Pham & Shively, 2018). Some authors reported that organic and conventional farming yielded the same revenue (Chavas et al., 2009; Helmers et al., 1986). Several studies have shown that organic agriculture is more profitable than conventional agriculture due to the organic price premium (Delate et al., 2003; Delbridge et al., 2011; McBride & Greene, 2009). Recently, it was reported that although organic rice farming had a higher production cost than conventional farming, organic farming was more profitable due to the higher price tag for organic rice (Suwanmaneepong et al., 2020).
From the foregoing, there are scanty studies on the profitability of organic maize production, especially in Nigeria, where information on profitability and its drivers is required for the development of organic maize farming. This study, therefore, fills the research gap in assessing the profitability of organic maize production enterprises in Northern Nigeria and their driving factors. However, the findings will serve as a policy reference point for promoting organic farming, food safety, and food security.

## 2 Methodology

### 2.1 Study area

This research was carried out in Northern Nigeria. The people of this region are known for farming cereals, especially maize, and legumes.

### 2.2 Sampling procedure

A multi-stage sampling procedure, which involved the selection of smaller groups and sampling units at each stage, was employed to get the maize farmers who served as respondents for this research. This involved the selection of two states (Niger and Kaduna) with the highest share of maize production in Nigeria to get the required respondents and a good representation of the population. From each state, four local gov-


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ernment areas (LGAs) were randomly selected. We further randomly selected three communities from each of these LGAs. However, to get the maize farmers to participate in organic farming, we employed the snowball technique to select twenty farmers at the last stage of the sampling procedure, resulting in a total of 480 maize farmers in the study areas.

### 2.3 Data collection techniques

A structured questionnaire was used to collect data from smallholder maize farmers. Farmers' age, gender, income, primary and secondary occupation, household size, level of education, marital status, membership in a cooperative association, years of farming experience, total farm size, access to credit, and access to extension services are among the socioeconomic data collected. Data on production information such as total outputs, revenue generated from the output, the number of inputs used in its production, and the amount spent on them were also collected.

### 2.4 Data analysis

To achieve the stated objectives of this study, we employed descriptive statistics, gross profit analysis, net profit, profit ratio, operating ratio, gross ratio, benefit-cost ratio, and a multiple regression model as means of data analysis.

#### 2.4.1 Descriptive statistics

Descriptive statistics such as pie charts, tables, means, and percentages were used to present the results.

#### 2.4.2 Profitability analysis

**Gross profit analysis:** The collected gross profit of organic maize farming was determined using gross profit analysis. It is the difference between revenue accrued from organic maize farming and the variable cost incurred in producing it. It is expressed as:

$$Gross\ profit\ (GP) = Total\ revenue - Total\ variable\ cost \quad (1)$$

Where:

Total revenue is the returns from organic maize farming in the study area and is calculated as the total output multiplied by the price per unit of the product that is, TR = P * Q (Falola et al., 2022b).

The total variable cost of organic maize farming is the sum of all variable input costs.

**Net profit:** Because net profit analysis considered the fixed cost of organic maize farming, it is used to ascertain the actual (net) profit after deducting all costs of production (Falola et al., 2022a). The fixed costs were derived by depreciating the fixed items using the straight-line method.

$$Net\ profi = Total\ Revenue - Total\ Cost \quad (2)$$

Or

$$Net\ profi = Gross\ profit - Total\ fixed\ cost \quad (3)$$

**Profit ratio:** This shows the financial viability, health, and performance of organic maize farms. It compares the net profit to the total revenue from sales of organic maize. It is expressed as:

$$Profitability\ Ratio = \frac{Net\ profit}{Total\ Revenue} \quad (4)$$

**Gross ratio:** It is a profitability ratio that gauges the organic maize farm's overall success. It indicates the ability of an organic maize farm to generate enough income to cover the total cost. The higher the returns per naira, the smaller the ratio, and vice versa. It is expressed as:

$$Gross\ Ratio = \frac{Total\ Cost}{Total\ Revenue} \quad (5)$$

**Operating ratio:** It measured the ratio of total variable costs to total revenue. A low ratio indicates the high profitability of the organic maize farm and vice versa (Mukaila, 2022). It is estimated as:

$$Operating\ Ratio = \frac{Total\ Variable\ Cost}{Total\ Revenue} \quad (6)$$

**Return on capital invested:** It measures the proportion derived as profit per unit of currency invested in organic maize farms. It is expressed as:

$$Return\ on\ capital\ invested = \frac{Net\ profit}{Total\ cost} \quad (7)$$

**The benefit-cost ratio:** This was further used to investigate the profitability of organic maize production. It is determined by dividing total revenue by total expense.

$$Benefit\ cost\ ratio = \frac{Total\ revenue}{Total\ cost} \quad (8)$$

### 2.4.3 Multiple regression model

We used the net profit from organic maize farming, which is continuous, as a proxy for the profitability of the farm enterprise. Multiple regression is the best fit in this regard as it can perfectly predict the explanatory variables driving the outcome, that is net profit. The model is explicitly estimated as:

$$NP = \beta_0 + \beta_1 OM + \beta_2 CMan + \beta_3 SD + \beta_4 TC + \beta_5 FS + \beta_6 SP + \beta_7 EXT + \beta_8 EXP + \beta_9 Ag + \beta_{10} AC + \beta_{11} IR + \beta_{12} ED + \beta_{13} HS + \beta_{14} MO + \beta_{15} CM + \mu_i \quad (9)$$

The definition of variables used in the multiple regression model with their expected signs is presented in Table 1.

## 3 Results

### 3.1 Profitability of organic maize farming

The results of the profitability analysis of organic maize production are presented in Table 2, while the share of each input in total cost is shown in Figure 1. As shown in Figure 1, the cost of labour accounted for 24.77%, the cost of renting land accounted for 24.49% of total costs, and the cost of equipment such as hoes, cutlasses, and watering cans accounted for 9.35% of the total production cost. Furthermore, the cost of organic maize seed accounted for 8.94% of the total production cost, the cost of organic manure accounted for 7.86%, storage costs accounted for 7.19% of the total cost, the cost of transportation accounted for 7.11%, and the cost of compost manure accounted for 6.48%. In addition, biocontrol costs accounted for 2.87%, and the cost of sacks accounted for 0.95% of the total production cost incurred in organic maize farming.

The average total variable cost incurred during organic maize farming production was USD 282.82 per hectare, which accounted for 58.97% of the total cost.

The average total fixed cost incurred during organic maize farming production was USD 196.76, which accounted for 41.03% of the total variable cost. Organic maize production earned an average total revenue of USD 887.63 per hectare. The gross profit from the production of organic maize farming was USD 604.81 per hectare. The net profit from the production of organic maize farming was USD 408.04 per hectare. Organic maize farming had a relatively high gross ratio of 0.54, a profit ratio of 0.46, a return on capital invested of 0.85, and a BCR of 1.85. The enterprise recorded a low operating ratio of 0.32, which is an indication of a profitable venture.

### 3.2 Determinants of organic maize farming net profit

The multiple regression results are presented in Table 3. The results revealed that the model is well-specified and has a good fit, which is shown by the significant F-value. Furthermore, 65.17% of the variation in the net profit of organic maize farms was explained by the explanatory variables included in the regression model. However, organic manure, compost manure, farm size, cooperative membership, extension contact, access to credit, irrigation, education, and major occupation were positively significant, indicating that an increase in them will increase the net profit of organic maize farms. While seed and transportation costs had a negative influence on the net profit of organic maize farms, an increase in them will result in a reduction in the net profit of the enterprise.


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**Table 1.** Definition of variables used in multiple regression model with their expected sign

| Variable name | | Description | Unit of measurement | Expected sign |
|---|---|---|---|---|
| NP | Net profit | Farmer's net profit made from organic maize farming. | Naira | |
| OM | Organic manure | Quantity of organic manure used | Kg | + |
| Cman | Compost manure | Quantity of compost manure used | Kg | + |
| SD | Seed | Cost of seed | Amount (Naira) | - |
| TC | Transportation cost | The cost incurred by farmers is to move farm inputs to the farm and take maize to the markets to sell. | Amount (Naira) | - |
| FS | Farm size | Farmland under cultivation | Hectare (10,000m²) | + |
| SP | Selling price | The selling price of organic maize | Amount (Naira) | |
| EXT | Access to extension | Access to agricultural extension services | Number of contacts | + |
| EXP | Experience | Number of years spent in farming | Years | + |
| Ag | Age | Age of farmers | Years | +/- |
| AC | Access to credit | Access to credit from formal and informal sources | Amount borrowed | + |
| IR | Irrigation | Organic maize farmers use water irrigation systems or watering cans to wet the soil. | Dummy (1, if a farmer used irrigation, 0, otherwise) | + |
| ED | Education | The educational level of farmers | Years in school | + |
| HS | Household size | The number of persons living in the same household. | Number of people | + |
| MO | Major occupation | Having maize farming as a major occupation | Dummy (yes = 1, no = 0) | + |
| CM | Cooperative membership | Membership in cooperative association by farmers | Dummy (Member = 1, non-member = 0) | + |

Source: Author's compilation.

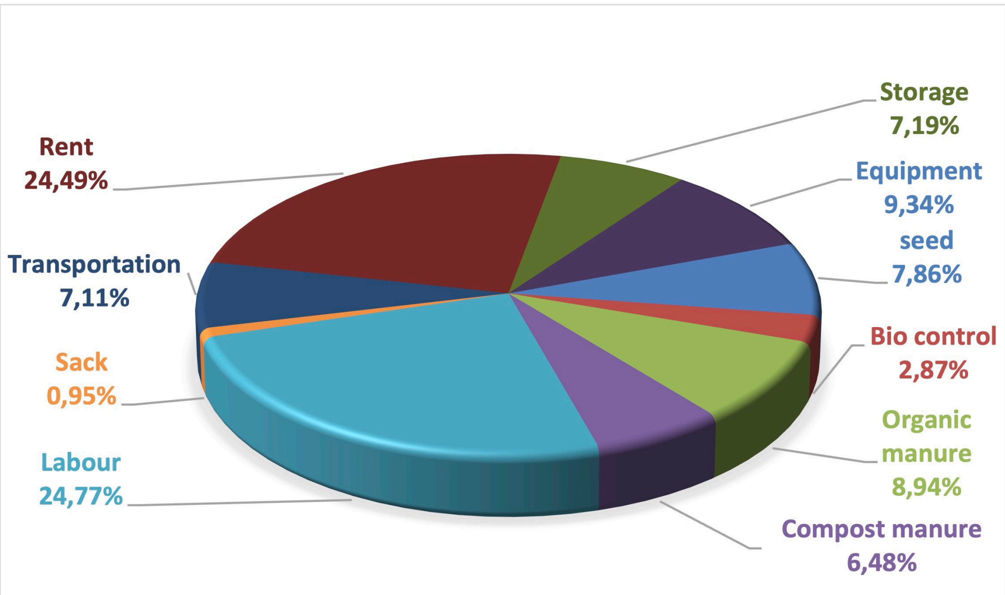


**Figure 1.** Shares of the total cost of organic maize farming

**Table 2.** Profitability of organic maize farming

| Variables | Amount (₦/ha) | Amount (USD/ha) |
|---|---|---|
| Total revenue (A) | 365,258.30 | 887.63 |
| Seed | 17,641.67 | 42.87 |
| Biocontrol | 5,654.17 | 13.74 |
| Organic manure | 15,504.17 | 37.68 |
| Compost manure | 12,795.83 | 31.1 |
| Labour | 48,878.30 | 118.78 |
| Sack | 1,883.33 | 4.58 |
| Transportation | 14,022.73 | 34.08 |
| Total variable cost (B) | 116,380.20 | 282.82 |
| Rent | 68,333.33 | 166.06 |
| Storage | 4,193.33 | 10.19 |
| Others (hoe, cutlass, and watering can) | 8,441.67 | 20.51 |
| Total Fixed Cost (C) | 80,968.33 | 196.76 |
| Total Cost (D = B + C) | 197,348.53 | 479.58 |
| Gross profit (E = A– B) | 248,878.10 | 604.81 |
| Net profit (F = E – C) | 167,909.77 | 408.04 |
| Profit Ratio (G = F/A) | 0.46 | |
| Gross Ratio (H = D/A) | 0.54 | |
| Operating Ratio (I = B/A) | 0.32 | |
| Return on Capital Invested (J = F/D) | 0.85 | |
| Benefit-Cost Ratio (K = A/D) | 1.85 | |

Source: Survey data, 2021.


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**Table 3.** Determinants of organic maize farming net profit

| | Coef. | Std. Error | t | P>t |
|---|---|---|---|---|
| Organic manure | 1177.17*** | 121.201 | 9.71 | 0.000 |
| Compost manure | 1684.5*** | 471.977 | 3.57 | 0.001 |
| Seed cost | 0.04240*** | 0.01618 | 2.62 | 0.010 |
| Transportation cost | -0.05120* | 0.03048 | 1.68 | 0.097 |
| Farm size | 519.954** | 228.286 | 2.28 | 0.025 |
| Selling price | 0.56249** | 0.27579 | 2.04 | 0.044 |
| Access to extension service | 3648.97** | 1803.85 | 2.02 | 0.046 |
| Experience | 4.95101 | 53.4302 | 0.09 | 0.926 |
| Age | 48.3384 | 57.1349 | -0.85 | 0.399 |
| Access to credit | 0.00161* | 0.00094 | 1.71 | 0.091 |
| Irrigation | 4190.53*** | 1185.25 | 3.54 | 0.001 |
| Education | 1705.08*** | 530.673 | 3.21 | 0.002 |
| Household size | 115.796 | 169.260 | 0.68 | 0.495 |
| Major occupation | 3094.85** | 1200.41 | 2.58 | 0.011 |
| Cooperative membership | 504.427** | 226.752 | 2.22 | 0.028 |
| Constant | -9513.46 | 3038.61 | -3.13 | 0.002 |
| F | 11.74 | | | |
| Prob > F | 0.0000 | | | |
| R-square | 0.6517 | | | |
| Adj R-squared | 0.5974 | | | |

*** (P<0.001), ** (P<0.05), * (P<0.1)

Source: Survey data, 2021

## 4 Discussion

Considering the labour-intensive nature of agriculture in most developing countries, the cost incurred is a significant factor in agricultural production. The cost of labour employed on organic maize farms had the largest share of total production costs in organic maize farming. This supports the finding by Sapkota et al. (2018) that labour accounted for a significant share of the cost of production in maize farming. The land is also an important factor of production in agriculture, especially in crop farming. The cost of renting land accounted for the second highest proportion of total production costs in organic maize farms. This was followed by the cost of farming equipment such as hoes and cutlasses used in weeding and planting, and watering cans used in manual irrigation of organic maize farms during the dry season. The next input in terms of the cost of production share is the cost of organic manure. Farmers used organic manure to supply needed nutrients to the plants instead of chemical fertilizers with health implications. This was followed by the cost of organic maize seeds. The share of organic seed per hectare in this study was higher than the cost of seed reported by Sapkota et al. (2018) in conventional maize farming. Next to this is the cost of storing farm inputs and output (organic maize) before it is ready for market. This was followed by the cost incurred in transporting farm inputs to the farm and farm output to the point of sale. The farmers incurred a smaller portion of their production cost in compost manure, which could be because most of the farmers prepared it themselves from weeds and other organic materials freely available on the farm. The cost of biocontrol and the cost of sacks were second to the last and last in the share of production costs in organic maize farming, respectively.

The variable costs accounted for a larger proportion of the total cost of production in organic maize farming, as the farmers incurred a variable cost and a fixed cost of USD 282.82 and USD 196.76 per hectare, respectively. The farmers made a high gross profit of USD 604.81, out of the total earned revenue of USD 887.63 per hectare, After the fixed costs incurred in the enterprise were deducted, organic maize farms had a positive net profit value (USD 408.04). These values were higher than the profit reported in conventional maize farming by Zalkuwi et al. (2010) in Nigeria; Sapkota et al. (2018) and Dahal and Rijal (2019) in Nepal; and Ferdausi et al. (2014) in Bangladesh. This was because of the high price paid for organically produced maize by consumers. This supports Suwanmaneepong et al. (2020), who found that organic farms made a higher profit due to the high price of organic foods. Furthermore, the farmers had a high gross ratio (0.54), which is an indication that the enterprise is profitable. According to the profit ratio (0.46), 46% of the total revenue generated by organic maize production was profit. The farmers used thirty-two percent of gross income as operating expenses, which was very low and further indicates a profitable venture.

In addition, for every USD 1 invested, USD 0.85 was made as returns from organic maize farming. Organic maize farms also had a BCR greater than 1. Therefore, from this study, it can be inferred that the practice of organic maize farming is profitable and economically viable. This supports previous findings that organic agriculture is profitable (Delbridge et al., 2011; McBride & Greene, 2009).

Regarding the determinants of organic maize profitability, the coefficient of organic manure was positively related to organic maize farming net profit. Effective use of organic manure increases maize fruiting, curb size, and output (Wang et al., 2017; Wang et al., 2020). Organic manure application is an important aspect of organic farming in Nigeria and other developing countries; thus, an increase in its application to the farm will simultaneously increase organic farm yield and, consequently, profit made. Therefore, the application of organic manure is an enhancing factor for the net profit of maize farming enterprises. In the same vein, the coefficient of compost manure application was positive in relation to organic maize farming net profit. This implies that the net profit of organic maize farming enterprises increases alongside compost manure usage. Thus, farmers who applied compost manure had a higher net profit than others. This is because compost manure will increase soil nutrients needed for the growth of maize to have a higher yield, which will consequently result in high revenue and net profit. In addition, compost manure had a low cost as most farmers prepared it on their farms; thus, its use reduced the cost of production, which, in turn, enhanced the net profit of the enterprise.

The coefficient of seed cost was negatively related to organic maize farming enterprise net profit. Organic seed is an important aspect of organic maize farming, accounting for a sizable portion of total production costs. Therefore, any increase in its price would increase the cost of production and consequently result in a reduction in net profit from organic maize farms. Similarly, the coefficient of transportation cost was negative in relation to the net profit of organic maize farms. This suggests that an increase in the cost incurred through the movement of inputs to the farm and moving farm output (maize) to the market will reduce the net profit of organic maize farming. This conforms with the apriori expectation as transportation costs are a vital cost in agriculture considering the location of farms (rural areas) and the location of major markets (semi-urban and urban areas). Thus, transportation costs add to the variable costs incurred in any agribusiness enterprise and reduce the income available at farmers' disposal. This supports the findings of Liverpool-Tasie et al. (2017) and Mukaila et al. (2022) that transportation costs reduce farm business profitability.

The coefficient of farm size had a positive relationship with the net profit of organic maize farm enterprises. This implies that the net profit of organic maize farms increases alongside farm size. Thus, large organic maize farms made a higher net profit than their counterparts with small farm sizes. A large farm enjoys economies of scale through the purchase of inputs such as organic maize seeds and organic manure, which reduce the cost of production and consequently enhance the net profit of the farm. This supports the findings of Ariyo et al. (2020) that profitability increases alongside farm size. Furthermore, the coefficient of selling price had a positive relationship with the net profit of organic maize farms. This implies that


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the selling price of organic maize enhanced the net profit of the enterprise.

This is because revenue derived from organic maize farms depends on the premium paid for the product. Suwanmaneepong et al. (2020) also reported that organically produced crops had a high price tag, which consequently enhanced net profit.

The coefficient of agricultural extension contacts also had a positive relationship with the net profit of organic maize farms. This implies that the net profit of organic maize farms increases as the probability of accessing agricultural extension services increases. The extension service is a vital means of getting relevant farming information to farmers and a means by which farmers relate their challenges to researchers (Akanbi et al., 2022; Falola et al., 2022b). They also train farmers in sustainable farming practices such as organic agriculture. Therefore, farmers who could access extension services are likely to have a higher net profit than those who could not access agricultural extension services. The coefficient of access to credit was positive in relation to the net profit of organic maize farming. This implies that the probability of having access to credit will increase the net profit of the organic maize farming enterprises. This is because financial assistance through credit or loans enhances farmers' investment and productivity (Falola et al., 2022c).

High investment and productivity will, in turn, lead to high revenue generated from the enterprise and, consequently, net profit. Thus, organic maize farmers who accessed credit facilities had a higher net profit than their counterparts who could not access credit. This is in tandem with the findings of Jonah et al. (2020) that access to credit facilities increases farm profit efficiency.

Furthermore, the coefficient of irrigation was also positive in relation to organic maize net profit. This implies that the use of irrigation systems enhances the net profit of organic maize farms. Constant application of water at the appropriate time plays an enormous role in crop growth and yield. Unavailability of water (rain), especially at the early planting stage, results in dead crops and a great loss in the farm enterprise. Thus, farmers who did not only rely on rain as a source of water for the growth of maize but also artificially added water to their farms made a higher net profit than those that did not engage in irrigation. The coefficient of education was positive in relation to the net profit of organic maize farms, which implies that educated organic maize farmers made a higher net profit in their production than their counterparts who had no formal education. Education influences farmers' access to information, decision-making, and productivity (Akanbi et al., 2022; Mukaila et al., 2021). These would consequently influence their total revenue and net profit as educated farmers would be able to combine production inputs in the right manner. This is in line with Tanko and Alidu (2017) that education enhances farm profit.

The coefficient of major occupation was also positively related to the net profit of organic maize farms. This implies that having maize farming as a major occupation increased the net profit of the enterprise. This supports Mukaila et al. (2022), who recently found that having a farm business as a major occupation enhanced the profitability of the enterprise. This could be a result of the full concentration given to the farm business. The coefficient of cooperative membership was positive in relation to the net profit of organic maize farms. This indicates that being a member of a farm cooperative organization increases the net profit of organic maize. This could be a result of several reasons: getting financial assistance from the organization; enjoying economies of scale; and training, as these, are among the core principles of cooperative organisations. A similar finding was reported by Jonah et al. (2020) that cooperative membership increases farm profit efficiency.

