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Quality of Cacao Beans as Influenced by Fermentation and Drying Durations

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ABSTRACT

This study evaluated the effects of fermentation and drying durations on the physical and chemical quality of cacao beans produced in Brgy. Sto. Niño, Koronadal City, South Cotabato. A 3 x 3 factorial experiment arranged in a Completely Randomized Design with three replications was used. The treatments consisted of three fermentation durations (6, 7, and 8 days) and three drying durations (5, 6, and 7 days). The quality parameters assessed were moisture content, pH, bean weight, bean count, defect percentage (moldy, slaty, and purple beans), bean purity, and bean grade. Data were analyzed using two-way Analysis of Variance and Least Significant Difference tests at the 5% level of significance. Results showed that fermentation and drying durations significantly influenced moisture content, with 7 days of fermentation combined with 6 to 7 days of drying producing moisture levels nearest the safe range for storage. Fermentation significantly affected pH, with 7 days producing a balanced acidity level, while drying significantly affected bean weight and bean count. Defect parameters and bean purity were not significantly affected, and all treatment combinations met Grade 1 standards with more than 90% purity. The study concludes that coordinated fermentation and drying management is essential in stabilizing moisture, improving acidity, and maintaining commercial bean quality. The recommended protocol is 7 days of fermentation followed by 6 to 7 days of drying for consistent Grade 1 cacao beans.

Keywords: *cacao bean quality, drying duration, fermentation duration, moisture content, postharvest processing*

INTRODUCTION

Cacao (Theobroma cacao L.) remains one of the most important high-value crops because it supports chocolate production, rural livelihoods, and local agro-industry. Historically, cacao has been valued as the basis of chocolate and other processed products, and its quality is strongly shaped by how beans are handled after harvest. Although genetic variety, climate, and farm management influence bean characteristics, the quality of raw cacao beans is largely determined by fermentation and drying, which are the most critical postharvest stages in the cacao value chain (Schwan & Wheals, 2004; Dzelagha et al., 2020).

The global demand for chocolate continues to increase, which places greater pressure on cacao-producing communities to deliver beans with consistent physical, chemical, and market quality. In the Philippines, cacao is processed into tablea, artisanal chocolate, and other value-added products. However, the local cacao sector continues to face quality inconsistency, particularly because many smallholder farmers still rely on traditional fermentation and drying practices without clearly standardized durations, turning schedules, moisture targets, or temperature management (Enhanced Provincial Commodity Investment Plan, 2023).

Fermentation initiates the biochemical changes necessary for flavor precursor development. Through the action of yeasts, lactic acid bacteria, and acetic acid bacteria, sugars and pulp components are transformed into acids and heat, which activate internal bean reactions responsible for reducing bitterness and astringency and developing the brown color of properly fermented beans (De Vuyst & Weckx, 2016; De Vuyst & Leroy, 2020). Drying, in turn, stabilizes the beans by reducing moisture to safe storage levels, limiting mold growth, and preserving the physical and chemical gains obtained during fermentation (Hii et al., 2019; Dzelagha et al., 2020).

In South Cotabato, cacao production supports local chocolate processors, cooperatives, and small-scale farmers, but product competitiveness depends on the consistency of bean quality. Since fermentation and drying are practical management points that farmers can control, this study evaluated how different fermentation and drying durations influence cacao bean quality in terms of moisture content, pH, bean weight, bean count, defect incidence, purity, and grade classification.

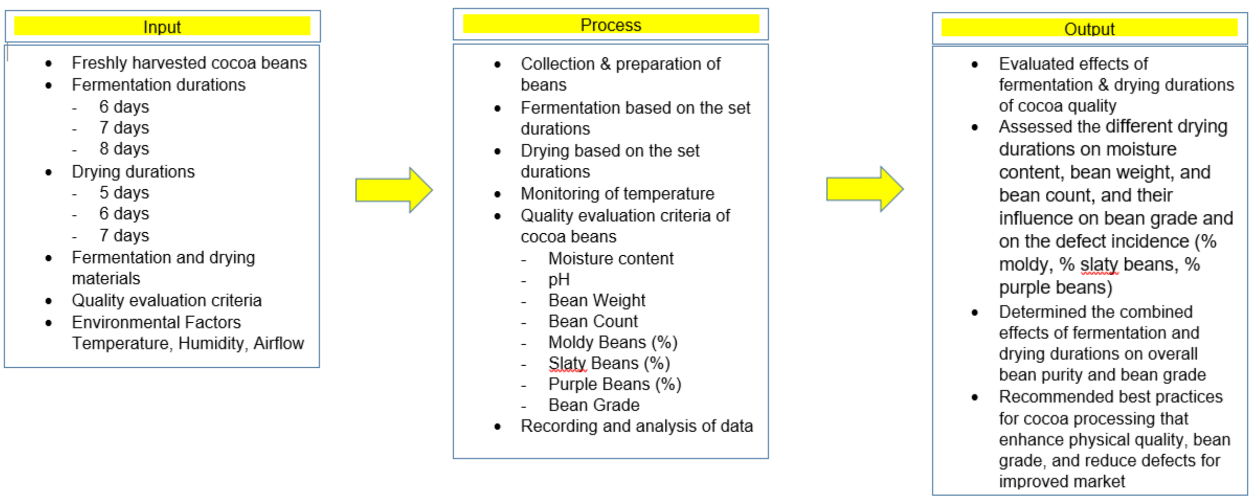

Figure 1. *Conceptual framework of the study.*

Literature Review

Cacao Production and Postharvest Quality

Cacao is cultivated in humid tropical environments and remains a major crop in equatorial regions. In the Philippines, Mindanao accounts for a large share of cacao production, with South Cotabato contributing to local cacao supply and tablea/chocolate processing. However, production and market competitiveness are limited by postharvest issues, including inconsistent fermentation, uneven drying, and insufficient facilities. These constraints affect bean grade, flavor potential, and market value (Enhanced Provincial Commodity Investment Plan, 2023; Medenilla, 2022).

The quality of cacao beans depends on both agronomic and postharvest factors. While pests, diseases, soil fertility, and climate influence yield, the final acceptability of beans for processing depends strongly on fermentation and drying control. Studies have shown that poor postharvest practices contribute to slaty, moldy, and purple beans, all of which reduce quality, lower market value, and affect chocolate flavor development (Kongor et al., 2016; Cilas & Bastide, 2020).