## Conclusion

This study revealed that organic maize farmers produced at an economical and profitable level. Organic maize farming had a high gross profit, net profit, profit ratio, gross ratio, benefit-cost ratio, and return on capital invested, as well as a low operating ratio, which shows that organic maize farming is a productive and profitable venture. The factors that resulted in the high profitability of the agribusiness enterprise are organic manure, compost manure, farm size, selling price, cooperative membership, extension contact, access to credit, irrigation, education, and major occupation. However, the net profit of organic maize farms

reduces as the seed and transportation costs increase. This is an indication that the high cost of seeds and transportation are significant inhibitors to organic maize farming profitability.
Given these findings, there is a need to promote organic farming, which is found to be profitable, among farmers. Thus, government and development agencies must intervene to make organic farming more sustainable and profitable by subsidizing seed costs and providing financial assistance to farmers. It is also critical for sustainable organic farming to have efficient inter- and intra-state transportation systems that are subsidized. These would enhance participation in organic farming, reduce the cost of production and make organic food items affordable to the general populace, which is needed for food safety and security.

## Conflict of Interest

The authors declare that there is no conflict of interest.

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# Effect of Fermentation on the bioactive compound of cocoa Beans: a systematic review and meta-analysis approach

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bioactive compound; cocoa; fermentation; meta-analysis; systematic review

Several studies have found the effect of cocoa bean fermentation on bioactive compounds through various fermentation characteristics; however, these studies have yet to adopt the meta-analysis approach. The effect of cocoa bean fermentation on six bioactive compounds: epicatechin, catechin, total phenolic content (TPC), anthocyanins, theobromine, and caffeine, were systematically reviewed. This study aims to determine which variables that can affect the loss of bioactive compounds during fermentation so that their decrease can be reduced. The Cochrane Library, Medline, Science Direct, and Google Scholar databases were used to search the literature through November 2021. Twenty-nine studies were systematically reviewed, and 15 could be processed for meta-analysis. The results of the random effect model (REM) showed that cocoa bean fermentation significantly ($p < 0.05$) reduced the levels of catechins, epicatechins, TPC, anthocyanins, theobromine, and caffeine. The study results explain the concept that fermentation can reduce the number of bioactive compounds in cocoa beans (although there is an increase in some cases). However, with certain genotype varieties, pod storage treatment and the addition of starter cultures are considered to be able to maintain a specific concentration of bioactive compounds.

## 1. Introduction

The scientific name *Theobroma cacao L.* (Gr. Theo-God; Broma-drink) refers to cocoa. Since chocolate is delicious, it is considered the food of the gods (Hernandez et al., 2017; Lima et al., 2011; Montagna et al., 2019). In addition, chocolate is liked by people of all ages and has a good effect on health. Cocoa consumption can suppress premature aging, oxidative stress, blood pressure regulation, and atherosclerosis due to its biologically active phenolic compounds (Andujar et al., 2012; Katz et al., 2011; Latif, 2013; Oracz et al., 2015).

Cocoa contains high concentrations of phenolic compounds, especially epicatechin, catechin, procyanidins, and their oligomer derivatives (Brito et.al., 2017; Evina et.al., 2016). Cocoa has high levels of flavonoids, more than tea, red wine, blueberries, cranberries, and other types of fruit (Brito et.al., 2017; Dang and Nguyen, 2019; Terahara, 2015). Furthermore, chocolate is also rich in procyanidin flavonoids, comparable to the levels in apples, which are rich in procyanidins. Methylxanthines in the form of theobromine, a bitter alkaloid, and caffeine are nitrogen-rich compounds in cocoa that function as central nervous system stimulants, diuretics, and smooth muscle relaxants (Latif, 2013; Bauer et al., 2011).

The cocoa beans are processed into edible chocolate products. The process includes fermentation, roasting, conching, and tempering (Barisic et al., 2019). Fermentation is an essential part of processing cocoa beans into chocolate, further contributing to flavor precursors' production. The flavor is converted into flavor in the roasting process, increasing the sensory attributes for consumer acceptance. Fermentation mainly aims to produce chocolate flavor precursors (Aprotosoaie et al., 2015).

Generally, cocoa bean fermentation is carried out spontaneously in large quantities using the heap, box, basket, tray, barrel, or platform method. Generally, fermentation lasts about 2–10 days (Lefeber et al., 2010; Pereira et al., 2012; Ho et al., 2014; Miguel et al., 2017; Vuyst & Weckx, 2016). Many studies have been carried out to analyze the growing microbes, isolate them, and use them as fermented cultures. Another research study on cocoa bean fermentation involved the use of laboratory-scale and small-scale to facilitate the formulation process and further research (Romanens et al., 2019; Serra et al., 2019; Pereira et al., 2020). However, several studies have stated that the bioactive compounds also decrease as the fermentation time increases. The decrease in bioactive compounds is caused by microbial metabolic activity in the pulp and seeds (Caporaso et al., 2018; Caprioli et al., 2016; Ho et al., 2014).

Cocoa beans consist of pulp and kernel or cotyledons with dry weight percentages of 10–14% and 86–90%, respectively (Afoakwa et al., 2013; Nazaruddin et al., 2006). Pulp is the structure that covers the beans in liquid pectin. Sugar, pectin, and other polysaccharides comprise relatively high pulp constituents. Although its texture is thick, it tastes sweet and slightly acidic and can be consumed immediately (Afoakwa et al., 2013; Crafact et al., 2013). Under anaerobic conditions, yeast produces ethanol (Ho et.al., 2014; Yao et.al., 2014).

Meanwhile, under aerobic conditions, acetic acid bacteria produce acetic acid. These metabolites have contributed to inhibiting seed germination, supporting the chemical changes that occur in the cotyledons (Vuyst & Leroy, 2020). Under aerobic conditions, acetic acid bacteria further lower the pH of cocoa beans. Cotyledons or cocoa beans are composed of two-thirds water and fat in equal proportions. The remainder, in small concentrations, consists of starch, sugar, phenolic compounds, and many other components. During fermentation, microbial metabolic activity in cocoa dregs can generate heat, and metabolites can kill cocoa beans (Afoakwa et al., 2013; Crafact et al., 2013). The extensive research on cocoa bean fermentation is majorly focused on the analysis of the product's physicochemical and functional properties and sensory attributes. Therefore, a meta-analysis approach aims to determine fermentation's effect on bioactive compounds' content. Meanwhile, within the scope of a systematic review, which variables can maintain the decrease in these bioactive compounds can be analyzed.

## 2. Materials and Methods

The steps in this systematic review and meta-analysis study refer to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines (Moher et al., 2015).

### 2.1 Data Search and Strategy

Online databases such as Cochrane Library, Medline, Science Direct, and Google Scholar were used for systematic reference searches. Keywords were used to identify potentially relevant studies published up to November 2021. The keywords in the search terms consist of: Cocoa OR Cocoa bean* OR Theobroma* OR "Theobroma cacao OR Chocolate OR Cocoa liquor OR pulp AND microbial OR bacteria OR yeast OR lactic acid bacteria OR acetic acid bacteria OR starter culture* OR solid-state fermentation* OR metabolite* OR starter OR fermented AND anthocyanin OR total phenolic content OR methylxanthine OR theobromine OR caffeine OR catechin OR epicatechin OR functional properties* OR antioxidant activity* OR bioactive phenolic compound*. All the papers from the four databases were exported to the Mendeley reference manager software for further accurate screening by two investigators (NK, LC).

### 2.2 Inclusion criteria

Studies were considered for the initial identification process if they fulfilled the following categories: 1. original articles published in English; 2. studies that used the cocoa fermentation process (with or without culture addition); 3. studies that produced at least one


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of the characteristic of functional properties; 4. especially in a meta-analysis, there are adequate data to show relevant values such as [mean (standard deviation)] or graphs that can be converted into data using data extraction software. The excluded articles were poster abstracts, proceedings, case reports, editorials, and reviews (Ahn & Kang, 2018). This study did not limit the use of fermentation methods and types of starter cultures.

### 2.3 Data extraction and analysis

Two reviewers (NK, LC) reviewed information from each study. The data summarized are the first author's name, year of publication, author's country, fermentation time, fermentation method, seed weight, cultivar, starter culture, and other information. NK and LC carried out data extraction. The software used is Review Manager (RevMan) (Computer program, Version 5.3, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). Quantitative data in mean ± standard deviation (SD) will be compiled to estimate the combined effect by meta-analysis. The REM was used based on the diversity of the data obtained. The p-value and I2 statistic could determine heterogeneity between studies. I2 values with numbers 0-30%, <30% to 60%, and more than 60% indicate low, medium, and high heterogeneity values, respectively. The significance value was indicated by a two-tailed test and p value <0.05.

**Table 1.** Characteristics of Included Studies

| References | Country | Fermentation Time (hour) | Fermentation Method / Vessel | Weight Cocoa Bean (kg) | Cultivar | Starter Culture |
|---|---|---|---|---|---|---|
| De-Brito et.al., 2001 | Brazil | 144 | Wooden boxes | 250 | Forastero, Trinitario, Criollo | No adding |
| Brito et.al., 2017 | Brazil | 168 | Wooden boxes | 45 | Forastero | No adding |
| Caprioli et.al., 2016 | Italy | 120 | Heap | 1 | Trinitario | No adding |
| Cruz et.al., 2015 | Brazil | 120 | Wooden box | 400 | Forastero | No adding |
| Dang et.al., 2019 | Vietnam | 168 | Wooden box | 75 | TD3 genotype | No adding |
| Estrada et.al., 2020 | Mexico | - | - | - | Criollo, Trinitario, Nacional | - |
| Evina et.al., 2016 | Belgium | 120 | Wooden box | 50 | Trinitario | No adding |
| Fang et.al., 2020 | China | 168 | Wooden boxes | 50 | - | No adding |
| Hernández et.al., 2018 | Spain | 144 | Wooden box | - | Different genotipe | No adding |
| Hurst et.al., 2011 | USA | 120 | - | - | Forastero | No adding |
| Junior et.al., 2021 | Brazil | 168 | Wooden boxes | - | Forastero | *Saccharomyces cerevisiae* and *Pichia kudriavzevii* |
| Kadow et.al., 2015 | Germany | 120 | Incubation medium | - | - | No adding |
| Lefeber et.al., 2012 | Belgium | 96 | heap | 150 | Forastero | - |
| Lessa et.al., 2017 | Brazil | 168 | - | - | - | *P. roqueforti* |
| Melo et.al., 2020 | Brazil | 144 | Wooden box | 40 | - | No adding |
| Misnawi et.al., 2003 | Malaysia | 120 | Wodden box | 200 | F1 hybrids (GC7 vs. SCA6/SCA12) | No adding |
| Nazaruddin et.al., 2006 | Malaysia | 120 | - | - | mixed-hybrids | No adding |
| Payne et.al., 2010 | USA | 120 | - | - | Forastero | No adding |
| Papalexandratou et.al., 2011 | Belgium | 100 | Fermentation box, heap | 96 | Nacional, Trinitario | No adding |
| Peláez et.al., 2016 | Peru | 120 | Fermentation box | 200 | Criollo | No adding |

**Continue Table 1.** Characteristics of Included Studies

| References | Country | Fermentation Time (hour) | Fermentation Method / Vessel | Weight Cocoa Bean (kg) | Cultivar | Starter Culture |
|---|---|---|---|---|---|---|
| Sandhya et.al., 2016 | India | 168 | Fermentation box | 10 | Forastero | Yeast:LAB:AAB (1:1:1) each 10-60% (w/v) |
| Saunshia et.al., 2018 | India | 168 | Wooden box | 10 | Forastero | three different types of microbial cultures |
| Servent et.al., 2018 | France | 144 | Nets | 0.7 | Trinitario, Criollo | No adding |
| Sunoj et.al., 2016 | India | 144 | Heap | 150 | Mixed F1 progeny variety | No adding |
| Yao et.al., 2014 | Cote d'Ivoire | 144 | Heap | 100 | Forastero, Trinitario, Criollo | No adding |

## 3. Results

### 3.1 Search Results

A total of 6,156 articles were obtained from keywords assigned to the database. Removal of duplicates and title/ abstract screening resulted in 171 articles, which two reviewers reviewed. Seventy-nine papers were read and reviewed. Based on the fully understood text, there were 25 articles used in the systematic review, and 16 were included in the meta-analysis data (Table 1). The PRISMA flow chart has presented the complete results from the initial search process to the final screening (Fig.1).

### 3.2 Overview of included studies

The 25 papers included in the systematic review are summarized in Table 2. Articles were published between 2003–2021, of which six studies were conducted in Brazil, three in Belgium, three in India, two in the USA, and two in Malaysia. Each country contributed to one study: Spain, Vietnam, Mexico, Peru, Italy, China, Germany, France, and Cote d'Ivoire.

### 3.3 Findings from the meta-analysis

The results of the forest plot (Figure 2. a-f) show several findings, including the most significant decrease in epicatechin and TPC compounds. Meanwhile, the compounds of catechin, anthocyanin, theobromine, and caffeine did not decrease much.

Epicatechin. Nine studies with 32 subjects contributed to determining the effect of cocoa fermentation on epicatechin. The pooled estimate from the REM showed that cocoa fermentation significantly decreased epicatechin (SMD: -12.33; 95% CI, -13.78 to -10.89; $p < 0.00001$). There was high heterogeneity and significant effect between studies (I2 = 100%; $p < 0.00001$).
Catechin. Ten studies with 33 subjects contributed to determining the effects of cocoa fermentation on catechin. The pooled estimate from the REM showed that cocoa fermentation significantly decreased catechins (SMD: -0.75; 95% CI, -0.83 to -0.68; $p < 0.00001$). There was high heterogeneity and significant effect between studies (I2 = 100%; $p < 0.00001$).
Total Phenolic Content. Five studies with 12 subjects contributed to determining the effects of cocoa fermentation on total phenolic content. The pooled estimate from the REM showed that cocoa fermentation significantly decreased the total phenolic content (SMD: -19.32; 95% CI, -30.52 to -8.12; $p < 0.00001$). There was high heterogeneity and significant effect between studies (I2 = 100%; $p < 0.00001$).
Anthocyanin. Four studies with 13 subjects contributed to determining the effects of cocoa fermentation on anthocyanin. The pooled estimate from the REM showed that cocoa fermentation significantly decreased anthocyanin (SMD: -0.30; 95% CI, -0.45 to -0.15; $p < 0.00001$). There was high heterogeneity and significant effect between studies (I2 = 100%; $p < 0.00001$).

Theobromine. Eleven studies with 34 subjects contributed to determining the effects of cocoa fermen-


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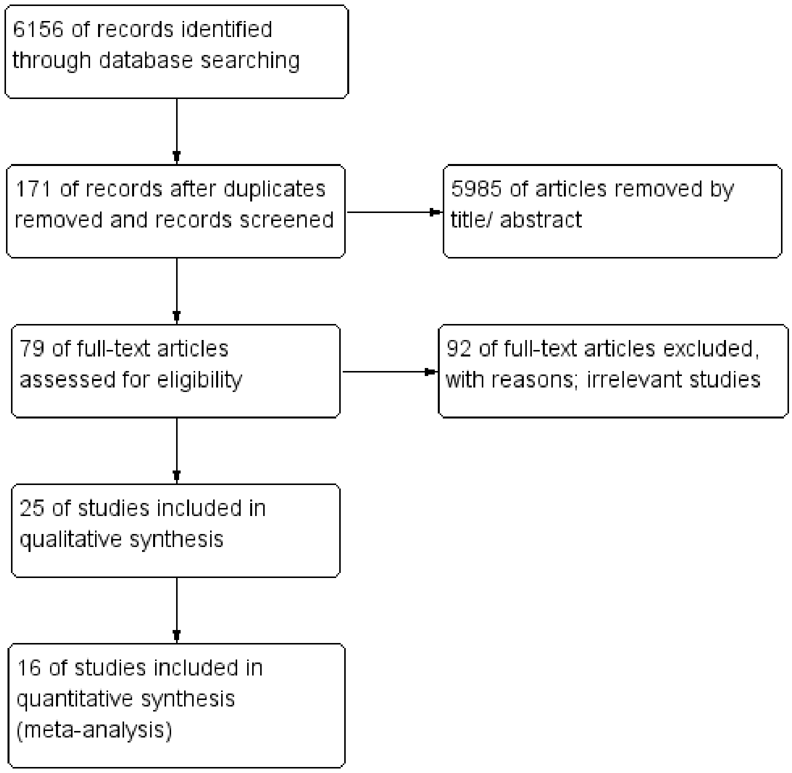


**Figure 1.** Flow Chart of the Study Screening Process

tation on theobromine. The pooled estimate from the REM showed that cocoa fermentation significantly decreased theobromine levels (SMD: -1.57; 95% CI, -2.16 to -0.98; $p < 0.00001$). There was high heterogeneity and significant effect between studies (I2 = 100%; $p < 0.00001$).

Caffeine. Ten studies with 34 subjects contributed to determining the effects of cocoa fermentation on theobromine. The pooled estimate from the REM showed that cocoa fermentation significantly decreased caffeine (SMD: -1.05; 95 % CI, -1.35 to -0.78; $p < 0.00001$). There was high heterogeneity and significant effect between studies (I2 = 100%; $p < 0.00001$).

Figure 3. Funnel Plot of the effect of cocoa fermentation on (a) Epicatechin, (b) Catechin, (c) Total Phenolic Content, (d) Anthocyanin, (e) Theobromine, and (f) Caffeine.

## 4. Discussion

In general, research on cocoa bean fermentation is carried out in vivo by using large-scale cocoa beans in wooden boxes. It is performed using different seed variants, including forastero, criollo, trinitario, or other genetic variants. Fermentation time is 120–168 hours. All studies show a decreased profile of bioactive compounds in fermented cocoa beans. However, there are also results that indicate an increase in these compounds. For example, studies using starter cultures such as Saccharomyces cerevisiae and Pichia kudriavzevii were able to improve functional properties compared to controls. Even the combined culture of the two was able to increase methylxanthine and phenolic and phenylethylamine compounds (Othman et al., 2010). Meanwhile, in another study, it was stated that the anthocyanin content seemed to increase, but it was not significant (Junior et al., 2021; Emmanuel et al., 2012). However, an increase in theobromine was found after fermentation. Yet, not much is explained as to what happens when this increase occurs (Melo et al., 2020). However, an increase in theobromine was found after fermentation. Yet, not much is explained as to what happens when this increase occurs. However, research assumes that an increase in theobromine and caffeine occurs when the cocoa pods are ripened first (Dang et al., 2019).


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**Table 2.** Profile of bioactive compounds in each study

| References | Epicatechin | Catechin | TPC | Anthocyanin | Caffeine | Theobromine |
|---|---|---|---|---|---|---|
| Brito et al., 2017 | | | - | - | | |
| Cruz et al., 2015 | +- | +- | | | +- | +- |
| Dang et al., 2019 | | +- | | | | +- |
| Estrada et al., 2020 | + | | | | | |
| Evina et al., 2015 | - | | | | | |
| Hernández et.al., 2017 | - | | | | | |
| Junior et.al., 2021 | + | | - | | | |
| Kadow et.al., 2015 | | | | | - | +- |
| Lessa et.al., 2017 | | | - | + | | |
| Melo et al., 2020 | - | - | - | | - | - |
| Misnawi et al., 2003 | - | | | | | |
| Nazaruddin et.al., 2006 | - | | | | | |
| Payne et al., 2010 | - | - | | | | |
| Peláez et.al., 2016 | - | - | | | - | - |
| Sandhya et al., 2016 | | | | - | - | - |
| Saunshia et.al., 2018 | - | - | - | | - | - |

*All treatments showed the value of bioactive compounds with a profile: (-) decreased; (+) increased; (+-) both

### 4.1 Findings from the meta-analysis

Based on the results of meta-analysis studies, cocoa bean fermentation causes a decrease in bioactive compounds. Several variables that are often used in cocoa bean fermentation research include pod storage time, fermentation time, cultivar type, the addition of starter culture, etc. Bioactive compounds have good benefits for health. However, in cocoa beans, through fermentation, some of them are degraded, along with increased flavor. Fermentation is mandatory in producing high-quality products. The decomposition or reduction of these compounds cannot be denied throughout the fermentation process. However, with the analysis of the fermentation variable, it is expected that the concentration of bioactive compounds can be reduced to smaller amounts.

### 4.2 Epicatechin

Epicatechin is a flavonoid compound that acts as one of the main antioxidants and is a procyanidin monomer (Katz et al., 2011; Afoakwa et al., 2013; Othman et al., 2010). Flavonoids are strong antioxidants in the main polyphenols class (Othman et al., 2010). Antioxidants are chemical substances that can significantly prevent the oxidation of substrates even though they are only present in relatively low concentrations in the body (Lobo et al., 2010).


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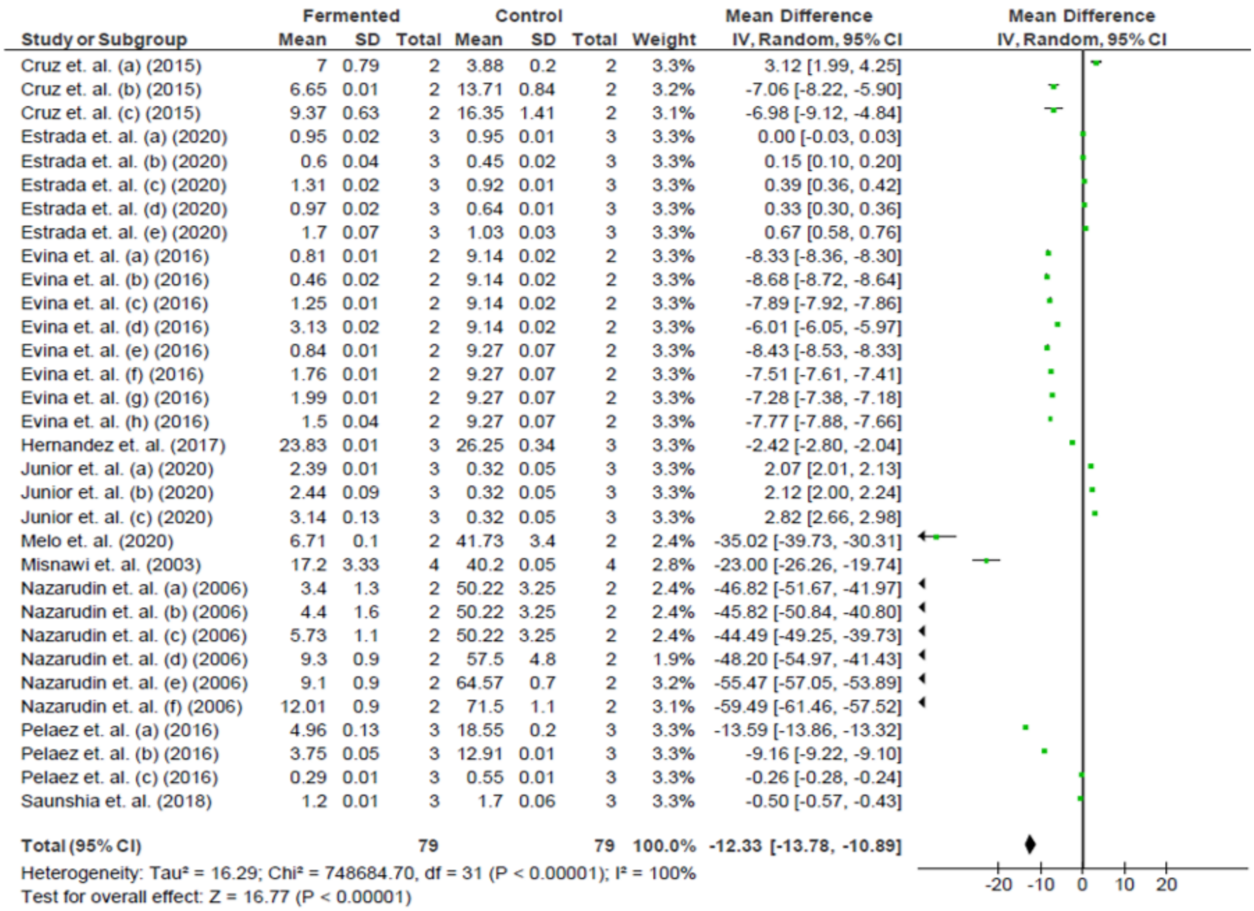
a)




b)

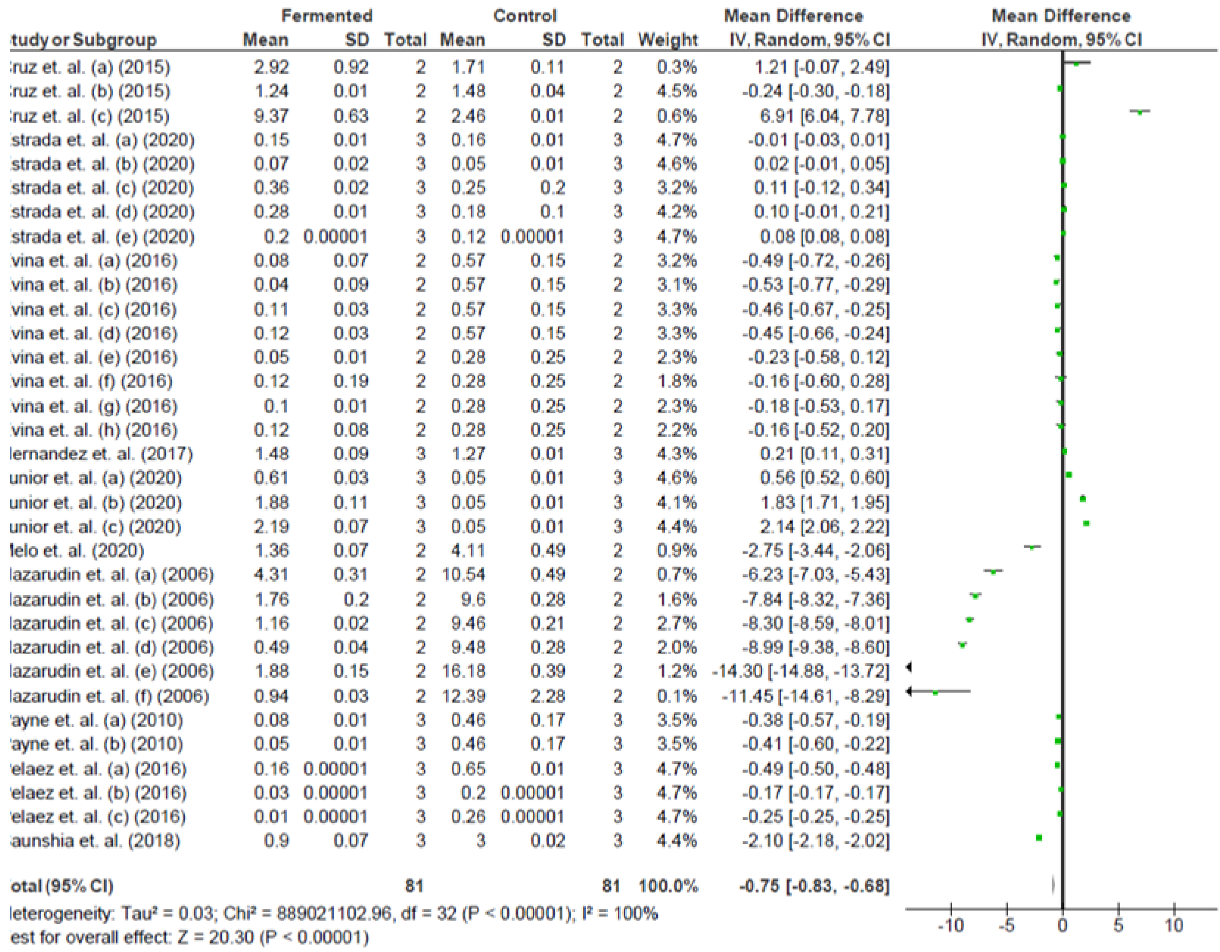
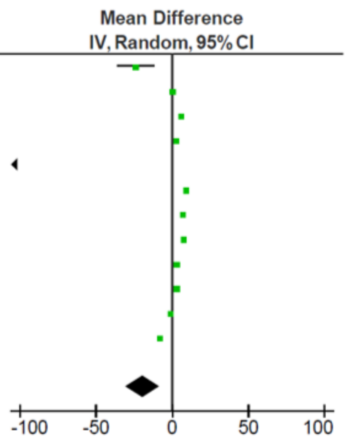



**Figure 2.** Forest Plot of the effect of cocoa fermentation on (a) Epicatechin, (b) Catechin, (c) Total Phenolic Content, (d) Anthocyanin, (e) Theobromine, and (f) Caffeine.

| Study or Subgroup | Fermented Mean | Fermented SD | Fermented Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Brito et al. (2017) | 53.26 | 10.72 | 3 | 77.31 | 2.25 | 3 | 7.6% | -24.05 [-36.44, -11.66] |
| Junior et. al. (a) (2020) | 26.59 | 1.1 | 3 | 26.35 | 0.9 | 3 | 8.4% | 0.24 [-1.37, 1.85] |
| Junior et. al. (b) (2020) | 32.25 | 0.4 | 3 | 26.35 | 0.9 | 3 | 8.4% | 5.90 [4.79, 7.01] |
| Junior et. al. (c) (2020) | 29.05 | 0.5 | 3 | 26.35 | 0.9 | 3 | 8.4% | 2.70 [1.53, 3.87] |
| Melo et. al. (2020) | 154.96 | 3.03 | 2 | 395.15 | 0.9 | 2 | 8.3% | -240.19 [-244.57, -235.81] |
| Sandhya et. al. (a) (2015) | 34 | 0.2 | 3 | 25 | 0.8 | 3 | 8.4% | 9.00 [8.07, 9.93] |
| Sandhya et. al. (b) (2015) | 32 | 0.2 | 3 | 25 | 0.8 | 3 | 8.4% | 7.00 [6.07, 7.93] |
| Sandhya et. al. (c) (2015) | 32.5 | 0.5 | 3 | 25 | 0.8 | 3 | 8.4% | 7.50 [6.43, 8.57] |
| Sandhya et. al. (d) (2015) | 28 | 0.2 | 3 | 25 | 0.8 | 3 | 8.4% | 3.00 [2.07, 3.93] |
| Sandhya et. al. (e) (2015) | 28 | 0.1 | 3 | 25 | 0.8 | 3 | 8.4% | 3.00 [2.09, 3.91] |
| Sandhya et. al. (f) (2015) | 24 | 0.8 | 3 | 25 | 0.8 | 3 | 8.4% | -1.00 [-2.28, 0.28] |
| Saunshia et. al. (2018) | 25 | 0.5 | 3 | 33 | 0.5 | 3 | 8.4% | -8.00 [-8.80, -7.20] |
| **Total (95% CI)** | | | **35** | | | **35** | **100.0%** | **-19.32 [-30.52, -8.12]** |

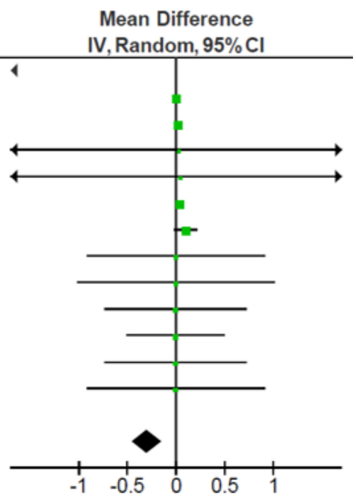
Heterogeneity: Tau² = 388.00; Chi² = 12854.66, df = 11 (P < 0.00001); I² = 100%
Test for overall effect: Z = 3.38 (P = 0.0007)




c)

| Study or Subgroup | Fermented Mean | Fermented SD | Fermented Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Brito et al. (2017) | 0.63 | 0.05 | 3 | 3.01 | 0.15 | 3 | 13.8% | -2.38 [-2.56, -2.20] |
| Estrada et. al. (a) (2020) | 0.08 | 0.01 | 3 | 0.08 | 0.01 | 3 | 17.1% | 0.00 [-0.02, 0.02] |
| Estrada et. al. (b) (2020) | 0.06 | 0.01 | 3 | 0.04 | 0.01 | 3 | 17.1% | 0.02 [0.00, 0.04] |
| Estrada et. al. (c) (2020) | 0.08 | 1 | 3 | 0.05 | 2 | 3 | 0.3% | 0.03 [-2.50, 2.56] |
| Estrada et. al. (d) (2020) | 0.12 | 0.01 | 3 | 0.08 | 7 | 3 | 0.0% | 0.04 [-7.88, 7.96] |
| Estrada et. al. (e) (2020) | 0.11 | 0.03 | 3 | 0.07 | 0.01 | 3 | 16.9% | 0.04 [0.00, 0.08] |
| Lessa et. al. (2018) | 0.5 | 0.1 | 3 | 0.4 | 0.03 | 3 | 15.5% | 0.10 [-0.02, 0.22] |
| Sandhya et. al. (a) (2015) | 0.01 | 0.7 | 3 | 0.011 | 0.4 | 3 | 2.3% | -0.00 [-0.91, 0.91] |
| Sandhya et. al. (b) (2015) | 0.0067 | 0.8 | 3 | 0.011 | 0.4 | 3 | 2.0% | -0.00 [-1.02, 1.01] |
| Sandhya et. al. (c) (2015) | 0.0055 | 0.5 | 3 | 0.011 | 0.4 | 3 | 3.4% | -0.01 [-0.73, 0.72] |
| Sandhya et. al. (d) (2015) | 0.005 | 0.2 | 3 | 0.011 | 0.4 | 3 | 5.8% | -0.01 [-0.51, 0.50] |
| Sandhya et. al. (e) (2015) | 0.0052 | 0.5 | 3 | 0.011 | 0.4 | 3 | 3.4% | -0.01 [-0.73, 0.72] |
| Sandhya et. al. (f) (2015) | 0.0047 | 0.7 | 3 | 0.011 | 0.4 | 3 | 2.3% | -0.01 [-0.92, 0.91] |
| **Total (95% CI)** | | | **39** | | | **39** | **100.0%** | **-0.30 [-0.45, -0.15]** |

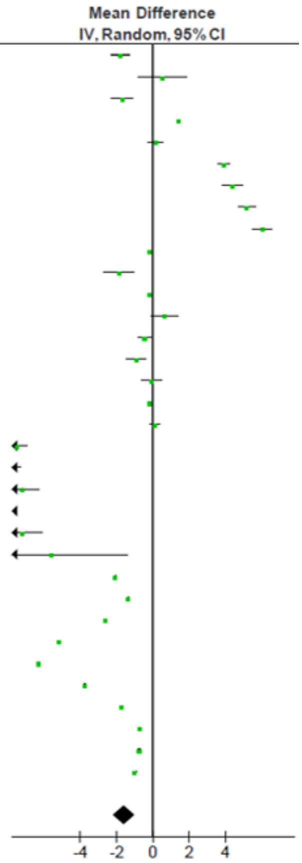
Heterogeneity: Tau² = 0.03; Chi² = 692.50, df = 12 (P < 0.00001); I² = 98%
Test for overall effect: Z = 3.94 (P < 0.0001)




d)

| Study or Subgroup | Fermented Mean | Fermented SD | Fermented Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Cruz et. al. (a) (2015) | 6.18 | 0.36 | 2 | 7.96 | 0.05 | 2 | 3.0% | -1.78 [-2.28, -1.28] |
| Cruz et. al. (b) (2015) | 5.97 | 0.48 | 2 | 5.45 | 0.85 | 2 | 2.6% | 0.52 [-0.83, 1.87] |
| Cruz et. al. (c) (2015) | 4.81 | 0.21 | 2 | 6.5 | 0.36 | 2 | 3.0% | -1.69 [-2.27, -1.11] |
| Dang et. al. (2019) | 10.88 | 0.03 | 3 | 9.48 | 0.01 | 3 | 3.1% | 1.40 [1.36, 1.44] |
| Estrada et. al. (a) (2020) | 12.16 | 0.29 | 3 | 12.02 | 0.25 | 3 | 3.0% | 0.14 [-0.29, 0.57] |
| Estrada et. al. (b) (2020) | 14.95 | 0.2 | 3 | 11.03 | 0.2 | 3 | 3.0% | 3.92 [3.60, 4.24] |
| Estrada et. al. (c) (2020) | 14.67 | 0.43 | 3 | 10.28 | 0.3 | 3 | 3.0% | 4.39 [3.80, 4.98] |
| Estrada et. al. (d) (2020) | 15.03 | 0.35 | 3 | 9.84 | 0.24 | 3 | 3.0% | 5.19 [4.71, 5.67] |
| Estrada et. al. (e) (2020) | 15.24 | 0.43 | 3 | 9.19 | 0.2 | 3 | 3.0% | 6.05 [5.51, 6.59] |
| Hernandez et. al. (2017) | 21.79 | 0.07 | 3 | 21.97 | 0.03 | 3 | 3.1% | -0.18 [-0.27, -0.09] |
| Junior et. al. (a) (2020) | 5.53 | 0.74 | 3 | 7.4 | 0.02 | 3 | 2.9% | -1.87 [-2.71, -1.03] |
| Junior et. al. (b) (2020) | 7.19 | 0.01 | 3 | 7.4 | 0.02 | 3 | 3.1% | -0.21 [-0.24, -0.18] |
| Junior et. al. (c) (2020) | 8.05 | 0.64 | 3 | 7.4 | 0.02 | 3 | 2.9% | 0.65 [-0.07, 1.37] |
| Lefeber et. al. (a) (2012) | 1.96 | 0.21 | 3 | 2.41 | 0.23 | 3 | 3.0% | -0.45 [-0.80, -0.10] |
| Lefeber et. al. (b) (2012) | 3 | 0.17 | 3 | 3.92 | 0.44 | 3 | 3.0% | -0.92 [-1.45, -0.39] |
| Lefeber et. al. (c) (2012) | 2.03 | 0.39 | 3 | 2.11 | 0.33 | 3 | 3.0% | -0.08 [-0.66, 0.50] |
| Lefeber et. al. (d) (2012) | 1.12 | 0.01 | 3 | 1.32 | 0.06 | 3 | 3.1% | -0.20 [-0.27, -0.13] |
| Lefeber et. al. (e) (2012) | 1.9 | 0.17 | 3 | 1.79 | 0.19 | 3 | 3.0% | 0.11 [-0.18, 0.40] |
| Melo et. al. (2020) | 9.79 | 0.22 | 2 | 17.29 | 0.33 | 2 | 3.0% | -7.50 [-8.05, -6.95] |
| Nazarudin et. al. (a) (2006) | 13.41 | 0.3 | 2 | 21.32 | 0.3 | 2 | 3.0% | -7.91 [-8.50, -7.32] |
| Nazarudin et. al. (b) (2006) | 14.87 | 0.6 | 2 | 22.09 | 0.34 | 2 | 2.8% | -7.22 [-8.18, -6.26] |
| Nazarudin et. al. (c) (2006) | 13.8 | 0.3 | 2 | 24.18 | 0.4 | 2 | 2.9% | -10.38 [-11.07, -9.69] |
| Nazarudin et. al. (d) (2006) | 18.1 | 0.7 | 2 | 25.3 | 0.4 | 2 | 2.8% | -7.20 [-8.32, -6.08] |
| Nazarudin et. al. (e) (2006) | 21.1 | 2.2 | 2 | 26.7 | 2.1 | 2 | 1.2% | -5.60 [-9.82, -1.38] |
| Pelaez et. al. (a) (2016) | 12.41 | 0.01 | 3 | 14.49 | 0.00001 | 3 | 3.1% | -2.08 [-2.09, -2.07] |
| Pelaez et. al. (b) (2016) | 9.52 | 0.02 | 3 | 10.88 | 0.01 | 3 | 3.1% | -1.36 [-1.39, -1.33] |
| Pelaez et. al. (c) (2016) | 10.63 | 0.04 | 3 | 13.24 | 0.07 | 3 | 3.1% | -2.61 [-2.70, -2.52] |
| Sandhya et. al. (a) (2015) | 2.2 | 0.08 | 3 | 7.4 | 0.04 | 3 | 3.1% | -5.20 [-5.30, -5.10] |
| Sandhya et. al. (b) (2015) | 1.07 | 0.01 | 3 | 7.4 | 0.04 | 3 | 3.1% | -6.33 [-6.38, -6.28] |
| Sandhya et. al. (c) (2015) | 3.64 | 0.02 | 3 | 7.4 | 0.04 | 3 | 3.1% | -3.76 [-3.81, -3.71] |
| Sandhya et. al. (d) (2015) | 5.66 | 0.02 | 3 | 7.4 | 0.04 | 3 | 3.1% | -1.74 [-1.79, -1.69] |
| Sandhya et. al. (e) (2015) | 6.65 | 0.06 | 3 | 7.4 | 0.04 | 3 | 3.1% | -0.75 [-0.83, -0.67] |
| Sandhya et. al. (f) (2015) | 6.64 | 0.04 | 3 | 7.4 | 0.04 | 3 | 3.1% | -0.76 [-0.82, -0.70] |
| Saunshia et. al. (2018) | 7 | 0.07 | 3 | 8 | 0.05 | 3 | 3.1% | -1.00 [-1.10, -0.90] |
| **Total (95% CI)** | | | **93** | | | **93** | **100.0%** | **-1.57 [-2.16, -0.98]** |

Heterogeneity: Tau² = 2.96; Chi² = 106139.57, df = 33 (P < 0.00001); I² = 100%
Test for overall effect: Z = 5.20 (P < 0.00001)




e)

**Figure 2.** Forest Plot of the effect of cocoa fermentation on (a) Epicatechin, (b) Catechin, (c) Total Phenolic Content, (d) Anthocyanin, (e) Theobromine, and (f) Caffeine.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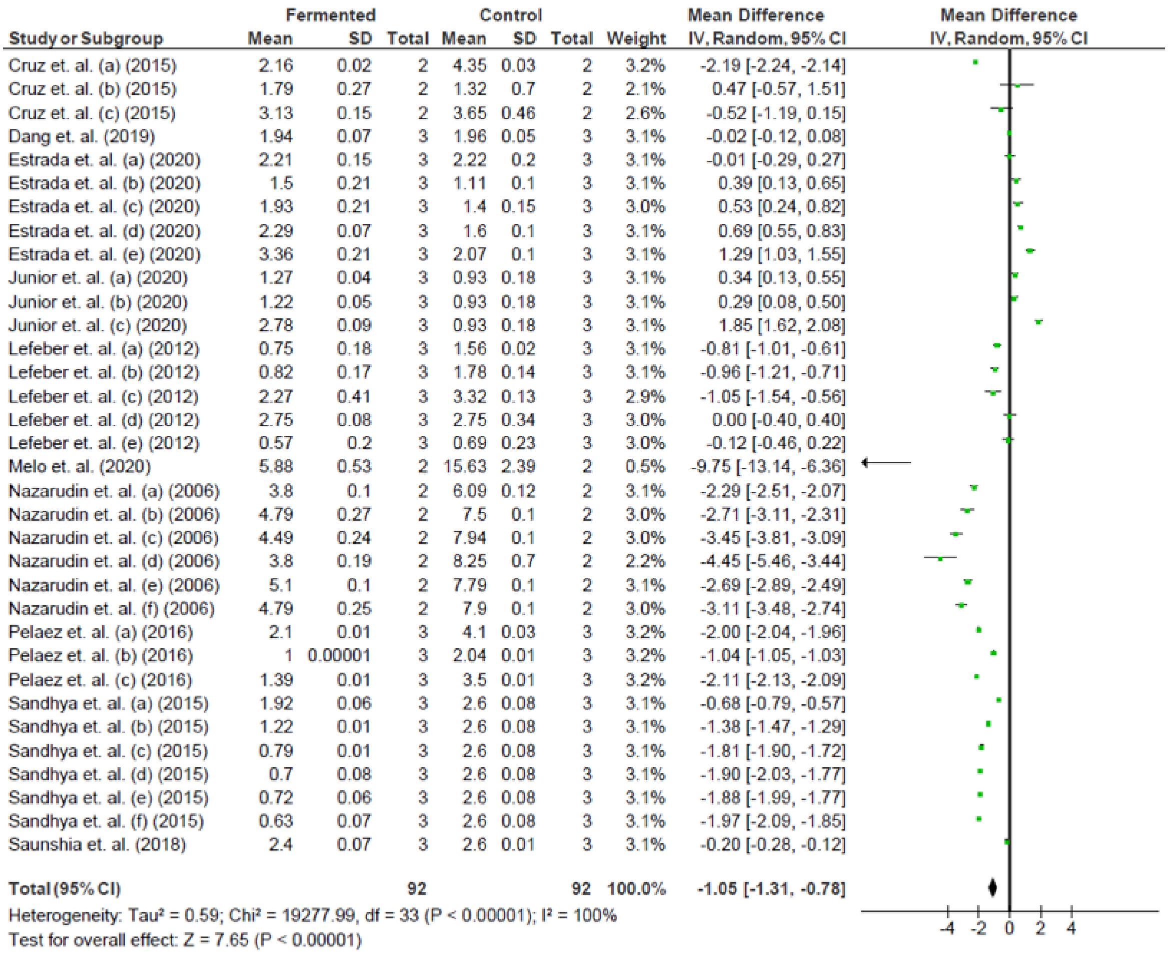