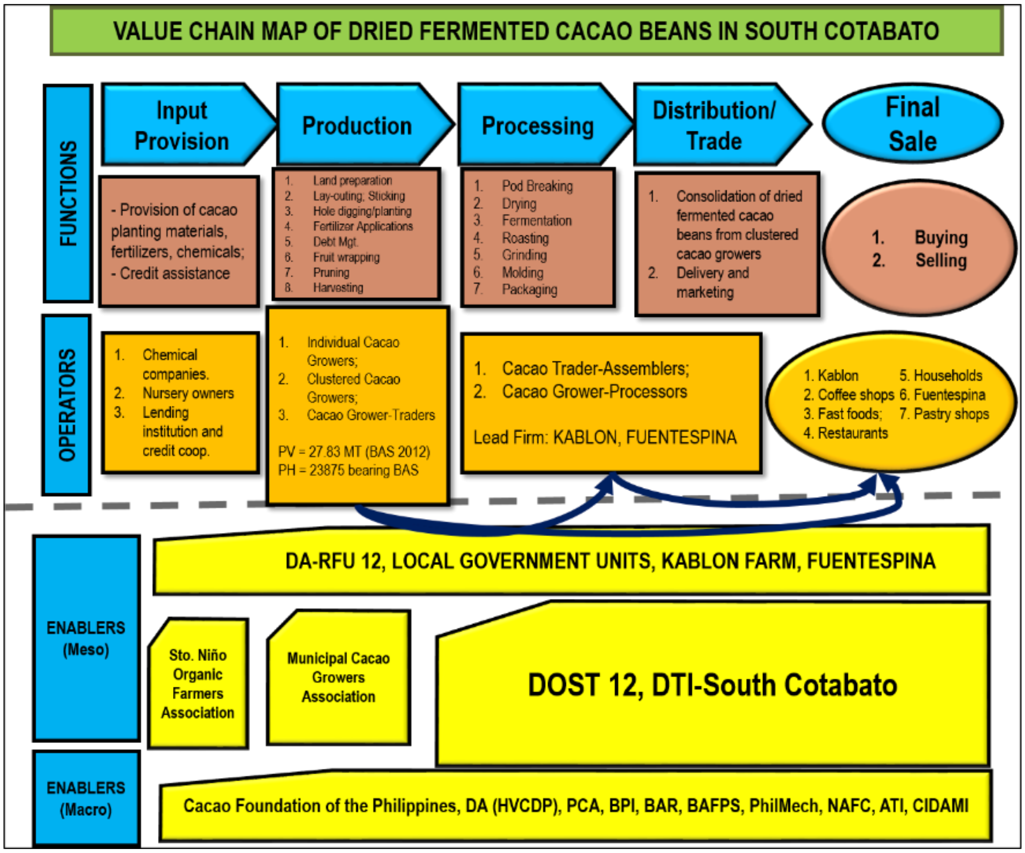

Figure 2. *Value chain map of cacao in South Cotabato.*

Fermentation Duration and Bean Quality

Fermentation is a naturally occurring microbial process that transforms cacao beans through heat generation, acid production, pulp degradation, and internal enzymatic reactions. Yeasts first convert pulp sugars into ethanol, lactic acid bacteria contribute to acidification, and acetic acid bacteria oxidize ethanol into acetic acid, generating heat and activating reactions that produce flavor precursors (Schwan & Wheals, 2004; De Vuyst & Weckx, 2016).

Fermentation duration is therefore a key control point. Short fermentation may result in slaty or purple beans because internal biochemical conversion remains incomplete, while excessive fermentation may produce off-flavors, high acidity, and greater risk of microbial spoilage. Studies commonly identify 5 to 8 days as a practical range, depending on variety, climate, pulp condition, and turning practices (Ackah & Dompey, 2021; Rodríguez-Campos et al., 2012; Calvo et al., 2021).

Drying Duration and Bean Stability

Drying reduces the moisture of fermented beans to levels that are safe for storage. The commonly recommended final moisture content is around 6 to 8%, because beans with excessive moisture are susceptible to mold and quality deterioration, while over-dried beans may become brittle and lose commercial value (Ackah & Dompey, 2021; Hii et al., 2019).

Drying is not merely a water-removal process; it also influences acidity, bean structure, and the stability of flavor precursors formed during fermentation. Gradual drying allows residual acids to diffuse and evaporate, whereas very rapid or poorly managed drying can trap acids and cause quality defects (Dzelagha et al., 2020; Lasisi, 2014).

Interaction of Fermentation and Drying

Fermentation and drying should be considered interdependent processes. The condition of the beans after fermentation influences how efficiently moisture is removed during drying, while drying stabilizes or compromises the results of fermentation. Tomlins et al. (1993) emphasized that fermentation practices strongly affect final bean characteristics, but inadequate drying can amplify defects that begin during fermentation.

Recent studies highlight the need for localized processing protocols because fermentation kinetics and drying efficiency are affected by ambient temperature, humidity, airflow, and rainfall patterns (Llano et al., 2024; González et al., 2024). For South Cotabato, localized evidence is needed to identify practical durations that match local climate conditions and smallholder processing realities.

METHODS

Research Design

The study employed a 3 x 3 factorial design arranged in a Completely Randomized Design with three replications. Factor A consisted of fermentation durations of 6, 7, and 8 days, while Factor B consisted of drying durations of 5, 6, and 7 days. The design produced nine treatment combinations and 27 experimental units. Each experimental unit consisted of approximately 5.0 kg of fresh cacao beans.

Table 1. *Treatment factors used in the experiment.*

Factor	Level	Description
Factor A	A1	6 days fermentation
Factor A	A2	7 days fermentation
Factor A	A3	8 days fermentation
Factor B	B1	5 days drying
Factor B	B2	6 days drying
Factor B	B3	7 days drying

Figure 3. *Experimental layout of the study.*

Locale of the Study

The study was conducted in Barangay Sto. Niño, Koronadal City, South Cotabato, from January to March 2026. The site was selected because of an established partnership with a local farmer-cooperator and the availability of an all-weather drying facility. The area experiences a tropical climate, with relatively high humidity and temperature conditions that may influence fermentation and drying behavior.

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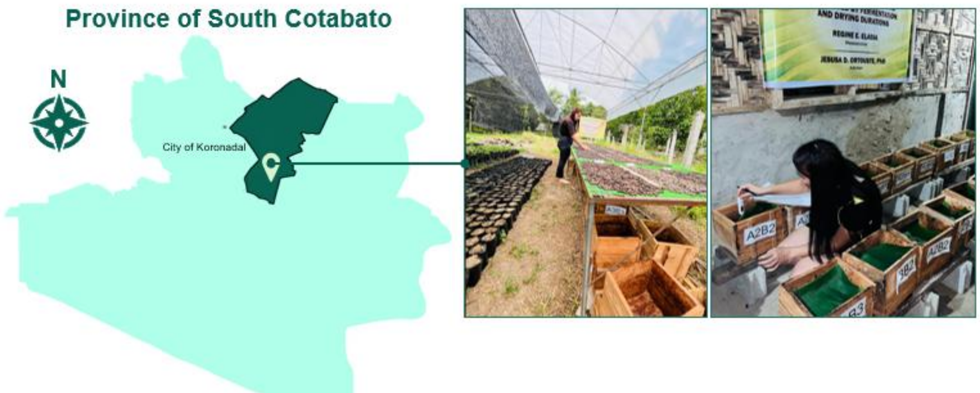

Figure 4. Location and field context of the study.