| Study or Subgroup | Fermented Mean | Fermented SD | Fermented Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Cruz et. al. (a) (2015) | 2.16 | 0.02 | 2 | 4.35 | 0.03 | 2 | 3.2% | -2.19 [-2.24, -2.14] |
| Cruz et. al. (b) (2015) | 1.79 | 0.27 | 2 | 1.32 | 0.7 | 2 | 2.1% | 0.47 [-0.57, 1.51] |
| Cruz et. al. (c) (2015) | 3.13 | 0.15 | 2 | 3.65 | 0.46 | 2 | 2.6% | -0.52 [-1.19, 0.15] |
| Dang et. al. (2019) | 1.94 | 0.07 | 3 | 1.96 | 0.05 | 3 | 3.1% | -0.02 [-0.12, 0.08] |
| Estrada et. al. (a) (2020) | 2.21 | 0.15 | 3 | 2.22 | 0.2 | 3 | 3.1% | -0.01 [-0.29, 0.27] |
| Estrada et. al. (b) (2020) | 1.5 | 0.21 | 3 | 1.11 | 0.1 | 3 | 3.1% | 0.39 [0.13, 0.65] |
| Estrada et. al. (c) (2020) | 1.93 | 0.21 | 3 | 1.4 | 0.15 | 3 | 3.0% | 0.53 [0.24, 0.82] |
| Estrada et. al. (d) (2020) | 2.29 | 0.07 | 3 | 1.6 | 0.1 | 3 | 3.1% | 0.69 [0.55, 0.83] |
| Estrada et. al. (e) (2020) | 3.36 | 0.21 | 3 | 2.07 | 0.1 | 3 | 3.1% | 1.29 [1.03, 1.55] |
| Junior et. al. (a) (2020) | 1.27 | 0.04 | 3 | 0.93 | 0.18 | 3 | 3.1% | 0.34 [0.13, 0.55] |
| Junior et. al. (b) (2020) | 1.22 | 0.05 | 3 | 0.93 | 0.18 | 3 | 3.1% | 0.29 [0.08, 0.50] |
| Junior et. al. (c) (2020) | 2.78 | 0.09 | 3 | 0.93 | 0.18 | 3 | 3.1% | 1.85 [1.62, 2.08] |
| Lefeber et. al. (a) (2012) | 0.75 | 0.18 | 3 | 1.56 | 0.02 | 3 | 3.1% | -0.81 [-1.01, -0.61] |
| Lefeber et. al. (b) (2012) | 0.82 | 0.17 | 3 | 1.78 | 0.14 | 3 | 3.1% | -0.96 [-1.21, -0.71] |
| Lefeber et. al. (c) (2012) | 2.27 | 0.41 | 3 | 3.32 | 0.13 | 3 | 2.9% | -1.05 [-1.54, -0.56] |
| Lefeber et. al. (d) (2012) | 2.75 | 0.08 | 3 | 2.75 | 0.34 | 3 | 3.0% | 0.00 [-0.40, 0.40] |
| Lefeber et. al. (e) (2012) | 0.57 | 0.2 | 3 | 0.69 | 0.23 | 3 | 3.0% | -0.12 [-0.46, 0.22] |
| Melo et. al. (2020) | 5.88 | 0.53 | 2 | 15.63 | 2.39 | 2 | 0.5% | -9.75 [-13.14, -6.36] |
| Nazarudin et. al. (a) (2006) | 3.8 | 0.1 | 2 | 6.09 | 0.12 | 2 | 3.1% | -2.29 [-2.51, -2.07] |
| Nazarudin et. al. (b) (2006) | 4.79 | 0.27 | 2 | 7.5 | 0.1 | 2 | 3.0% | -2.71 [-3.11, -2.31] |
| Nazarudin et. al. (c) (2006) | 4.49 | 0.24 | 2 | 7.94 | 0.1 | 2 | 3.0% | -3.45 [-3.81, -3.09] |
| Nazarudin et. al. (d) (2006) | 3.8 | 0.19 | 2 | 8.25 | 0.7 | 2 | 2.2% | -4.45 [-5.46, -3.44] |
| Nazarudin et. al. (e) (2006) | 5.1 | 0.1 | 2 | 7.79 | 0.1 | 2 | 3.1% | -2.69 [-2.89, -2.49] |
| Nazarudin et. al. (f) (2006) | 4.79 | 0.25 | 2 | 7.9 | 0.1 | 2 | 3.0% | -3.11 [-3.48, -2.74] |
| Pelaez et. al. (a) (2016) | 2.1 | 0.01 | 3 | 4.1 | 0.03 | 3 | 3.2% | -2.00 [-2.04, -1.96] |
| Pelaez et. al. (b) (2016) | 1 | 0.00001 | 3 | 2.04 | 0.01 | 3 | 3.2% | -1.04 [-1.05, -1.03] |
| Pelaez et. al. (c) (2016) | 1.39 | 0.01 | 3 | 3.5 | 0.01 | 3 | 3.2% | -2.11 [-2.13, -2.09] |
| Sandhya et. al. (a) (2015) | 1.92 | 0.06 | 3 | 2.6 | 0.08 | 3 | 3.1% | -0.68 [-0.79, -0.57] |
| Sandhya et. al. (b) (2015) | 1.22 | 0.01 | 3 | 2.6 | 0.08 | 3 | 3.1% | -1.38 [-1.47, -1.29] |
| Sandhya et. al. (c) (2015) | 0.79 | 0.01 | 3 | 2.6 | 0.08 | 3 | 3.1% | -1.81 [-1.90, -1.72] |
| Sandhya et. al. (d) (2015) | 0.7 | 0.08 | 3 | 2.6 | 0.08 | 3 | 3.1% | -1.90 [-2.03, -1.77] |
| Sandhya et. al. (e) (2015) | 0.72 | 0.06 | 3 | 2.6 | 0.08 | 3 | 3.1% | -1.88 [-1.99, -1.77] |
| Sandhya et. al. (f) (2015) | 0.63 | 0.07 | 3 | 2.6 | 0.08 | 3 | 3.1% | -1.97 [-2.09, -1.85] |
| Saunshia et. al. (2018) | 2.4 | 0.07 | 3 | 2.6 | 0.01 | 3 | 3.1% | -0.20 [-0.28, -0.12] |
| **Total (95% CI)** | | | **92** | | | **92** | **100.0%** | **-1.05 [-1.31, -0.78]** |

Heterogeneity: $Tau^2 = 0.59$; $Chi^2 = 19277.99$, $df = 33$ ($P < 0.00001$); $I^2 = 100\%$

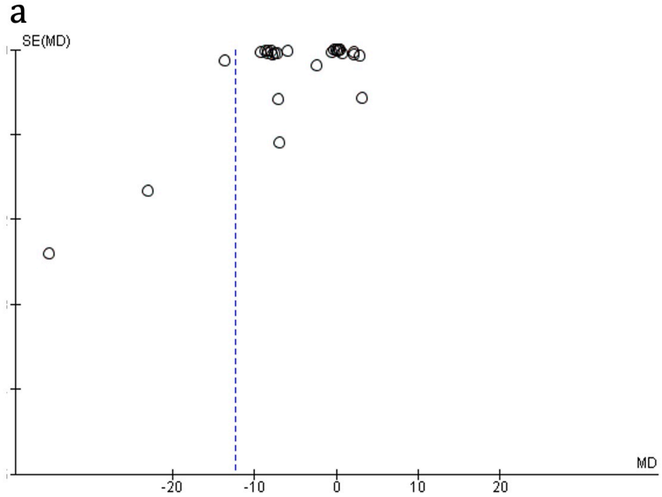
Test for overall effect: $Z = 7.65$ ($P < 0.00001$)



f)

**Figure 2.** Forest Plot of the effect of cocoa fermentation on (a) Epicatechin, (b) Catechin, (c) Total Phenolic Content, (d) Anthocyanin, (e) Theobromine, and (f) Caffeine.

a




b

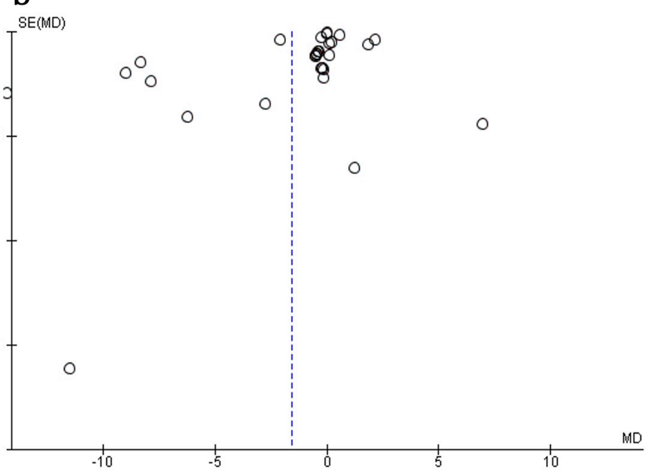



**Figure 3.** Funnel Plot of the effect of cocoa fermentation on (a) Epicatechin, (b) Catechin, (c) Total Phenolic Content, (d) Anthocyanin, (e) Theobromine, and (f) Caffeine.

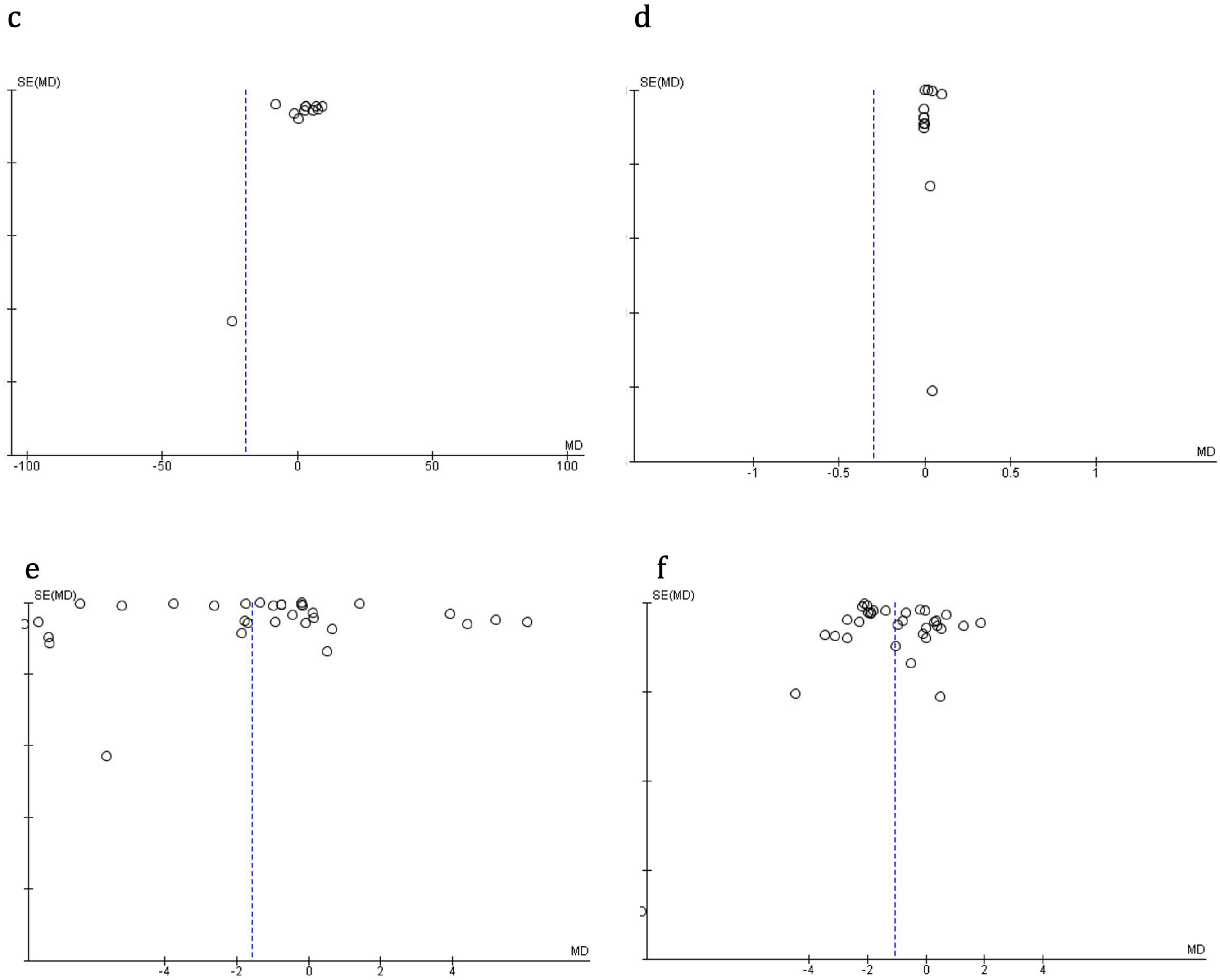



**Figure 3.** Funnel Plot of the effect of cocoa fermentation on (a) Epicatechin, (b) Catechin, (c) Total Phenolic Content, (d) Anthocyanin, (e) Theobromine, and (f) Caffeine.

The meta-analysis study (Figure 2.a) showed decreased epicatechin in fermented cocoa beans. This proved that epicatechin is degraded during the fermentation process. This process reduces the polyphenol content through oxidation or exudation (Misnawi et al., 2003). An indicator that can be recognized as a result of this process is a change in the color of the seeds from purple to brown (Nazaruddin et al., 2006). The epicatechin content varies in each variety of cocoa. Many studies have shown a decrease in epicatechin in the beans after the fermentation stage. Fermentation causes hydrolysis of tannins and procyanidins and converts them into monomeric epicatechin compounds, reducing proanthocyanidin levels (Nazaruddin et al., 2006). In specific genotype variants, epicatechin content varies; for example, the RIM105, MO31, and MO33 genotypes have higher concentrations of theobromine, epicatechin, and catechins than other genotypes tested (Hernández et al., 2018).

The research showed an increase in epicatechin after fermentation due to the presence of microorganisms that can hydrolyze phenolic complexes into free and also soluble phenols, and there has been an increase in the number of these compounds (Junior et al., 2021). Yeast species such as Pichia kudriavzevii are known to facilitate the release of this compound, thereby leading to the measurement of a high epicatechin content (Ooi et al., 2020). However, in general, epicatechin levels will decrease during the fermentation process.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The funnel plot results show publication bias (Figure 3. a).

### 4.3 Catechin

Cocoa is rich in polyphenols, especially flavan-3-ol or catechins, particularly with high content of flavanol monomers such as epicatechin and catechin) as well as oligomers (procyanidins). The main flavan-3-ol or catechin in cocoa beans consists of (−)-epicatechin as well as (+)-catechin, (+)-gallocatechin, and (−)-epigallocatechin (Andujar et al., 2012; Aprotosoaie et al., 2015). Thus, bioactive compounds have been reported that can reduce lipid peroxyl radicals and inhibit lipid peroxidation (Othman et al., 2010).

Figure 2.b reflects the observation that cocoa fermentation can reduce the content of catechin compounds. The funnel plot graph shows no publication bias (Figure 3.b). The decrease in the content of these compounds can occur due to enzymatic oxidation reactions with microorganism activity in the early stages of fermentation; then, these compounds diffuse out of the seeds so that the decrease in compounds in the seeds can be measured (Albertini et al., 2015). In addition, several studies have shown that pulpal preconditioning contributes to a reduction in the amount of (−)-epicatechin and (+)-catechin, theobromine, and caffeine. It was stated that preconditioning the pulp for 15 days was the optimum condition for reducing the number of these compounds (Nazaruddin et al., 2006).

Each variety of cocoa beans contains a different amount of catechin compounds. Differences in the profile and concentration of these compounds can be influenced by genetics and the environment (Katz et al., 2011). The amount of the type of (+)-catechin contained in cocoa beans tends to decrease less than for epicatechin. It can even be said that the amount is almost constant during the fermentation process (Cruz et al., 2015).

In addition, reducing pulp volume, for instance, during pulp washing or using a depulper machine, contributes to accelerating the diffusion of catechins. Pressing the seeds can also cause the loss of some of these catechin compounds. This reduction in catechins reduces the astringency level in cocoa beans (Nazaruddin et al., 2006; Lessa et al., 2017).

### 4.4 Total Phenolic Content

The results of the meta-analysis study revealed that the fermentation process could cause a decrease in the total phenol content (Figure 2. c), suggesting a publication bias (Figure 3.d). The formation of polyphenols increased with the level of fruit maturity. There are three main categories of polyphenols in cocoa beans: catechins or flavan-3-ols, proanthocyanidins, and anthocyanins (Oracz et.al., 2015). Polyphenols in cocoa beans are primarily stored in the pigment cells of cotyledons and cocoa leaves (Osman et al., 2004). This pigment is closely related to the number of anthocyanins, namely polyphenol storage pigment cells, which range from white to dark purple (Nazaruddin et al., 2006). In measuring antioxidant activity, phenolic compounds such as alkaloids, flavonoids, and terpenoids are often detected. Several studies have stated that there is a correlation between polyphenol measurements and antioxidant activity (Lessa et al., 2017; Fang et al., 2020).

Each study has cocoa cultivars with varying characteristics that affect the amount of each phenolic compound (Figure 2. c). The polyphenol content decreased gradually due to the fermentation process. The presence of microbial activity in the pulp supports this. Various studies on cocoa bean fermentation have observed a decrease in total polyphenols with increasing inoculum concentration. The results showed that high inoculum levels decreased the duration of fermentation by accelerating the loss of anthocyanins and polyphenols. Even though there was a decrease in polyphenol content or total phenol content, this compound still has considerable potential to act as a high antioxidant. However, decreasing the phenolic content can increase the taste precursors. The production of flavor precursors and the low residual amount of individual raw cocoa phenolic compounds can be controlled by the effects of heat and the acidity formed (Kadow et al., 2015; Bastos et al., 2019; Moreira et al., 2018; Bortolini et al., 2016). The decrease in phenolic compounds was detected as polymer formation due to the oxidation reaction. This condition is a stress response from the reduced available nutrients during the fermentation period30. The amount of polyphenols usually decreases during controlled and natural fermentation (Afoakwa et al., 2013; Calvo et al., 2021; Pérez et al., 2018; Qin et al., 2017; Rottiers et al., 2019).

It was found that the presence of polyphenol oxidase (PPO) activity caused the degradation of polyphenols, which correlated with the enzymatic browning reaction and resulted in brown cocoa beans. In one study, measurements were made by looking at the cut test and fermentation index. The fermentation index indicates the completeness of the cocoa bean fermentation process. This is related to the change in seed color from purple to brown due to the diffusion of polyphenols, followed by oxidation and reduction with other cellular compounds (Hernández et al., 2017; Kresnowati & Febriami, 2015). In addition, polyphenol oxidase enzymes contribute to the formation of synergistic complexes with polyphenols, peptides, and other proteins by converting polyphenolic compounds and anthocyanins to quinones during fermentation. This process causes the reduction of phenolic compounds (Shahidi & Ambigaipalan, 2015). The polyphenol oxidase enzyme works optimally at a specific temperature and pH, generally on the third day of fermentation, with temperatures between 42–45°C (Caporaso et al., 2018; Ho et al., 2014).

### 4.5 Anthocyanin

The forest plots (Figure 2.d) show that the fermentation significantly decreased anthocyanins. Anthocyanins can be lost from cocoa beans through microbial activity and polyphenol oxidase enzyme activity. In the fermentation process, the anthocyanins in cocoa beans can be hydrolyzed faster by increasing the inoculum levels of starter microbes. The microbial inoculum and the anthocyanin released were higher than the natural and fermented inoculum. The literature review showed that anthocyanins decreased very quickly during fermentation.

In addition, it was found that during the fermentation process, anthocyanins can be hydrolyzed by glycosidases to anthocyanidins and produce cotyledon brightness (Oracz et al., 2015). The decrease in anthocyanin content is considered an index of quality degree during cocoa bean fermentation. Anthocyanins are compounds that give the characteristic purple color. The change in color of the seeds from purple to brown indicates successful fermentation (Brito et al., 2017; Ramos et al., 2014). Furthermore, during drying, polyphenols were reduced enzymatically catalyzed by polyphenol oxidase and diffused out of the seeds. The anthocyanin value has been used as an index representing the degree of fermentation of cocoa beans (Saunshia et al., 2018). The funnel plot graph reflects a publication bias (Figure 3.d).

### 4.6 Theobromine

Methylxanthines, such as theobromine, theophylline, and caffeine, are another group of bioactive compounds found in cocoa beans. Theobromine is the dominant alkaloid in cocoa, and its presence is influenced by the origin and maturity of cocoa and the fermentation process (Montagna et al., 2019). However, the presence of theobromine, along with other methylxanthine compounds and phenolic compounds, is considered to affect the characteristics of cocoa beans, namely the presence of sensory attributes such as bitter and astringent taste (Miguel et al., 2017).
Figure 2. e shows how the cocoa bean fermentation process negatively affects the concentration of the theobromine compounds. The content of methylxanthines (theobromine and caffeine) generally increases over the first few days of fermentation and then gradually decreases (Peláez et al., 2016). High theobromine content was found in samples and natural fermentation starters. This means that microbial metabolic activity can accelerate the decrease in theobromine. Another indication of a decrease in theobromine is its conversion to tannins or evaporation. The diffusion of these compounds caused the decrease in theobromine and caffeine in fermented cocoa cotyledons during fermentation. Meanwhile, if there is a large enough increase during fermentation, it is not in the cocoa beans but in the husks. The results of the funnel plot study reflect no publication bias (Figure 3. e). Based on cultivar variations, there was no significant difference in the theobromine content of each type of cocoa bean (Nazaruddin et al., 2006).

The values found for these methylxanthines can be discussed from two perspectives: first, from a technological aspect since these compounds, along with polyphenols, are responsible for the bitterness and astringency of the resulting chocolate (Miguel et al., 2017). Unlike caffeine, theobromine has no stimula-


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tory effect because the action of theobromine in the central nervous system is very mild or almost non-existent. However, it can act as a vasodilator, muscle relaxant, and diuretic as well as lower blood pressure (Peláez et al., 2016).

### 4.7 Caffeine.

Figure 2. f shows that the decrease in caffeine occurred significantly after fermentation; however, the value was relatively small, as was the decrease in theobromine and anthocyanins. Funnel plots show similar results to other studies, reflecting no publication bias (Figure 3. f). The results of several studies showed that higher caffeine content was found in fresh cocoa beans. Another study showed that the Trinitario variety had higher caffeine content than the Criollo and Forastero varieties. The decrease in alkaloid concentration was probably caused by compounds that diffuse out of the seeds when the seeds die.

The riper the cocoa pods, the higher the alkaloid concentration. Because these alkaloid compounds exist with phenolic compounds stored in the same storage cell (Dang et al., 2019), they can co-evolve with the phenolics during maturation.

Sensory changes due to changes in chemical compounds can be identified by the appearance of a brown color gradually; the bitter taste slowly disappears, further changing the texture. The characteristic astringent taste of raw cocoa is mainly due to the phenolic compounds. Raw cocoa with a low fermentation rate still has an unacceptable sensory attribute: a strong, unpleasant taste. The content of epicatechins, catechins, total polyphenols, and total flavonoids was influenced by the clones' fermentation process and type. The content is higher in number if the cocoa beans are not fermented (Nazaruddin et al., 2006).

From existing references, cocoa bean fermentation research appears to be done conventionally. However, research has now been developed for the laboratory scale. Small-scale research saves research raw materials by adjusting the fermentation process according to its natural conditions. This meta-analysis research has limitations: the variables used are uniform, and the variables considered in very few studies have only obtained meaningful results.

## 5. Conclusion

This study revealed that cocoa fermentation, in general, reduced epicatechin, catechin, total phenol levels, anthocyanins, theobromine, and caffeine levels. There was no difference in the results regarding the decrease in bioactive compounds based on cocoa pod cultivar variables, fermentation time, and the number of beans. However, the genotype of the cross of cocoa pods and the addition of starter cultures such as yeast found higher concentrations of bioactive compounds. It was found that these bioactive compounds generally decreased due to the metabolic activity of microorganisms and the increase in temperature during fermentation and other processing. Correlation with the fermentation index and cut test, changes in sensory attributes such as reduced bitterness and astringent taste, and changes in seed color from purple to brown. In general, epicatechin compounds and TPC underwent a more significant reduction than catechins, anthocyanins, theobromine, and caffeine compounds.

## Conflict of Interest

All authors declare no conflict of interest. LC screened literature, tabulated data, analyzed, and wrote manuscripts. AR, NA, and WD discussed the results and commented on the manuscript.

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**Research Paper**

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# The effect of the addition of pineapple residue (*Ananas comosus L.*) on texture, physicochemical properties, and sensory acceptability of the plant-based minced meatball

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**Keywords**

Dietary fiber; Pineapple residue; Plant-based meatball; Texture; Sensory acceptability.

This study aims to develop plant-based meat alternatives with unique textures by adding pineapple residue at four different ratios (0, 5, 10, 15, and 20% w/w). The developed products' textures, sensory characteristics, nutritional values, and consumer acceptance were all assessed. The results showed that an increase in the pineapple residue content caused lightness (L*), redness (a*), as well as yellowness (b*) to increase. The textural properties of the plant-based minced meatballs in this study were relatively lower than those of beef minced meatballs. The adhesiveness, springiness, and chewiness of the plant-based minced meatballs showed a declining tendency with an increase in the amount of fiber in the formulation, especially at 20% pineapple residue. This would be beneficial for consumers' consumption. This study clearly showed that the addition of pineapple residue at 5–20% w/w provided an overall liking score of more than 6.0, which was considered acceptable. Therefore, the combination of mushroom and pineapple residues could influence the color, texture, and liking scores, especially at 20%. Producing plant-based meat products from pineapple by-products is an efficient way to improve dietary fiber in diets, lower global warming, and increase future food security, while also increasing nutritional values.

## 1. Introduction

Ground meat products such as meatballs, burgers, and meat patties are highly accepted and consumed worldwide (Turgut et al., 2017), mainly due to the increase in the number of fast foods worldwide and their convenience as well as low prices (Selani et al., 2016). However, ground meat products have some drawbacks such as the quantity (20–30%) (Jiménez-Colmenero, 2000) and quality of their fat as well as the cholesterol content, which are associated with the occurrence of some chronic diseases (Fernández-Ginés et al., 2005).

Oostindjer et al (2014) reported that red and processed meat contained a high content of fat, especially saturated fat. Red and processed meat consumption of more than 500 g per week increases the risk of diseases such as cancers, obesity, and cardiovascular disorders. Additionally, with an increase in global population and rapid economic development, the last two decades have seen a 58% growth in the global demand for meat (Whitnall and Pitts, 2019) and it is predicted that this market will expand by 15% by 2027 (OECD/FAO, 2018). However, in recent years, concerns about the negative effects of meat consumption on human health and the inefficiency of meat production compared to crop harvesting have been widely discussed (Hygreeva et al., 2014). Hence, growing health concerns and consumer demand has led to the development of healthier food varieties. Among all commercial meat alternatives, plant-based meat has the most potential to become a mainstream product. Due to the recent development of various plant-based meat brands such as Beyond Meat™, Impossible Food™, and Light Life ™, public media has reported that 2019 has been the year of plant-based burgers (He et al., 2020).

With consumers believing these products promote good health while also being environmentally friendly, interest in plant-based meats is growing rapidly. A life cycle analysis commissioned by the industry revealed that the manufacture of plant-based meat products generated 90% less greenhouse gas emissions (GHGe) and used 46% less energy and 93% less land than the manufacture of beef-based meat products (Estell et al., 2021). Plant-based ingredients such as wheat gluten, soy protein, mushrooms, rice, and legumes are processed in combination with flavoring additives to produce a final product that tastes like meat (Kyriakopoulou et al., 2019). Therefore, a challenge for producing a plant-based meatball with satisfactory meat-like characteristics is to develop plant-based meats from mushrooms, fibers, and other ingredients.

Mushrooms are a great option for plant-based meat production because they are rich in sulfur-containing amino acids, which can help to achieve a meaty flavor. In addition, mushrooms are rich in biological activity components, which can provide many health benefits including an antitumor property (He et al., 2020). The use of dietary fibers as a functional ingredient is related to their interesting properties that can positively affect meat products (Selani et al., 2016). Fibers have been effectively applied to improve the water-holding and swelling capacities of products, along with boosting yield and modifying texture and viscosity (Elleuch et al., 2011). In addition, it is acknowledged that insoluble dietary fibers act as a bulking agent, normalizing intestinal motility, and preventing constipation; while soluble fibers are associated with decreasing the intestinal absorption of cholesterol and glucose (Silveira et al., 2003).

Dietary fibers are mainly obtained from cereals. However, fruits and vegetable by-products still have high dietary fiber content (Mateos-Aparicio and Matias, 2019). Pineapple is a widely consumed tropical fruit and part of its production is intended for the manufacture of juices, fruit salads, canned fruits, and jams.

The manufacture of these products generated residues which are mainly composed of peel and core and account for about 25–35% of the fruit. According to a previous study, pineapple by-products presented DF as its major component (75.8%) (Selani et al., 2016). Moreover, pineapple residue is a potential cost-effective source of nutraceuticals and functional foods as it is rich in phytochemicals, and that have healing properties on humans such as anti-hypertension, anti-cancer, anti-cardiovascular, and other degenerative diseases (Gupta et al., 2017). Aparecida Damasceno et al. (2016) and Selani et al (2016) reported pineapple residue is processed into healthy food such as cereal bars, and beef burgers. However, the application of pineapple residue in food is very limited data.

Therefore, this study aims to evaluate the effect of the addition of pineapple residue (PR, pineapple by-product extracts) on the textures, sensory characteristics, and nutritional values of the plant-based minced meatball which could contribute towards healthy food and a sustainable environment

## 2. Materials and Methods

### 2.1 Preparation of raw materials

Pineapple residue (*Ananas comosus L.*) was obtained from a pineapple processing factory (V & K Pineapple Canning Co., Ltd, Ratchaburi, Thailand). At the factory, the pineapple was sanitized with 200 ppm of sodium hypochlorite, rinsed with water, and then sent through the pulp extractor, where the by-product was collected. The material was kept frozen until being transported. Samples were ground using a knife mill (Marconi, Piracicaba, SP, Brazil), passed through a 40-mesh sieve (diameter 420 µm), and stored at -18°C. Before processing plant-based meatballs, pineapple residue underwent a thermal blanching treatment at 100°C for 2 h to inactive the bromelain (Selani et al., 2016). Beef meat and king oyster mushroom were purchased from a supermarket in Bangkok. The raw materials were ground using a knife mill and stored at -18°C.

### 2.2 Plant-based meatball manufacture


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The plant-based meatballs (PBM) were produced following Yuliarti et al. (2021) formula, which was used to produce plant-based nuggets. Each composite ratio contained ice water(~4°C) 57%, 18% potato starch, 3.5% vegetable oil, 0.2% calcium chloride, 0.3% salt, 2.5% baking powder, and 1.5% MC in order to make 100 g of ground mushroom. All ingredients were homogenized in a food processor for 3 min at low speed; deionized (DI) water was used throughout the study. This step was carried out to fully hydrate the sample. Pineapple residue at four different ratios (0, 5, 10, 15, and 20%) was added to the samples. The meatball from minced beef was served as a control. The ground raw materials in each group were emulsified at 0°C–4°C for 3 h and then manually made into meatballs with a diameter of 2.5 cm-diameter and a weight of 20 g. These meatballs were pan-fried in canola oil (180°C, 3 min) on a tilting frying pan until they reached a core temperature of 75°C. After cooking, the meatballs were placed on a paper towel for 10 min to remove excess oil on their surface. Before further analysis, all meatballs were naturally cooled at room temperature (25°C) (Zhang et al., 2020).

### 2.3 Physical properties

#### 2.3.1 Color

The color of the meatballs was measured using a Hunter Lab apparatus (Hunter Lab, UltraScan PRO; USA), which measures the parameters: lightness (L*), red-green (a*), and yellow-blue (b*) (Selani et al., 2016). The measurements were taken of the inside and outside on the surface of each of the samples. The average values of 10 measurements were recorded

#### 2.3.2 Texture profile analysis (TPA)

TPA was performed following a method of Kehlet et al. (2017) with slight modifications. The texture analyzer was equipped with a 100 kg load cell and a 100 mm cylindrical probe (P/100). Samples were measured at room temperature; pre-test speeds, test speeds, and post-test speeds of 1.0, 5.0, and 5.0 mm/s, respectively; 75% strain; and trigger force of 5.0 g. The hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness of meatballs were determined.

#### 2.3.3 Sensory evaluation

Untrained panelists (n = 50) were recruited from Suan Sunandha Rajabhat University, Bangkok, Thailand. The inclusion criteria were panelists who were between 18 and 60 years old, were regular minced meatball consumers, and had no history of food allergy. Panelists with asthma or an allergy were excluded. Each panelist received a sample served in a cup coded with a 3-digit random number to avoid bias. Panelists were provided with drinking water to clean their mouths between consecutive tastings. They were instructed to first visually evaluate the acceptability of product appearance and color and then to bite and swallow each sample before scoring it for odor, taste, firmness, and overall liking using a 9-point hedonic scale according to Meilgaard et al. (1999).

#### 2.3.4 Analysis of nutrition values

The nutritional values of the most appropriate developed plant-based minced meatball product were evaluated in the energy, total fat, protein (N x 6.25), carbohydrate, dietary fiber, and sodium per 100 g, compared to the commercial beef minced meatball and plant-based meatball products in triplicate according to the Association of Official Analytical Chemists International (2019).

#### 2.3.5 Statistical analysis

The data were analyzed using analysis of variance facilitated by the IBM SPSS® version 23 software (IBM SPSS Inc.; USA). Duncan's multiple range test was used to determine multiple comparisons of mean values with a statistically significant difference established at $p < 0.05$.

## 3. Results and discussion

### 3.1 Physical properties

#### 3.1.1 Color

The color values (CIE L*, a*, b*) of different plant-based minced meatballs made from mushroom and pineapple residues are presented in Table 1. For both inside and outside meatballs, the increase in pineapple residue ratio caused the plant-based minced meatball to have L* lower than the control. This is probably due to the high dietary fiber from mushroom and pineapple residues (Selani et al., 2016). It was reported that adding dietary fiber caused a decrease in L* value, because of a combination of low light reflection, surface drying (Turgut et al., 2017), water holding capacity, and swelling capacity of fiber (Elleuch et al., 2011). These results were in accordance with a study by Yuliarti et al (2021), which reported the L* value of the plant-based nugget presented 57.02–63.73. In addition, an increasing pineapple residue caused an increase in a* (redness) and b* (yellowness) of inside plant-based minced meatballs but had no significant effect on the a* and b* values of outside plant-based minced meatballs. Furthermore, a pineapple residue ratio of 20% tended to increase the L*, a*, and b* more than the other ratios. The change in color might result from the color nature of the pineapple residue and a Maillard browning reaction of the mixture occurring during the pan-frying process. The plant-based minced meatball with high pineapple residue had a reddish-brown when compared to the beef minced meatball (control) which had a dark red-brown, as shown in Fig. 1. Studies on instrumentally measured meat color often pay great attention to a* value, which indicates redness, due to its importance on the visual appeal of meat for customers (Turgut et al., 2017).

**Table 1.** Color of the beef minced meatball and plant-based minced meatball with different pineapple residue ratios

| Treatments | L* | a* | b* |
|---|---|---|---|
| Inside meatballs | | | |
| Control | 69.57 ± 0.95$^{a}$ | 3.91 ± 0.31$^{d}$ | 17.96 ± 0.67$^{c}$ |
| 0% PR | 44.76 ± 0.55$^{c}$ | 7.35 ± 1.02$^{c}$ | 18.97 ± 0.79$^{bc}$ |
| 5% PR | 44.23 ± 0.69$^{c}$ | 9.74 ± 0.77$^{b}$ | 20.67 ± 0.84$^{abc}$ |
| 10% PR | 45.94 ± 1.17$^{c}$ | 9.70 ± 0.19$^{b}$ | 20.31 ± 0.78$^{abc}$ |
| 15% PR | 45.34 ± 0.49$^{c}$ | 9.97 ± 0.55$^{b}$ | 21.24 ± 0.41$^{ab}$ |
| 20% PR | 60.11 ± 0.62$^{b}$ | 13.43 ± 0.35$^{a}$ | 22.45 ± 0.40$^{a}$ |
| Outside meatballs | | | |
| Control | 60.21 ± 0.63$^{a}$ | 8.23 ± 0.96$^{ns}$ | 27.05 ± 0.14$^{ns}$ |
| 0% PR | 38.22 ± 0.27$^{c}$ | 10.10 ± 0.78$^{ns}$ | 18.93 ± 1.03$^{ns}$ |
| 5% PR | 43.87 ± 0.55$^{b}$ | 10.22 ± 0.82$^{ns}$ | 22.95 ± 0.24$^{ns}$ |
| 10% PR | 45.91 ± 0.90$^{b}$ | 11.42 ± 0.36$^{ns}$ | 23.93 ± 0.58$^{ns}$ |
| 15% PR | 47.85 ± 0.26$^{b}$ | 11.96 ± 0.86$^{ns}$ | 25.57 ± 0.83$^{ns}$ |
| 20% PR | 55.98 ± 0.17$^{a}$ | 12.39 ± 0.67$^{ns}$ | 29.54 ± 0.81$^{ns}$ |

PR = pineapple residue; Control = beef minced meatball

L*: lightness. a*: red to green. b*: yellow to blue

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different; ns = not significantly ($p > 0.05$) different


**Figure 1.** Color of the beef minced meatball (control) and plant-based minced meatball with different pineapple residue (PR) ratios (0, 5, 10, 15, and 20%).


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### 3.1.2 Texture properties

Results of the texture profile analysis of the plant-based minced meatballs compared to the control are shown in Table 2. Results demonstrated a significant difference ($p < 0.05$) in adhesiveness, springiness, and chewiness, whereas the addition of pineapple residue had no significant effect on the hardness, cohesiveness, and gumminess of the treatments ($p > 0.05$). Regarding the effect of the addition of the pineapple residue (by-product extracts), it is worth noting that the plant-based minced meatballs made from mushroom and pineapple residues showed a lower texture parameter than the control. Lund et al. (2011) reported that the hardness of meat contributed to a higher intensity in protein reactions, leading to the formation of crosslinking and polymerization in proteins. It might be concluded that using plant-based ingredients to replace the meat proteins caused a decrease in the hardness of the samples compared to the control.

These results were in accordance with a study by Yuliarti et al (2021), which reported that the hardness of the plant-based nugget decreased when the amount of protein in the formulation decreased. Additionally, it was observed that adhesiveness and springiness in plant-based minced meatballs with 20% PR were significantly lower than those with 0% PR ($p < 0.05$). In general, the adhesiveness, springiness, and chewiness of the plant-based minced meatballs trend to decrease with an increasing amount of fiber in the formulation.

For example, the formulation of 20% PR which had the highest amount of fiber had the lowest adhesiveness and springiness, followed by formulations of 15% PR, 10% PR, and 5% PR. In the case of the chewiness, there was no obvious trend; however, the 20% PR in the plant-based minced meatballs formulated a decreased trend compared to the control. This reason would be advantageous for consumers' consumption due to chewiness, which was defined as the energy required to masticate the plant-based minced meatballs (Szczesniak, 2002). The textural properties of the plant-based minced meatballs in this study were relatively lower than those of beef minced meatballs. These differences may result from the meatball formulation as well as the preparation method. The incorporation of both fibers caused the meat analogs' textural characteristics to vary. A similar observation was found in the plant-based nugget (Yuliarti et al., 2021).

### 3.2 Sensory evaluation

The pineapple residue content was the most important affecting the plant-based minced meatball's acceptance scores on a 9-point hedonic scale. Table 3 shows that increasing pineapple residue content from 0% to 20% resulted in liking scores of all sensory attributes ranging from 5.86–6.86 (slightly likely - moderately likely). Appearance, color, taste, firmness, and overall liking scores for all pineapple residue ratios slightly decreased ($p < 0.05$) compared to the control, whereas odor scores had no significant differences ($p > 0.05$).

This could be due to the combination of mushroom and pineapple residues, providing a flavor like meat flavor. He et al. (2020) reported that mushrooms were rich in sulfur-containing amino acids, which helped to achieve a meaty flavor. The plant-based minced meatballs with 5–20% pineapple residues tended to increase the liking scores more than those with 0% pineapple residue. This outcome may be because of the physicochemical properties of fibers. Fibers have been applied to improve water holding and swelling capacities, which are useful in meat products that require hydration, increase yield, and modify texture (Elleuch et al., 2011). Besides, the overall liking scores of 5–20% pineapple residues in the plant-based minced meatball were more than 6 (slightly likely). Giménez et al. (2008) used an average value of 6 on a 9-point hedonic scale as the minimum acceptability limit for consumers liking a product. Therefore, it might be concluded that plant-based minced meatballs made from mushroom and pineapple residues could improve consumer acceptance.

### 3.3 Nutritional values

The nutritional values of the most appropriate developed plant-based minced meatball contained 128.82 kcal of energy, 3.68 g of protein, 2.82 g of total fat, 22.18 g of carbohydrate, 8.72 g of dietary fiber, and 293.99 mg of sodium per 100 g of sample. Calculating nutritional values in 100 g of the developed product found that this product had lower energy than commercial brands A (228.00 kcal) and B (239.32 kcal) which was related to protein and fat content. This was because the main ingredients of the product developed in this work were mushroom and pineapple residues, whereas the main ingredients of brands A and B were made from beef meat and pea proteins, respectively. According to sodium analysis, the salt content of this developed product was 293.99 mg/100 g sample, which was 1.40–2.86 times less than that of brands A and B. For dietary fiber, it was observed that the developed product had a higher dietary fiber content (8.72 g/100 g sample) than commercial brands A and B. Several reviews have recommended adding dietary fiber to meat products to enhance consumer fiber intake while also improving nutritional values (Kehlet et al., 2017).