Materials and Processing Facilities

Freshly harvested cacao pods were used as the raw material. The study utilized the BR25 cacao variety, a Trinitario clone cultivated in the Philippines. Fermentation boxes made of untreated hardwood were used to avoid contamination and to maintain uniform bean depth and heat buildup. Raised drying platforms lined with green mesh netting were used during drying to allow airflow and minimize contamination.

Figure 5. Fermentation boxes and treatment labels used in the study.

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Figure 6. Drying platform and processing area used in the study.

Fermentation and Drying Procedures

For each experimental unit, approximately 5.0 kg of fresh cacao beans was placed in a fermentation box lined with banana leaves. The beans were lightly compacted and covered with additional banana leaves. Fermentation was conducted according to the assigned duration. Beans were turned after 48 hours and then every 24 hours thereafter to promote aeration and uniform microbial activity. Temperature and pH were monitored during the process.

After fermentation, the beans were spread evenly on raised mesh drying platforms based on the assigned drying duration. Beans were turned every two to three hours to promote uniform drying. Plastic covers were used during rainfall. Drying continued until the beans reached the expected safe moisture range for storage, and moisture was measured using a digital moisture meter.

Cut Test and Quality Evaluation

The cut test was conducted following ISO 2451:2017 and PNS/BAFS 58:2019 procedures. Representative bean samples were mixed, reduced by quartering, and cut lengthwise to expose the cotyledons. Beans were classified as moldy, slaty, purple, or good based on internal appearance. The percentage of each defect category was computed, and bean purity was calculated as the proportion of sound beans remaining after accounting for defects.

Statistical Analysis

Data were subjected to two-way Analysis of Variance to determine the main effects of fermentation duration, drying duration, and their interaction on cacao bean quality parameters. When significant differences were detected, Least Significant Difference tests at the 5% level of significance were used to compare treatment means. Microsoft Excel and the STAR Statistical Tool Application were used for data processing.

RESULTS AND DISCUSSION

Moisture Content

Table 2. *Moisture content (%) of cacao beans as influenced by fermentation and drying durations.*

Fermentation duration	5 days drying	6 days drying	7 days drying	Mean
6 days	11.60a	9.63a	9.87a	10.37
7 days	8.23b	7.93b	7.73b	7.97
8 days	8.83b	7.87b	9.30a	8.67
Mean	9.56	8.48	8.97	

Moisture content was significantly affected by fermentation duration, drying duration, and their interaction. Beans fermented for 6 days retained the highest moisture levels, indicating that shorter fermentation did not sufficiently prepare the beans for efficient water loss during drying. In contrast, 7 days of fermentation produced moisture levels closest to the recommended safe storage range, especially when combined with 6 or 7 days of drying.

This result confirms that drying duration alone cannot compensate for insufficient fermentation. Fermentation breaks down pulp, improves drainage, and alters bean structure, allowing water to be removed more effectively during drying (Schwan & Wheals, 2004; De Vuyst & Leroy, 2020). The finding supports previous studies emphasizing that moisture control requires coordination between fermentation and drying rather than simple extension of either process (Ackah & Dompey, 2021; Dzelagha et al., 2020).

Potential of Hydrogen (pH)

Table 3. *pH of cacao beans as influenced by fermentation and drying durations.*

Fermentation duration	5 days drying	6 days drying	7 days drying	Mean
6 days	5.65	5.71	5.84	5.74b
7 days	6.35	6.35	6.28	6.33a
8 days	5.81	6.11	5.98	5.97b
Mean	5.94ns	6.06ns	6.03ns	

Fermentation duration significantly affected pH, while drying duration and the interaction effect were not significant. The 7-day fermentation treatment produced the highest and most balanced pH, suggesting better acid regulation. During fermentation, microbial activity produces organic acids that diffuse into the cotyledon, but as fermentation progresses, partial volatilization and drainage help moderate acidity. This balance is essential because excessive acidity may produce sour or astringent notes, while insufficient acid development may result in weak flavor formation (Afoakwa et al., 2008; Rottiers et al., 2019).