## 4. Conclusion

A pineapple by-product from the manufacture of juices, fruit salads, canned fruits, and jams may be an effective and cheap solution to improve the quality of plant-based meat products. This study indicated that pineapple by-products could be used as food ingredients to produce healthier plant-based meat products. The pineapple residues were found to impact the color, texture, and liking scores. The 20% pineapple residue content was the most suitable for producing

**Table 2.** Texture parameters of the beef minced meatball and plant-based minced meatball with different pineapple residue ratios

| Treatments | Hardness$^{ns}$ (N) | Adhesiveness (N x sec) | Springiness (cm) | Cohesiveness$^{ns}$ | Gumminess$^{ns}$ (N) | Chewiness (N × cm) |
|---|---|---|---|---|---|---|
| Control | 17014.45 ± 1070.79 | -7.51 ± 14.04$^{a}$ | 0.21 ± 0.03$^{a}$ | 0.17 ± 0.03 | 2685.80 ± 305.35 | 617.41 ± 169.36$^{a}$ |
| 0% PR | 15616.82 ± 1199.85 | -11.17 ± 13.78$^{a}$ | 0.11 ± 0.01$^{c}$ | 0.14 ± 0.02 | 2281.65 ± 302.93 | 262.36 ± 60.07$^{b}$ |
| 5% PR | 15693.45 ± 2258.72 | -82.34 ± 55.31$^{b}$ | 0.12 ± 0.02$^{c}$ | 0.14 ± 0.02 | 2247.19 ± 341.56 | 268.46 ± 68.70$^{b}$ |
| 10% PR | 14788.71 ± 604.10 | -108.49 ± 26.41$^{bc}$ | 0.13 ± 0.01$^{bc}$ | 0.15 ± 0.01 | 2172.96 ± 126.52 | 276.94 ± 23.33$^{b}$ |
| 15% PR | 15396.49 ± 2607.33 | -107.73 ± 37.99$^{bc}$ | 0.13 ± 0.06$^{bc}$ | 0.15 ± 0.03 | 2181.69 ± 484.27 | 224.04 ± 62.37$^{b}$ |
| 20% PR | 15380.93 ± 866.33 | -137.94 ± 24.81$^{c}$ | 0.17 ± 0.02$^{b}$ | 0.15 ± 0.03 | 1865.51 ± 713.59 | 330.31 ± 53.33$^{b}$ |

PR = pineapple residue; Control = beef minced meatball

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different; ns = not significantly ($p > 0.05$) different

**Table 3.** Sensory liking of the beef minced meatball and plant-based minced meatball with different pineapple residue ratios

| Treatments | Appearance | Color | Odor$^{ns}$ | Taste | Firmness | Overall liking |
|---|---|---|---|---|---|---|
| Control | 6.76 ± 1.35$^{a}$ | 6.72 ± 1.46$^{a}$ | 6.62 ± 1.63 | 6.72 ± 1.58$^{a}$ | 6.92 ± 1.45$^{a}$ | 6.92 ± 1.41$^{a}$ |
| 0% PR | 6.06 ± 1.48$^{a}$ | 6.06 ± 1.39$^{b}$ | 6.04 ± 1.31 | 6.12 ± 1.71$^{b}$ | 5.86 ± 1.52$^{b}$ | 5.92 ± 1.47$^{c}$ |
| 5% PR | 6.16 ± 1.49$^{b}$ | 6.20 ± 1.12$^{b}$ | 6.36 ± 1.27 | 6.54 ± 1.34$^{ab}$ | 6.26 ± 1.45$^{b}$ | 6.54 ± 1.32$^{ab}$ |
| 10% PR | 6.22 ± 1.22$^{b}$ | 5.94 ± 1.25$^{b}$ | 6.06 ± 1.28 | 6.46 ± 1.30$^{ab}$ | 6.26 ± 1.26$^{b}$ | 6.28 ± 1.23$^{ab}$ |
| 15% PR | 6.46 ± 1.40$^{ab}$ | 6.26 ± 1.31$^{b}$ | 6.46 ± 1.34 | 6.18 ± 1.44$^{b}$ | 6.32 ± 1.11$^{b}$ | 6.14 ± 1.20$^{bc}$ |
| 20% PR | 6.26 ± 1.23$^{b}$ | 6.24 ± 1.22$^{b}$ | 6.36 ± 1.24 | 6.02 ± 1.60$^{b}$ | 6.32 ± 1.13$^{b}$ | 6.34 ± 1.08$^{bc}$ |

PR = pineapple residue; Control = beef minced meatball

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different; ns = not significantly ($p > 0.05$) different


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**Table 4.** Nutritional values of developed plant-based minced meatballs and commercial minced meatballs based on 100 g

| Nutritional values | Developed plant-based minced meatballs | Beef minced meatballs from brand A | Plant-based minced meatballs from brand B |
|---|---|---|---|
| Total energy (kcal) | 128.82 ± 1.70 | 228.00 | 239.32 |
| Moisture (g) | 69.47 ± 0.22 | N/A | N/A |
| Protein (g) | 3.68 ± 0.01 | 17.90 | 15.70 |
| Total fat (g) | 2.82 ± 0.12 | 15.20 | 17.40 |
| Carbohydrate (g) | 22.18 ± 0.17 | 4.50 | N/A |
| Dietary fiber (g) | 8.72 ± 0.01 | 1.10 | 2.50 |
| Ash (g) | 1.85 ± 0.06 | N/A | N/A |
| Sodium (mg) | 293.99 ± 11.85 | 840.00 | 413.00 |

***Note:*** N/A**,** Product's nutrition fact label is not found.

plant-based meat products. In addition to improving the nutritional values, producing plant-based meat products from pineapple by-products is an effective solution to increase dietary fiber in diets, reduce global warming, and increase food security in the future.

## Ethics statements

This study was approved by the Ethics Committee of Suan Sunandha Rajabhat University (Approval no. COE. 1-088/2021).

## Conflict of interest

The authors declare no conflict of interest.

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# Measuring of social sustainability through community perceptions for prima certified fruit development in east Java

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The multidimensional perspective of ecological and socially sustainable agriculture in the global agri-food system has resulted in the emergence of certification schemes as an important mode of governance, but there are still few agricultural actors in Indonesia who register for product certification and recertification. The purpose of this research is to analyze community perception in order to determine the development of Prima certified fruits in East Java. The sampling technique used quota sampling, with 5 people (25 percent), community leaders, 10 people (50 percent), and village heads or sub-district staff, as many as 5 people (25 percent), for a total of 20 respondents per research location. The descriptive analysis enabled by IBM SPSS software version 23 is used in this study. According to the research's findings, the Pasuruan Regency community views employment opportunities and the possibility of local and international markets as crucial factors in the development of Mango certified Prima. On the other hand, Kediri Regency residents primarily view the potential of local and export markets, as well as location-specific goods, as essential factors in the growth of Prima certified pineapple in Kediri Regency. Prima Certification will support social sustainability behind several social development pillars, particularly the elimination of hunger and poverty and the enhancement of life expectancy for a long and prosperous life.

## 1. Introduction

Ensuring sustainable use of natural resources is a global challenge in the transformation of food production systems (FAO 2019). According to the FAO report, countries must fulfill commitments to change food systems and promote sustainable agriculture while also working toward the goal of eliminating hunger and malnutrition by 2030. This scenario was developed in response to growing concerns about matching rising food demand with more sustainable agricultural practices (Laurett et al., 2021; Skaf et al., 2019; Calicioglu et al., 2019). According to (Dixon, Gulliver, and Gibbon 2001), institutional and socio-economic factors have control over or an impact on many levels of agricultural systems, which are complex matrices of land, crops, animals, labor, capital, and other production methods. Because of this, the agricultural system is a complex socio-ecological system that includes agricultural activities related to and constrained by broad-scale socio-ecological patterns and processes, such as bio-physical conditions, policy and institutional support, socio-economic characteristics, and the willingness and ability of farmers to be oriented toward sustainable agriculture (Redman et al. 2004; Virapongse et al. 2016; Behnassi, Shahid, and Mintz-Habib 2014).

The global agri-food system's multidimensional view of ecological and socially sustainable agriculture has resulted in the emergence of certification schemes as an important mode of governance in the global food commodity chain (Bianco, 2016; Bonisoli et al., 2019; Schleifer & Sun, 2020; Rathgens et al., 2020). Prima certification is the process of awarding a product cultivation system certificate that is used in Indonesia after passing inspection, testing, and supervision and meeting all requirements to obtain product labels with the names Prima Satu (P-1), Prima Dua (P-2), and Prima Tiga (P-3) in accordance with the regulations outlined in the Regulation of the Minister of Agriculture No. 48/Permentan/OT.140/10/2009 on Good Fruit and Vegetable Cultivation (Indo-GAP) (Euriga, Boehme, and Amanah 2021). The main goals of prime certification are to raise the added value and competitiveness of the product, as well as to give quality assurance and food safety, guarantees, and protection to the general public and consumers.

Ironically, there are just 192 farmers nationwide who are prepared to register a certificate, according to statistics from the website http://keamananpangan.bkp.pertanian.go.id/okkp/ issued by the Food Safety Competent Authority (OKKP). Prime. Similarly, when a fruit producing hub was discovered in the East Java Province, not every one of them desired to renew their certification. based on eight years' worth of data from the Regional Food Safety Competent Authority (OKKP-D) East Java Province (2012-2019). Farmer groups individually and as a group are agricultural business actors. Four business units' certification periods have already run out in 2012. Since 2015 was the expiry year, the majority of the 24 farmer groups or combinations of farmer groups that registered for the prima certificate were farmers. There were 9 business units with expired prime certificates in the subsequent four years, specifically in 2019.

The issue becomes more complicated when fruit certification results in benefits for both the agricultural process and social demands (Silva, Barbosa, and Fontes 2014). Smith & McDonald (1998); Pannel., J. & Schilizzi (1997) concur that social sustainability is related to the quality of life of those who work and live on farms as well as the surrounding community. This includes encouraging the sharing of agricultural value added to more members of society through more use of labor, which will increase social cohesion and equity. According to (Zhen and Routray 2003), social sustainability entails having enough food, distributing it fairly, having access to resources and support services, and having farmers who are knowledgeable about resource conservation.

Prima Certificate has a key position to conduct in-depth investigations because the system and process for quality control and safety of fresh food such as fruits are still far from society's expectations. Existing fruit products, the majority of which are still purposely made using excessive synthetic chemicals and additives that are not in accordance with the dosage, and components that are prohibited for business purposes exclusively. Consequently, the existence of a Prima Certificate has the advantage of providing guarantees and protection for the public from the distribution of fresh food products that meet the safety and quality requirements (physical contamination, biological contamination, and chemical contamination that exceeds the minimum limit set), providing legal certainty guarantees for business actors who carry out production and distribution of fresh food products, and making it easier to trace back the origins of the fresh food products. This clarifies the relationship between the Prima Certificate, which indicates a standard of safe fruit for consumption or P3 label, and the assessment of social sustainability because the influence of people's decisions has genuine consequences for their life. A community campaign for healthy food supply chains can be long-term and sustainable.

The concept of social sustainability for the perpetrators of Prima certified fruit farming, as individuals and communities living side by side in the cultivation area, should be able to build a perception in which the environment is not only an object to meet human needs (human-centric), but must also be maintained and organized for the sake of environmental sustainability itself (ecocentric). Although the outcomes are not always positive in terms of sustainability, they are frequently negative, namely the depletion of natural resources regardless of environmental risks.

Perception is a crucial aspect of interpersonal communication because it affects communication choices and is an active process that arises from one's experiences, goals, needs, and desires as well as from the external world (DeVito 2016). According to (Wachenheim and Rathge 2000), an individual's experience, knowledge, socioeconomic traits, attitudes, and temporal variables might affect opinions about agriculture. This research, which offers details on how the communities' opinion is formed, has a favorable impression of advanced farming. The majority of survey participants firmly believe that farmers have a positive impact on their local economy (70.9%), that environmental issues like noise, smell, and others are minimal in their region (62.4%), that farmers' losses will seriously harm local economies (61.8%) and that governments should do more to support farmers in their communities in order for them to continue operating (51.5 %). According to (Nawarathne, Dissanayake, and Ginigaddara 2020), the community's perception of upland crop cultivation in the dry season in the Kaduwelalahan urban area of Sri Lanka took into account knowledge of environmentally friendly agricultural practices, knowledge of traditional agricultural practices, the farming experience of the head of the household, and access to agriculture. providing farming advice.

The research position supports the idea of renewability, which is to describe the development of prime certified fruits by investigating social sustainability through unexplored community perceptions. Numerous studies only evaluate how individual farmers perceive the effectiveness of sustainable agriculture, according to the research gap empirically related to social sustainability. (Röös et al. 2019) concentrates specifically on social sustainability; his research aims to identify aspects of significant relevance to the social situation of breeders in Sweden, such as the financial situation, having the same standard of living as others, not being overly stressed, having a job that means, having reasonable working hours, and having a desirable family situation. (Euriga et al. 2021) states that farmers' perceptions of motivation to do business and prospects for increased income are important factors in the social sustainability dimension in the sustainability of vegetable farming. (Füsun Tatlidil, Boz, and Tatlidil 2009) concluded that the higher the socio-economic status of farmers (more frequent contact with extension services, higher education, land ownership, etc.) the more likely to succeed in making farmers prefer towards sustainable agriculture. Various findings constrain the context of the discussion of social sustainability, despite the fact that in the field, agricultural management by local people is frequently found to be founded on culture and traditions that have been in place for a long time. In contrast, there has been limited research into social sustainability in the context of Prima certified fruit development in East Java, emphasizing the importance of understanding community attitudes. Therefore, this study intends to analyze community perceptions as a dimension of social sustainability that has been formed towards the sustainability of Prima certified fruit production, including the fulfillment of aspects of Good Agriculture Practices as a requirement in obtaining a Prima Certificate. The research aims to analyze community perceptions to determine the development of Prima-certified fruits in East Java, Indonesia.

## 2. Materials and Methods

### 2.1 Location

A sample area aimed at cities or districts in the Province of East Java, namely Pasuruan Regency and Kediri Regency, determines the location selection. The regional sampling technique was chosen for several reasons, including 1) Regions or regions that show the existence of Poktan and Gapoktan that have registered Prima 3 Certification as a key subject sourced from the inventory of Regional Food Safety Competent Authority (OKKPD) East Java Province's. 2) Based on the Horticultural Statistics of East Java Province published by the Central Bureau of Statistics (BPS) of the Province of East Java in the last three years, namely 2019 - 2021, the area or region as a planting center area. 3) These two places were chosen because they are renowned in East Java Province to have location-specific fruit commodities. Pasuruan Regency has an icon of a clonal 21 mango or avocado mangoes fruit-producing area, whereas Kediri Regency has an icon of a Kelud pineapple-producing area. As a result, the two varieties of fruit should be preserved to ensure their long-term production.

### 2.2. Sampling

The community component that is regarded as a stakeholder in or has an interest in the production of


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Prima certified fruits at certain places makes up the population on the social sustainability dimension. Quota sampling is used in the sampling method. A method of gathering data by contacting study participants who can satisfy the criteria for the population characteristics is known as quota sampling. By allocating specific quotas to each group, samples are taken using this method. Each sampling unit was the subject of direct data collection. In this study, the sampling quota was set at 40 participants, with 20 participants per regency location. The categories for classifying quota samples in this study consist of 1). Staff representatives in the field of horticultural crop production at the Regency Agriculture Office who know the need for research data, especially issues related to the production of Prima-certified fruits, as many as 5 people (25%). 2). Community leaders, as a symbol of collective agreement from the ideas, actions, and behavior of the community to address problems and perceptions to assess the production of Prima certified fruits, as many as 10 people (50%). 3). Village heads and staff in selected areas, cross-check the production of Prima-certified fruit providing economic welfare to farmers or the community in their area of 5 people (25%).

### 2.3. Data Analysis

A descriptive analysis approach is used in this study. The percentage of answers on each questionnaire was obtained from the Likert scale. The scale criteria used to quantify the parameters used to identify community perceptions of agricultural commodity development (Jin et al., 2022; Ramli, 2015; Spiegal et al., 2018; Cone & Myhre, 2000) are as follows: 1) Conformity with community aspirations; 2) Labor absorption; 3) Location-specific commodities; and 4) Potential for local and export markets. and 5) Cost, technology, and institutional barriers. The Likert scale rating weights in this study are Strongly Agree (weight = 5), Agree (weight = 4), Net (weight = 3), Disagree (weight = 2), and Strongly Disagree (weight = = 1). After scoring the questionnaire answers, the next step is to present each of the five parameters of community perception with software support, namely IBM SPSS version 23 with the formula:

$$P^2 = \frac{F}{N} \times 100\%$$

Where
P = Percentage
F = Frequency obtained
N = Number of Respondents

Following the conclusion drawn from the findings of this investigation, the average value is calculated using the following formula:

$$M = \frac{\sum x}{N}$$

Where
M = Mean
x = Sum of existing scores
N = Number of scores

## 3. Results and Discussion

### 3.1. Community Profile

Characteristics of research Respondents are research subjects who will participate in experiments to investigate perceptions of the development of Prima certified fruits in East Java. The characteristics of the respondents used in this study were classified by age, gender, age, and education. The findings revealed that the majority of the respondents, as many as 23, were between the ages of 46 and 55. Respondents aged 36-45 years old came in second with 11 people. The proportion of respondents' identities based on age demonstrates the level of experience and maturity of mindset, particularly maturity to consider things both for themselves and the surrounding environment in this context is the development of Prima certified fruits.

Gender is the biological difference between a woman and a man that is present at birth. Figure 2 shows that the community's profile as respondents is predominantly male, with as many as 30 people (75%) being male, while the remaining 10 people are female (25%). According to (Laurett et al. 2021), demographic factors such as age, education level, and gender can have an impact on how sustainability is perceived and practiced. It emphasizes the significance of external and internal influences, as well as demographic characteristics, in determining how people perceive sustainability. In order to find out how different groups

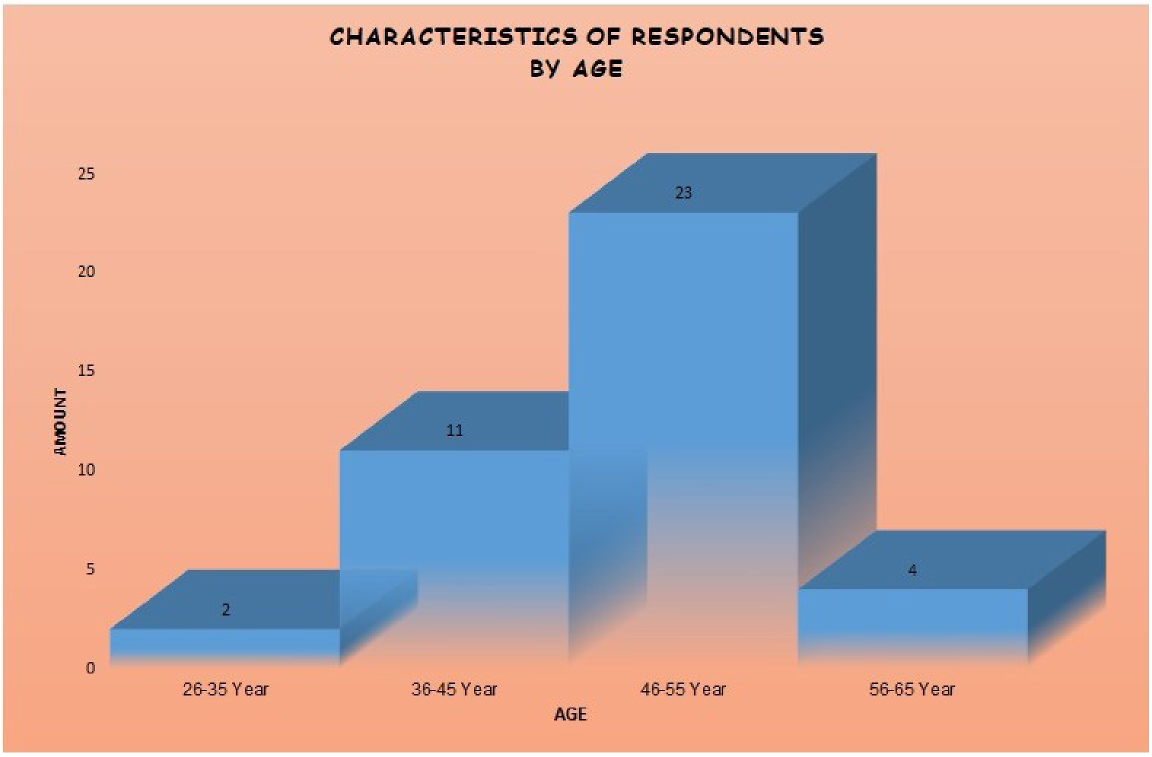


**Figure 1.** Profile by Age (Source : Data Analysis, 2022)

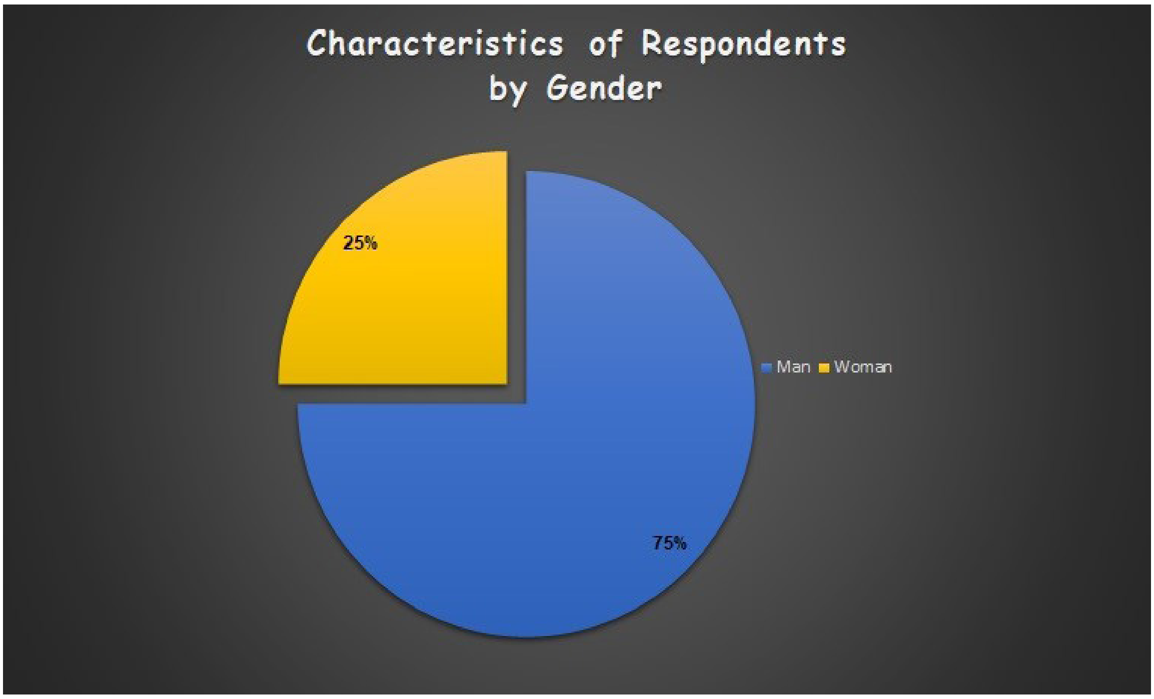


**Figure 2.** Profile by Gender (Source : Data Analysis, 2022)


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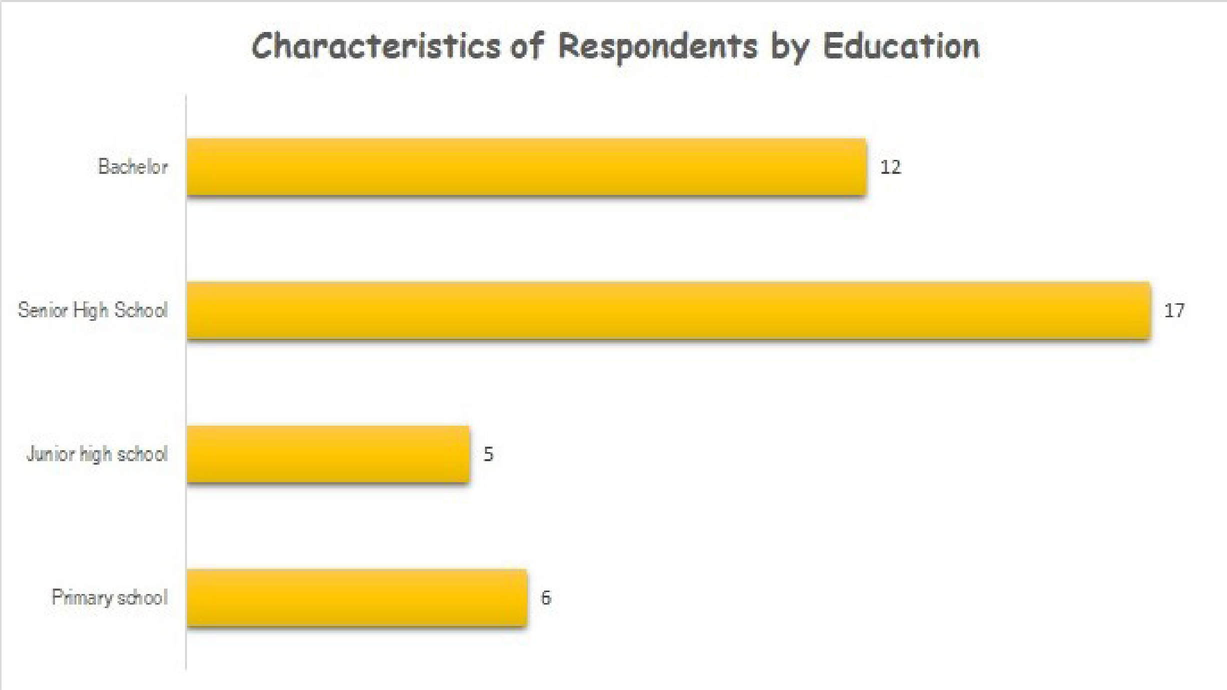


**Figure 3 .** Profile by Education (Source : Data Analysis, 2022)

of people view sustainable development, (Laurett et al. 2021) suggested that local farmers, businesses, government organizations, and consumers engage in dialogue with one another. The respondents in this study come from a variety of professions, including community leaders, sub-district employees at the research site, and professionals from the district agriculture office working in the area of horticulture crop production. All vocational professions are dominated by men, which is understandable given that they provide the majority of the family's income.

The research's findings also revealed that the respondents' highest degree of education was high school, followed by undergraduate studies, with 17 and 12 respondents, respectively. Education may point something in a positive direction in terms of how it will be perceived. This finding is supported by research from (Euriga et al. 2021), which shows that formal education has a significant impact on farmers' perceptions of sustainable horticulture. An in-depth examination of the educational factor reveals a significant positive effect on ethical perception. Several other researchers agree that education has a positive impact on perception (Abdollahzadeh et al., 2015; Ntshangase et al., 2018). Because education can take the form of learning a group of people's knowledge, skills, and habits that are passed down from generation to generation.

### 3.2. Community Perception of Prima Certified Fruit Development

Perception is derived from the Latin perceptio, which means to receive or take. Perception is the experience of objects, events, or relationships gained through inference and message interpretation. Perception, according to (Ritonga 2019), is the process of giving meaning to sensations in order for humans to gain new knowledge; in other words, perception converts sensations into information. As a result, perception can be defined as an experience of objects, events, or relationships gained through inference and message interpretation.

According to (Salisah 2015), proposes that in certain instances we purposefully design our behavior to prevent exposure to specific stimuli that we would prefer to ignore. Although paying attention to stimuli causes them to become more powerful and alive in our consciousness, it does not guarantee that our perceptions will be completely accurate. Attention and perception are heavily influenced by motivational forces.

While the functional factors that influence perception are derived from needs, past experiences, and other factors, we will refer to these as personal factors. The characteristics of the person who responds to the stimuli, rather than the type or form of stimuli, are the determinants of perception. We choose a message based on perception and ignore other messages. The greater the degree of similarity in perception between individuals, the easier and more frequently they communicate, and thus the more likely they are to form identity groups. Table 1 shows the community's perception of the development of Prima certified fruits.

Based on Table 1, the development of Prima certified mango fruit that is perceived as very good has a 'potential for local and export markets' with a score of 4.05. The prima certified mango being studied is clonal mango 21, also known as mango avocado. This mango is the offspring of a cross between the Gadung Mango and the Arumanis. Granting of Horticultural Plant Variety List Signs in 2016. According to information obtained through interviews with several administrators of the Gadung Mango Farmers Association (APMG 21), clonal 21 mangoes have market potential, both locally and internationally, because most farmers choose to sell through association intermediaries because it is more profitable rather than wholesaler with a slash system.

Furthermore, this association organizes marketing channels to traditional markets and collaborates with exporters. Clonal 21 mango marketing objectives include large cities such as Surabaya, Malang, Jakarta, Solo, and Semarang, as well as continuous exports to Malaysia and Singapore. The high mean score in perceiving the potential of local and export markets for Mango Clonal 21 indicates that communities are beginning to recognize that fruit entering foreign markets must meet quality guaranteed requirements and come from Good Agriculture Practices (GAP) gardens, as evidenced by the placement of a label Prime 3 on each fruit. (Sarkar et al. 2011) discovered in their research that when it comes to perceptions of what constitutes best agricultural practice, the majority of farmers (63 percent) believe that aiming for high yields is the most important criterion. Organic cultivation is the least preferred option for additional plant pest protection, it is difficult to obtain organic certification. However, there is high market demand.

The community views the development of Prima certified mango fruit favorably because it can absorb labor with a known average score of 4.04. The selling price of clonal 21 mangoes is around Rp. 35,000 - 45,000 per kg, making it a very profitable crop for many farmers in Rembang District, Pasuruan Regency. Even though agriculture in Indonesia is experiencing regeneration issues, there are many children of mango farmers who want to follow in their parent's footsteps to maintain their livelihoods, and they are open to obtaining various types of information both on and off-farm via social media such as WhatsApp, Facebook, and Instagram.

**Table 1.** Community Perception of the Development of Prima Certified Fruits

| No. | Perception Evaluation Elements | Average Score | |
|---|---|---|---|
| | | Mangoes from Pasuruan Regency | Pineapple from Kediri Regency |
| 1. | Conformity with the aspirations of the community | 3.97 | 3.81 |
| 2. | Employment | 4.04 | 3.72 |
| 3. | Location-specific commodities | 3.97 | 4.04 |
| 4. | Local and export market potential | 4.05 | 4.15 |
| 5. | Cost, technology, and institutional barriers | 3.64 | 3.84 |

Source : Data Analysis (2022)


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The study's findings make an important contribution because the community believes that agricultural workers motivated by market certainty and high product selling prices from the Prima Certification guarantee will be able to reduce the negative impact of agricultural regeneration issues, and in the long run, it is expected to be able to restore existing labor conditions to have high productivity and a high level of working time in line with efforts to attract potential employees. This finding is consistent with the research (Laurett et al. 2021) that farmers in Brazil perceive socioeconomic benefits such as increased profitability, healthy food production, improved farmer health, efficiency, improved quality of life, increased production costs, long-term profitability, and field creation, employment, and income from existing sustainable agricultural practices.

The Prima-certified mango cultivation activity drew attention because it met the community's expectations, with a known average score of 3.97. The community recognizes that farmers' use of good agriculture or Good Agriculture Practices (GAP) is an effort to ensure the welfare of farmers, their families, and workers, while consumers receive quality products with safe nutritional value. The complicated requirements of GAP are actually designed to ensure environmental sustainability so that the application of GAP can restore the state of agricultural land in their area, which is increasingly damaged due to the excessive use of chemical fertilizers and pesticides.

Different research locations and respondents, but the same element of perception assessment that the highest perception of pineapple fruit commodities from Kediri Regency is 'Local and export market potential,' which is 4.15, indicating that the community perception that has been built also recognizes that the commodity has a high chance of being demanded by local and international markets. Local marketing areas are well-known in major cities such as Surabaya, Jakarta, Yogyakarta, and Bali. Surprisingly, because this fruit has been labeled with Prima 3, it has been successful in entering large-scale modern retail outlets such as Transmart, Hypermarket, and Superindo. Meanwhile, the export market is able to send fresh and processed products to the United Arab Emirates, Japan, Hong Kong, Singapore, Oman, Kuwait, and Canada with the help of exporters.

Furthermore, community perception evaluates the development of pineapple as a Prima certified fruit due to 'location-specific commodities' with an average score of 4.04. This means that most people agree that pineapples primarily come from Ngancar District, Kediri Regency, distinguished by a sweeter taste, thicker flesh than ordinary pineapples, and a relatively large size of 1.5 to 2 kilograms supported by the topography is a mountainous area namely Mount Kelud. Several location-specific varieties have been developed, including Honey Pineapple, Queen, and Pasir Kelud. According to (Ramli 2015), community structural changes can be expected to increase low agricultural productivity. Development of key concepts for increasing income and community welfare through the expansion of location-specific agricultural commodities.

The community perception of 'cost, technology, and institutional barriers', on the other hand, is highly rated, with an average score of 3.84. According to the community in Kediri Regency, the development of pineapple fruit to continue to be certified Prima has a cost constraint due to the need for such large farming capital, given that the sandy soil certainly requires a lot of fertilizer and pesticide treatment to maximize fruit production, while the capital of small farmers is small. So far, capital has been granted to the People's Farming Credit (KUR), but it is deemed insufficient to meet the needs of production facilities other than seeds.

Observing the community's perspective, the success of tissue culture techniques for the Pasir Kelud variety is not repeated, especially during the Covid-19 pandemic, nursery activities have ceased due to social constraints. Whereas the new variety will broaden consumers' options for purchasing pineapples. The existence of farmer groups that are considered less professional to handle GAP, especially individual (individual) farmers, marketing reach is still limited and can be improved, and reluctance when re-administering Prima Certificates due to distance, namely visiting the service office, is perceived by the community as still having problems. The Regional Food Safety Competence Authority of East Java Province is based in Surabaya.

## 4. Conclusion

Based on experiences, requirements, and wants, various community perspectives about how far fruit cultivation has progressed to earn a Prima Certificate in their local environment have been investigated. The five components of assessment have generally been positively received when communities are asked to evaluate the sustainability of mango and pineapple production,

Furthermore, investigation reveals that the potential for the local and international markets as well as employment are seen as crucial perception components for the development of sustainable mangoes in Pasuruan Regency. Many people express their agreement with the statements that "mangoes in Pasuruan Regency sell well in traditional markets spread throughout the region" and even "mangoes can enter and meet the product criteria determined by modern markets or retail (supermarkets/minimarkets)," which are based on community perceptions of the parameters of local and export market potential. Most people have a negative impression of the labor absorption criterion in the sentence, "the existence of fruit farmers who have survived up until now because there are no other jobs." Aside from financial considerations, the community believes that agriculture should be preserved because it has been a job passed down through the generations and has met the requirements of their families up until this point. Then, as their parents lose the strength to continue farming, these young farmers gradually take over that position.
On the other hand, the majority of residents in Kediri Regency view the potential of the local and export markets as well as site-specific commodities as being crucial to the development of the pineapple fruit in Kediri Regency. The research comes to an interesting conclusion when the location-specific commodity parameters in the statement of preserving pineapple fruit commodities with distinctive location specifications support the idea of sustainable agriculture as the most widely accepted response. This means that pineapple farming must be able to raise people's income and welfare in line with increasing production while still taking care of the environment. Additionally, it was discovered that many individuals agree on the criteria of local and export market potential, particularly the statement "pineapple commodity in Kediri Regency has the potential to continue to be developed." Pineapple fruit is a popular fruit both around the world. This creates a reasonable market opportunity for pineapples. This increase in production is attributable to an increase in pineapple consumption. Kediri Regency, as a pineapple-producing center in Indonesia, has enormous potential to continue planting pineapples.

The findings have a wide-ranging impact on the concept of social sustainability of Prima certified fruit farming in East Java. Because the determinant parameter of community perceptions in the two regions is a practical implication that agricultural activity is related to the quality of life of those who work and live in agriculture, as well as those of the surrounding community. Promoting broader market reach through increased use of available labor will improve social cohesion and equity. Certification establishes the quality assurance of agricultural products, it is also one method of increasing product competitiveness in the market. Thus, certification becomes a driving force behind several social development pillars, particularly the elimination of hunger and poverty and the enhancement of life expectancy for a long and prosperous life. A stable and healthy social structure, as well as natural resources and the environment, serve as the foundation for economic activity, while economic prosperity is required for sustaining socio-cultural stability and protecting natural resources and the environment.

## Conflict of interest

The authors declare no conflict of interest.

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# Stakeholders' knowledge of organic rice quality in Indonesia

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In recent years, the demand for organic rice has increased along with the increasing consumer awareness of it. However, information or knowledge systems regarding consumer expectations of the quality of organic rice have not been well developed. In order to develop the quality of organic rice, this study intends to explain deficiencies in information or knowledge systems along the supply chain. Focus group discussions were conducted with farmers, processors, and consumers, from which key information or knowledge was categorised and weighted to describe which was the dominant factor for quality development. The study found that the definition of organic rice quality differs among farmers, processors, and consumers. The farmers tend to define the quality based on environmental context. However, processors consider the product's attributes, while consumers tend to focus on both the product's attributes and the process.

## 1. Introduction

Consumer knowledge of the latest products is an essential point in the discourse of service innovation. In this case, common knowledge becomes a bridge to improve the relationship between two parties, especially consumers and producers (Salunke et al., 2019). While achieving common knowledge means that both parties 'acknowledge' and 'agree' on common terms and procedures, the level of consumer knowledge and product characteristics have become a point of interest (Singh et al., 2021). This shows that the process of forming common knowledge is highly dependent on how consumers experience, feel, and use the product.

Since the level of knowledge can be a reference to accelerate the achievement of common knowledge, both consumers and producers must cooperate to create a dialectical situation. This suggests that common knowledge is developed by the process of synthesis that is carried out by both parties (Nonaka & Toyama, 2015). There is "room" for multiple points of view due to the level of product knowledge; producers and consumers may have opposing or complementary opinions regarding a given product. From both sides, the internalization of knowledge will continue to occur, and tacit knowledge is the reason for formulating common knowledge. However, common knowledge in product development is majorly driven by the customer perception of the product (Stolzenbach et al., 2013). In addition, knowledge acquisition between both parties is urgently needed to drive the adoption of 'new' products regarding both usability and social trends (Risselada et al., 2014). Consequently, the term 'consumer power' reinforced by the digital revolution has changed how consumers interpret a product, and this has impacted the way producers capture consumer knowledge (Labrecque et al., 2014).

The growth of technological products and daily demands are influenced by a product's mastery of knowledge in a variety of ways. This may refer to products developed to meet needs (that evolve over time) or products that are cultural-based and whose processing is not eroded over time. In Indonesia, certain food products have been manufactured and consumed for generations, but only a few consumers are aware of the advantages of one product over another.

Consumers state that foods labelled as organic are nutritionally superior and safer than their conventionally produced equivalent (Bergam & Pandhi, 2023). For organic foods, organic rice is the second highest-demanded organic product in Indonesia (David & Ardiansyah, 2017a). Since 2010, the Indonesian government has been supporting organic food production. The Department of Agriculture pushed the enthusiasm to practice organic agriculture and to consume organic products with the slogan 'Go Organic 2010' (Dalmiyatun et al., 2018). Currently, organic food production has been increasing. Organic products in Indonesia represent 0.03% of global demand, with a per capita expenditure of USD 0.06 in 2021. With a growing number of consumers interested in organic products and the emerging economy in Indonesia, the potential for organic products seems optimistic when considered in the long term, with a forecast value CAGR of 6.1% for 2021 to 2026 (Euromonitor International, 2022). The demand for organic food has steadily increased in Indonesia, the global market, and developed and developing countries due to increasing consumer awareness of health and environmental issues (Joshi et al., 2019).

Because the organic farming approach follows some basic principles such as health, ecology, fairness, and care, it is considered an efficient agricultural practice for environmental sustainability (Dhiman, 2020). Consuming organic food enables a healthy and environmentally conscious lifestyle, which in turn creates a global green movement known as green consumerism and a sign of green identity. (Wilujeng, 2021). Today, consumers and producers around the world have become more conscious of the danger of using synthetic chemicals in farming, which may have negative effects on human health and may equally cause environmental damage. Consumers need assurance that their food is safe and has a high nutritional value (Export News Indonesia, 2017).

According to David and Ardiansyah (2017b), in consumer perception of organic rice, health concerns, and less pesticide residue were essential factors that influenced the purchase of the product by the consumers. However, what consumers do not know is that when the organic rice is polished, like the conventional one, then the nutritional content of both will be similar (David et al., 2019; David et al., 2020). Meanwhile, the consumer spends more on organic rice's nutritional quality than the conventional one. The selling price of organic rice ranges from 1.5 USD to 4 USD. The wide price range is assumed to be asymmetric information along with the milling process.

The price cannot reflect the dilemma between the degree of milling and the nutritional properties of rice. Consumer perception of brown rice is lower where the nutritional properties are high. Meanwhile, for farmers and processors, the highest degree of milling reflects an increase in the price. In the area of organic food, consumers and their purchasing behaviour have been the subject of several studies. Even though there is still a lack of consistent findings and precise descriptions of consumers' perception of organic food quality in terms of its health benefits, safety, and environmental sustainability, as well as in terms of the determinants of perceived quality (Lamonaca et al., 2022). Food quality is commonly associated with nutritional and sensory aspects, especially taste. In the case of organic products, the notion that organic food is more nutritious than conventionally produced foodstuffs is still debatable, and the conclusion is not clear yet. Moreover, some people may be able to differentiate the taste of organic and non-organic food, but others may find no difference. Various factors influence food quality besides the farming process, such as harvesting time, post-harvest process, storage conditions, room temperature and packaging material, and cooking practices.

Given the above situation, this study aims to analyse the common knowledge of organic rice quality by its consumers and producers and how they develop a consensus of information. The study further identifies which knowledge/information is not fully understood by these stakeholders as well as the one that both can


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understand.

## 2. Methodology

To examine how the discourse of shared knowledge is formed between producers and consumers, we approached groups of stakeholders in organic rice in Indonesia. The stakeholders consisted of a group of farmers (n=13), a group of processors/intermediaries (n=10), and a group of consumers (n=18). We collected data by focus group discussion (FGD) which was performed in three groups of separate sections. The Group of Farmers (GF) is an organic rice grower practicing organic agriculture for about ten years. The GF were between 36 and 58 years old and all of them were males. The Group of Processors (GP) is a processor of rice milling and a middleman trader who has been practicing for more than 15 years. They mill both conventional and organic rice milling. Consumers of organic rice between the ages of 25 and 50 make up the Group of Consumers (GC). An FGD was conducted for about 90 minutes under the supervision of one facilitator. Data was collected and documented.

Data from the FGD was collected using an affinity diagram and was weighted according to the expert panel. The expert panel consisted of consumers, farmers, and processors. Data was coded and weighted to describe which key knowledge was the main gap/barrier. Data was translated from Indonesian into English, and all actors were asked what their expectation of organic rice was and what was yet to be accomplished. Five key questions were addressed to all actors (farmers = F) (Processor = P) and (consumer = C). 1) Are you satisfied with organic rice information/knowledge? (Yes/No) 2) Do you consider the milling degree to be the problem? (Yes/No/Do not Know) 3) How do you rate the current quality of organic rice? (1= low, 5= best) 4) Is the quality/price ratio satisfactory? (Yes/No) 6) Do all actors think the quality should be improved? (Yes/No/Don't know)

The qualitative data was computed to Xlstate (R) Base Version 2021. The Audio analysis was carried out using f4 software developed by Marburg University, Germany. After importing, editing, and formatting, content analysis was done. Data were analysed using Multiple Correspondence Analysis (MCA) which was performed by Xlstat Base Version 2021. Correspondence analysis aimed to represent as much of the inertia on the first principal axis as possible, with a maximum of the residual inertia on the second principal axis and so on, until all the total inertia was represented in the space of the principal axes.

## 3. Results

The comparison of key information among the actors can be seen in Table 2. The GF recognised that the quality of organic rice was guaranteed by the information that no fertilizer or pesticide was used in its growth implying that there would be no additional chemical residue on their yield. The farmers agreed that when they practised organic farming, they gained a high yield and a better selling price. They believed that organic farming could be beneficial to the Environment. However, they still assumed that organic rice should be milled like conventional rice since more the degree of milling, the better the appearance of the rice.

Unlike farmer groups, for the processor, the indication of organic rice quality is based on the degree of milling and whiteness. These indicators are contrary to the aim of organic rice, while the increasing milling time reduces the nutritional value (David et al., 2019). In terms of price, processors expected a higher price for organic rice than conventional rice. Since the demand for white organic rice is high, processors continue to produce organic rice with a higher degree of milling.

Consumers define organic rice quality based on its sensory and non-sensory attributes. The taste of organic rice is an important attribute. David et al. (2020) confirmed that aroma and taste are the attributes that consumers appreciate before buying an organic rice product. However, the dilemma is that the better the taste, the higher the degree of milling, resulting in lower nutritional content in the organic rice. In addition, consumers rarely consider the freshness of organic products, whereas freshness greatly impacts food product taste and nutritional value. During processing, transporting, or storage, some chemical changes affect sensory perception and can result in the loss of some specific nutrients. Furthermore, some organic products are still being produced on a limited scale, making them less accessible than other products. In such cases, the organic product may be transported for quite a long distance and may stay on the market

**Table 1.** Characteristics of actors

| Actors | Aged range | Education | Years exposed to organic product |
|---|---|---|---|
| Farmers (n=13) | 20–30 (n= 0)<br>30–40 (n=3)<br>50 < (n=10) | Elementary School (n=9)<br>Junior High School (n=1)<br>Senior High School (n=3)<br>University (n=0) | 0–5 (n=2)<br>5–10 (n=11)<br>20< (n=0) |
| Processor (n=10) | 20–30 (n= 0)<br>30–40 (n= 2)<br>50 < (n=8) | Elementary School (n=0)<br>Junior High School (n=1)<br>Senior High School (n=8)<br>University (n=1) | 0–5 (n=8)<br>5–10 (n=2)<br>20< (n=0) |
| Consumer (n=18) | 20–30 y (n= 2)<br>30–40 (n=10)<br>50 < (n=6) | Elementary School (n=0)<br>Junior High School (n=0)<br>Senior High School (n=2)<br>University (n=16) | 0–5 (n=8)<br>5–10 (n=10)<br>20< (n=0) |

long before it is sold and consumed. Further, a study showed that rice's physicochemical properties change during storage at various temperatures. Milled rice stored at higher temperatures contains higher fat acidity than the one at low temperatures. Storing milled rice above room temperature increases cohesiveness and hardness. Moreover, after 1 month of storage at 30oC and 40oC, there will begin a significant decrease in all sensory values (Park et al., 2012).