Bean Weight and Bean Count

Table 4. *Bean weight (g) as influenced by fermentation and drying durations.*

Fermentation duration	5 days drying	6 days drying	7 days drying	Mean
6 days	1.85	1.49	1.68	1.67ns
7 days	1.70	1.68	1.67	1.68ns
8 days	1.79	1.66	1.76	1.74ns
Mean	1.78a	1.61b	1.70ab	

Table 5. *Bean count per 100 g as influenced by fermentation and drying durations.*

Fermentation duration	5 days drying	6 days drying	7 days drying	Mean
6 days	69.78	87.67	89.06	82.17a
7 days	74.94	78.56	82.94	78.81a
8 days	70.28	84.78	72.17	75.74b
Mean	71.67ns	83.67ns	81.39ns	78.91

Bean weight was significantly influenced by drying duration, indicating that mass changes were mainly driven by moisture loss. Beans dried for shorter periods retained more weight, while extended drying reduced bean mass. However, heavier beans do not necessarily indicate better quality because retained moisture may increase mold risk during storage (Hii et al., 2019). Bean count was significantly affected by fermentation, drying, and their interaction, reflecting the combined influence of moisture loss, shrinkage, and structural changes in the beans.

Moldy, Slaty, and Purple Beans

Table 6. *Percentage of moldy beans as influenced by fermentation and drying durations.*

Fermentation duration	5 days drying	6 days drying	7 days drying	Mean
6 days	1.89	0.78	1.44	1.37ns
7 days	2.00	1.44	2.22	1.89ns
8 days	1.78	1.78	2.33	1.96ns
Mean	1.89ns	1.33ns	2.00ns	1.74

Table 7. *Percentage of slaty beans as influenced by fermentation and drying durations.*

Fermentation duration	5 days drying	6 days drying	7 days drying	Mean
6 days	1.33	1.11	1.78	1.41ns
7 days	0.67	2.00	0.67	1.11ns
8 days	2.11	2.11	2.00	2.07ns
Mean	1.37ns	1.74ns	1.48ns	1.53

Table 8. *Percentage of purple beans as influenced by fermentation and drying durations.*

Fermentation duration	5 days drying	6 days drying	7 days drying	Mean
6 days	1.67	3.44	4.67	3.26ns
7 days	5.00	2.22	3.22	3.48ns
8 days	5.22	2.44	4.67	4.11ns
Mean	3.96ns	2.70ns	4.19ns	3.62

The percentages of moldy, slaty, and purple beans were not significantly affected by fermentation duration, drying duration, or their interaction. The overall incidence of moldy and slaty beans remained below the usual Grade 1 threshold, indicating that all treatments produced commercially acceptable beans. Mold development is highly dependent on moisture and storage conditions, while slaty beans indicate incomplete fermentation. The low defect levels suggest that the tested processing range provided generally adequate fermentation and drying conditions (Camu et al., 2008; Sukha, 2019).

Purple beans showed numerical variation but no statistically significant trend. Purple coloration reflects partial fermentation and incomplete oxidation of polyphenols. The inconsistent pattern suggests that time alone does not fully control purple bean development; turning, aeration, temperature distribution, and microbial activity may be equally important (Misnawi et al., 2002; De Vuyst & Weckx, 2016).

Figure 7. Moldy beans observed during the cut test.

Figure 8. Slaty beans observed during the cut test.

Figure 9. Purple beans observed during the cut test.

Bean Purity and Grade Classification

Table 9. *Percentage purity of cacao beans as influenced by fermentation and drying durations.*

Fermentation duration	5 days drying	6 days drying	7 days drying	Mean
6 days	95.11	94.67	92.11	93.96ns
7 days	92.33	94.33	93.89	93.52ns
8 days	90.89	93.67	91.00	91.85ns
Mean	92.78ns	94.22ns	92.33ns	93.11

Table 10. *Bean grade classification of cacao beans as influenced by fermentation and drying durations.*