Even though the price of organic rice is now expensive for some individuals, the consumer is nevertheless eager to purchase it under these circumstances. Those who understand the advantages of organic rice nonetheless concur that the product is worthwhile for the money spent on it.

As shown in Table 2, the study results show that the differences in general knowledge about organic products between actors are quite prominent. We highlight three factors to explain how these differences occur, including personal preferences, social values, and breadth of literacy. Personal preference influences the actors' usage and consumption choice of organic products. This factor creates a gap among the actors since each of them has their way of describing the term 'organic'. When asked to define the quality of organic rice, each provided three distinct answers. The GF replied that organic rice is processed with fewer pesticides and no chemicals. The processors said that organic rice has to do with whiteness. The consumers replied that organic rice is a product of healthy and tasty rice. Using a definition of knowledge as a 'highly valued state in which a person is in cognitive contact with reality' (Zagzebski, (2017), personal preference is highly related to the cognitive aspect of actors toward the product. When the actors were asked about the expectation of organic rice, all of them replied from two different points of view. Farmers and processors have their knowledge as the 'sellers' while consumers have theirs as the 'buyers'. This describes the variation in the answers provided by these three institutional actors.

They expressed their views on organic food based on their norms, values, social statuses, and professional backgrounds. The practices and norms upheld by the actors are developed based on their institutional


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**Table 2.** The group has mentioned the most frequent choice of the word.

| Questions | Farmers | Processor | Consumers |
|---|---|---|---|
| What is your definition of the quality of organic rice? | Less pesticide (n=10)<br>No Fertilizer (n=13)<br>No Chemical Residue (n=13)<br>High Yield (n=10) | Refined rice (n=10)<br>Degree of whiteness (10) | Taste (n=17)<br>Healthy (n=15)<br>Organic (n=17)<br>Nutritional (n=18) |
| What are your expectations of the organic rice price? | The best-selling price of Paddy (n=10) | The best-selling price of rice (n=7) | The best buying price (n=17) |
| What is your Motive for producing or consuming organic rice? | Good for the Environment (n=11)<br>Best Selling price (n=13) | There is a demand (n=7) | For health reasons (n=15)<br>For Environment (n=5) |
| What is your opinion about the degree of milling? | Depending on the rice milling unit (n=10) | Important to keep the rice valuable to sell (n=9) | Taste (17)<br>Aroma (n=9) |

practices (Thornton and Ocasio, 2010). When the actors were asked about their motivation for producing organic rice, their three different answers suggested a variation in knowledge regarding such rice. The GF was motivated by the fact that growing organic rice is good for the Environment, while the consumers thought that organic rice is healthy. Lastly, we pointed out that the ability to acquire external knowledge of organic products is related to the literacy of the actors. The question regarding the opinion on the degree of milling shows the breadth of their literacy. A high level of literacy is needed to expand knowledge of organic products.

The distribution of knowledge of all actors based on the five keys of information can be seen in Figure 1 as follows:

Figure 1 explained: in the Upper Right Quadrant (URQ), farmers' and processors' responses are that the quality/price ratio of appropriate and current quality is reflected in range 4, which means that both farmers and processors are satisfied with the current quality/price as well as current quality. Conversely, in the Upper Left Quadrant (ULQ), most of the consumers' response shows the lowest current quality and their dissatisfaction with the information/ knowledge about organic rice. If we refer to Table 2, most of the consumers think that the definition of the taste is organic, healthy, and nutritional, but they do not get this information correctly. Therefore, they are not satisfied with the product. This condition is positively correlated with the importance of the degree of milling which also has been studied in the previous research (David et al., 2019). According to Fitzgerald (2017) translucence, shape, and uniformity are important aspects of rice end-use quality for consumers, millers, wholesalers, and retailers but not farmers.

Moreover, in the Lower Right Quadrant (LRQ), the farmer and processor respond that they are satisfied with the quality when the quality ranges are between three and five. This condition may be because of the Indonesian National Standard for Rice (SNI 6218 2020), which has grouped the quality of rice into three

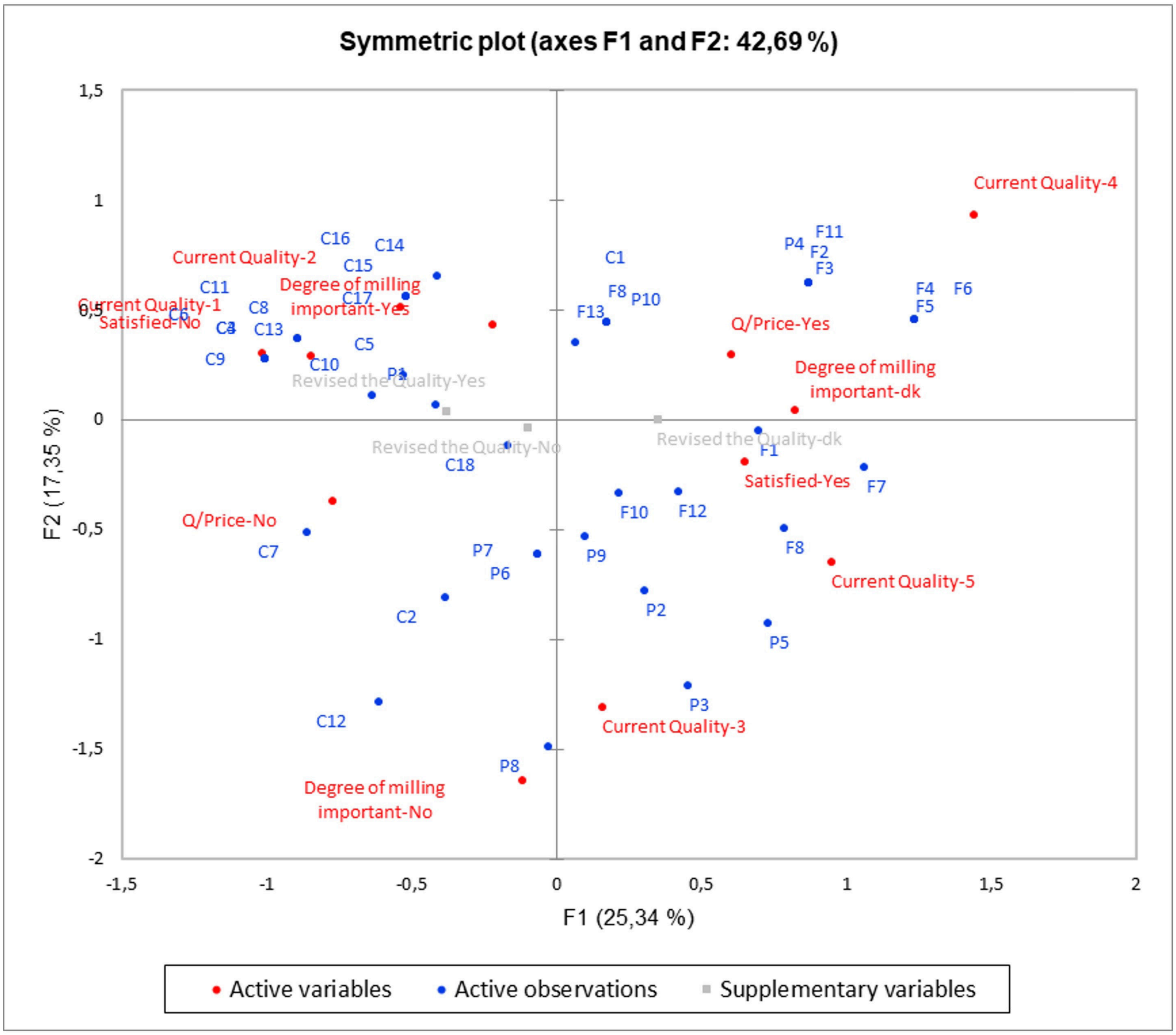


**Figure 1.** Distribution of knowledge of all actors regarding the five keys information/knowledge

different classes. The Lower Left Quadrant (LLQ) belongs to the group that thinks there is no satisfaction with the quality/price and to which the degree of milling is not that important.

## 4. Conclusion

Based on this study, we conclude that farmers have some knowledge in terms of defining quality with more focus on the environmental issue. At the same time, the processor is more focused on the degree of milling. Conversely, consumers have their definition of quality as closely related to the nutritional value of the product. In terms of common knowledge, there are gaps among actors in defining and perceiving the term 'organic'. This is also indicated by people's perceptions and knowledge of the advantages of using organic rice in the organic food ecosystem. We can say that farmers/processors fulfil the term organic by growing rice with its high selling price.

On the other hand, consumers do not pay more attention to price than to the benefits of organic rice for their health and life quality. However, knowledge of the nutritional value should be connected to the degree of milling to fill the consumer's expectation gap. When the degree of milling meets the appropriate nutritional ingredient of the rice the gap can be reduced. On the other hand, farmers should communicate with processors regarding price/quality, as this may be a


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barrier to these two actors in defining which degree of milling will benefit both actors. Our paper provides a direction for further study, positing that common knowledge concerns the same knowledge among actors. This may be achieved with different stakeholders and different pieces of knowledge, but it forms knowledge ecosystems.

## Conflict of Interest

The authors declare that there is no conflict of interest.

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## Bumble Bee Study Reveals Surprising Dietary Preferences and Flower Favorites in Ohio and the Upper Midwest

A recent study has discovered the preferred flower species for bumble bees in Ohio and the Upper Midwest, indicating that these bees have more discerning dietary preferences than previously thought. The research, which involved observing nearly 23,000 bumble bee-flower interactions over two years, revealed that bumble bees do not always choose the most abundant flowers in their foraging areas.

This information can assist both professional and amateur conservationists in making informed decisions about planting to support bee populations. The study identified several top flower species favored by bumble bees, including milkweed, native thistles, morning glory, purple cone flower, bee balm, beard-tongue, red clover, vetch, rosinweed, Culver's root, and wild indigo. Out of the 16 bumble bee species historically found in Ohio, researchers observed 10 species, with the most frequently observed being the Common Eastern Bumble Bee. The study emphasized the need for comprehensive analysis due to limited data on rarer species and the potential for any species to become rare.

The research team visited various locations, including unmanaged fields, restored roadsides, meadows, and planted urban patches and hayfields, to collect data on bumble bee interactions with 96 different species of wildflowers. The analysis revealed nonrandom patterns of bumble bee visits to specific plants, indicating their preference for certain flowers. The study also highlighted certain plants, such as alsike clover, black-eyed Susan, and prairie cone flower, which were commonly used in pollinator conservation plantings but consistently ignored by bumble bees.

Furthermore, the research showed that different bumble bee species had varying preferences for flowers, with only one-third or less overlap in their choices, indicating reduced competition and the ability for multiple species to coexist. The study provides valuable insights for managing bumble bee habitats and conservation efforts, considering the threats they face from habitat loss, climate change, and disease.

1. Jessie Lanterman Novotny, Andrew Lybbert, Paige Reeher, Randall J. Mitchell, Karen Goodell. **Bumble bee banquet: Genus- and species-level floral selection by Midwestern Bombus**. Ecosphere, 2023; 14 (2) DOI: 10.1002/ecs2.4425

## Montreal Protocol: A Climate Treaty's Surprising Impact on the Arctic

The implementation of the Montreal Protocol, an international treaty aimed at protecting the ozone layer, is not only safeguarding the Earth from harmful ultraviolet radiation but also delaying the occurrence of the first ice-free Arctic summer. A recent study led by climate researchers at Columbia Engineering and the University of Exeter reveals that the Montreal Protocol is pushing back the timeline for an ice-free Arctic by up to 15 years. This significant delay is dependent on future emissions and highlights the tangible results achieved by the treaty within a few decades of its implementation.

The reduction in atmospheric concentrations of ozone-depleting substances (ODSs) driven by the Montreal Protocol has proven to be a successful climate mitigation effort, offering a surprising by-product of protecting the Arctic ecosystem.

The study's findings emphasize the importance of the Montreal Protocol in mitigating climate change, as the rapid melting of Arctic sea ice is one of the clearest indicators of anthropogenic global warming. Without the Montreal Protocol, the estimated global mean surface temperature would be around 0.5°C warmer by 2050, with the Arctic polar cap being almost 1°C warmer.

Although the primary goal of the treaty was to regulate ODSs and protect the ozone layer, its impact on reducing greenhouse gas warming and slowing Arctic climate change has been significant. Continued monitoring and adherence to the Montreal Protocol are crucial to maintain the progress achieved and prevent any potential rise in ODS concentrations that could undermine the healing of the ozone layer and exacerbate global warming.

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## Plant Biologists Uncover Molecular Mechanism Controlling Root Formation, Paving the Way for Improved Crop Growth

An international team of plant biologists has discovered a molecular mechanism involving the target of rapamycin (TOR) protein that controls the formation of lateral roots in plants. By studying the model plant Arabidopsis thaliana, the researchers found that glucose breakdown and carbohydrate consumption in the pericycle, the outermost cell layer of the main root cylinder, are essential for the formation of lateral roots.

TOR protein acts as a gatekeeper, ensuring that sufficient sugar resources are available before activating the genetic growth program responsible for root formation. The researchers also demonstrated that TOR plays a similar role in the formation of adventitious roots. Understanding this mechanism could lead to strategies for optimizing plant growth under different environmental conditions and improving crop yields.

The research was funded by the German Research Foundation and involved collaborations with institutions in France, Germany, Spain, and Ireland. The findings were published in The EMBO Journal.

1. Michael Stitz, David Kuster, Maximilian Reinert, Mikhail Schepetilnikov, Béatrice Berthet, Jazmin Reyes-Hernández, Denis Janocha, Anthony Artins, Marc Boix, Rossana Henriques, Anne Pfeiffer, Jan Lohmann, Emmanuel Gaquerel, Alexis Maizel. T**OR acts as a metabolic gatekeeper for auxin-dependent lateral root initiation in Arabidopsis thaliana**. The EMBO Journal, 2023; 42 (10) DOI: 10.15252/embj.2022111273

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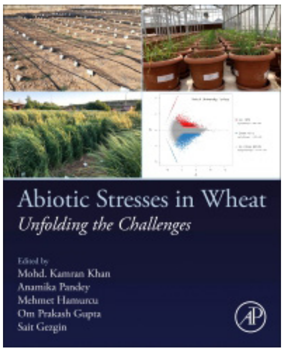


# Abiotic Stresses in Wheat: Unfolding the Challenges

A review by Diana Ismael

Edited by Mohd. Kamran Khan, Anamika Pandey, Mehmet Hamurcu, Om Prakash Gupta, Sait Gezgin
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*The book, "Abiotic Stresses in Wheat:* Unfolding the Challenges," explores the current challenges and advancements in managing abiotic stresses in wheat crops. It covers various stress conditions and discusses the latest research-based strategies and tools for enhancing wheat resilience. With a comprehensive approach, the book delves into genetic, biochemical, physiological, and molecular aspects, as well as emerging frontiers such as transgenic approaches. This valuable resource offers a holistic perspective on mitigating the effects of abiotic stresses in wheat, providing translational insights and facilitating efficient comparisons.

The first chapter highlights the adverse effects of various abiotic stresses on wheat crops, including water stress, temperature stress, heavy metal toxicity, salinity stress, and UV-B exposure. These stresses impede growth and development, disrupt biological and physiological processes, alter biochemical functions, and induce changes in gene expression patterns and antioxidant activities. The chapter addresses the challenges posed by these stresses and provides future perspectives for mitigating their harmful effects on wheat crops.

Chapter 2 explores conventional breeding methods for enhancing abiotic stress tolerance in wheat. The chapter addresses challenges posed by drought, temperature extremes, and salinity, leading to reduced crop output. The authors stress the importance of genetic resistance in overcoming yield limitations. Various breeding tactics, including genotype screening and traditional methods, are discussed to develop stress-resistant wheat cultivars. These approaches have shown promise in improving production and mitigating abiotic stress impacts.

Chapter 3 explores the concept of speed breeding as a valuable tool for accelerating crop research and breeding programs. The chapter addresses the global challenge of food security and the limitations of traditional breeding methods. Speed breeding techniques, such as manipulating generation time and extending light exposure, are discussed as means to reduce generation time and expedite plant breeding. These techniques allow for multiple generations of crops to be developed in a shorter timeframe, enhancing breeding efforts for various crops.

Chapter 4 discusses the significance of wheat as a staple food and the importance of enhancing its abiotic stress tolerance. The chapter explores marker-assisted breeding, a technique that utilizes molecular markers to select desired traits related to stress tolerance in wheat. By linking markers with target genes, breeders can expedite the selection of stress-tolerant varieties. This approach offers a precise and efficient way to incorporate stress tolerance traits into wheat breeding programs, ultimately improving food security.

Chapter 5 presents an overview of epigenetic mechanisms and their significance in regulating plant responses to abiotic stresses. It discusses the consequences of these mechanisms and their potential applications in mitigating abiotic stress in wheat crops. The chapter contributes to our understanding of the role of epigenetics in crop improvement and highlights its potential for enhancing the resilience of wheat crops to adverse environmental conditions.

Chapter 6 discusses physiological and biochemical approaches to mitigate abiotic stresses in wheat. It highlights challenges such as salinity, drought, heat, and preharvest sprouting, impacting wheat productivity. Traditional breeding alone may not be enough, requiring advanced research


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in physiology, genetics, and breeding. The chapter emphasizes identifying traits associated with stress tolerance and understanding genetic factors. It explores stress mitigation techniques like plant hormones, agronomic interventions, genetic management, and biotechnology to enhance wheat performance and ensure sustainable productivity.

Chapter 7 delves into the role of phytohormones in regulating abiotic stresses in wheat. With wheat facing significant production losses due to abiotic stresses, understanding the role of plant growth regulators (PGRs) becomes crucial. This chapter explores the physiological changes in wheat under various stresses and highlights the advancements made by PGRs like melatonin, salicylic acid, brassinosteroids, and polyamines in enhancing stress tolerance. Further research is emphasized to unravel the mechanisms through which these PGRs mitigate the adverse impacts of stressful conditions on wheat crops.

Chapter 8 delves into the consequences, survival mechanisms, and mitigation strategies related to abiotic stress-induced reactive oxygen species (ROS) production in wheat. As a crucial cereal crop, wheat contributes significantly to global grain production and food security. However, abiotic stress disrupts plant growth and development, leading to redox imbalance and the generation of ROS as by-products of cellular metabolism. Increased ROS production under various environmental conditions triggers oxidative damage, cell death, and sterility in wheat, affecting pollen development and physiological, biochemical, and morphological processes. This chapter explores the implications of ROS production in wheat and discusses strategies to mitigate its detrimental effects.

Chapter 9 deals with the circadian clock's role as a timekeeper and its synchronization with the environment. By limiting peak response periods, circadian gating enhances stress resistance without compromising plant development. The chapter explores the general mechanism of the circadian clock, its association with abiotic factors, and its response in monocot plants. Additionally, it highlights clock-mediated gene responses in wheat under abiotic stress. The presence of Arabidopsis clock gene homologs in wheat suggests potential for developing climate-resilient, high-yielding wheat varieties. While chapter 10 discusses the diminished tolerance of agricultural crops to environmental stresses due to plant breeding. It highlights the significance of climate-resilient varieties with improved root system architecture for adaptation.

Chapters 11 and 12 highlight the major abiotic stresses that affect wheat, such as drought, salinity, waterlogging, and extreme temperatures, leading to decreased yield. The chapters discuss the impact of these stresses on photosynthesis, biochemical processes, and regulatory mechanisms. The role of enzymes, transcription factors, and phytohormones in supporting photosynthesis under stress conditions is explored. The use of CRISPR-Cas technology for developing abiotic stress-tolerant wheat is emphasized, along with the challenges and potential benefits of genome editing in improving wheat resilience and ensuring global food security in a changing climate.

Chapters 13 and 14 focus on abiotic stress and its impact on wheat productivity. The chapters discuss the challenges faced by wheat researchers in improving crop resistance to salinity, drought, submergence, and high temperatures. They highlight the importance of genetics, physiology, and breeding research in understanding abiotic stress tolerance. The complex signal transduction pathways and the involvement of numerous genes in the plant's response to stress are explored. The chapters also emphasize the use of functional genomics and transcriptomics to uncover the molecular mechanisms and identify differentially expressed genes (DEGs) involved in metabolic pathways under stress conditions. These advancements provide insights for future studies and the development of abiotic stress-tolerant wheat varieties.

Chapter 15 focuses on studying the effects of stress conditions on wheat proteins, particularly in relation to carbohydrate metabolism, photosynthesis, and calcium metabolism. Proteomic techniques are employed to identify changes in protein expression under stress, providing insights into grain formation. Chapter 16 explores the role of small RNAs, specifically microRNAs, in regulating gene expression and enhancing abiotic stress tolerance in wheat. The chapter highlights the significance of miRNAs in plant development and emphasizes their potential for improving stress tolerance in wheat.

Chapter 17 focuses on the significance of combined abiotic stress in wheat, which occurs when multiple adverse environmental stresses affect plant development and growth. This chapter highlights the need for more research in this area and provides insights into which aspects should be prioritized to address yield loss under different combined abiotic stress conditions in wheat.

Chapter 18 explores the impact of ultraviolet (UV) radiation on wheat and its coping mechanisms. UV radiation can disrupt plant growth and development, and plants activate defense mechanisms to counteract its effects. This chapter delves into the physiological, molecular, and cellular changes that occur in wheat in response to UV radiation stress, providing an understanding of the mechanisms underlying adaptation to radiation stress in wheat.

The rest of the chapters deals with very exciting topics related to advancement in mitigating the effects of drought stress, heavy metal toxicity, and boron stress in wheat.

"Abiotic Stresses in Wheat: Unfolding the Challenges" is an invaluable resource that addresses the pressing issues related to abiotic stress in wheat crops. The book covers a wide range of abiotic stress conditions and explores cutting-edge research and management strategies to enhance the resilience of wheat plants. It offers comprehensive insights into genetic, biochemical, physiological, molecular, and transgenic approaches for mitigating the effects of these stresses. This book is a significant contribution to the field, providing essential information for researchers and practitioners seeking to improve wheat productivity under challenging growth conditions. Its comprehensive coverage and translational insights make it a valuable reference for understanding and comparing different abiotic stresses in wheat.

**About the author:**

Diana Ismael is a sensory specialist with a PhD in Food and Sensory Science/Consumer Behavior from Kassel University, Germany. Her research focuses on understanding the intention-behaviour gap in organic food consumption. Currently, she works as the Managing Editor at the Future of Food Journal: Journal on Food, Agriculture & Society.


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