Treatment	Moldy (%)	Slaty (%)	Purple (%)	Purity (%)	Grade
A1B1 (6F:5D)	1.89	1.33	1.67	95.11	Grade 1
A1B2 (6F:6D)	0.78	1.11	3.44	94.67	Grade 1
A1B3 (6F:7D)	1.44	1.78	4.67	92.11	Grade 1 (Acceptable)
A2B1 (7F:5D)	2.00	0.67	5.00	92.33	Grade 1 (Acceptable)
A2B2 (7F:6D)	1.44	2.00	2.22	94.33	Grade 1
A2B3 (7F:7D)	2.22	0.67	3.22	93.89	Grade 1
A3B1 (8F:5D)	1.78	2.11	5.22	90.89	Grade 1 (Borderline)
A3B2 (8F:6D)	1.78	2.11	2.44	93.67	Grade 1
A3B3 (8F:7D)	2.33	2.00	4.67	91.00	Grade 1 (Acceptable)

Bean purity remained consistently high across all treatments, with an overall mean of 93.11%. Since moldy, slaty, and purple defects were not significantly affected, overall purity likewise remained statistically unchanged. All treatment combinations were classified as Grade 1 based on defect limits and purity,

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indicating that the tested fermentation and drying durations produced commercially acceptable cacao beans under local conditions. Treatments involving 7 days of fermentation and 6 to 7 days of drying were particularly favorable because they balanced moisture reduction, pH, and grade performance.

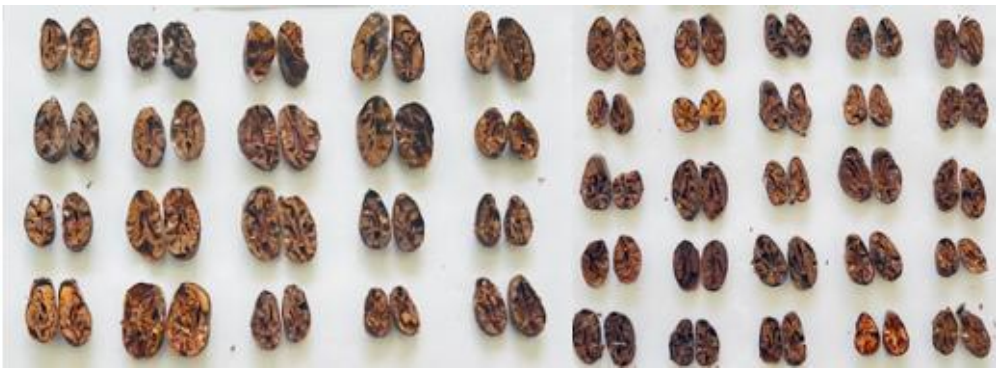

Figure 10. Good beans observed during the cut test after adequate fermentation and drying.

Figure 11. Good beans from the A3B3 treatment during cut test evaluation.

Synthesis of Findings

The results show that moisture content was the most sensitive quality indicator because it responded significantly to fermentation, drying, and their interaction. pH was mainly controlled by fermentation, while bean weight and bean count were shaped by drying-related moisture loss and shrinkage. Defect levels and purity were stable across treatments, suggesting that the tested duration range is generally safe for producing Grade 1 cacao beans. However, the most balanced protocol was 7 days of fermentation followed by 6 to 7 days of drying, as it produced moisture near the safe range, stable pH, high purity, and Grade 1 classification.

CONCLUSION

The study concludes that fermentation and drying durations influence important quality attributes of cacao beans, especially moisture content, pH, bean weight, and bean count. Fermentation duration significantly affected moisture and pH, with 7 days of fermentation producing the most favorable and balanced outcomes. This duration allowed adequate biochemical activity and acid regulation while supporting moisture reduction during drying. In contrast, 6 days of fermentation retained higher moisture and acidity, while 8 days produced less consistent quality outcomes.

Drying duration significantly influenced moisture, bean weight, and bean count. A drying period of 6 to 7 days was most effective in reducing moisture to safe levels while maintaining quality. A 5-day drying period tended to leave higher residual moisture, while extending drying beyond the useful period did not consistently improve quality. The interaction between fermentation and drying significantly affected moisture content and bean count, showing that the two postharvest stages must be coordinated rather than treated independently.

Defect parameters, including moldy, slaty, and purple beans, were not significantly affected by the tested treatments, and all treatment combinations achieved Grade 1 classification with more than 90% purity. Overall, 7 days of fermentation followed by 6 to 7 days of drying produced the most reliable combination for attaining stable moisture, balanced pH, high bean purity, and commercial Grade 1 cacao quality under the conditions of Brgy. Sto. Niño, Koronadal City, South Cotabato.

Recommendation

Farmers and processors are encouraged to adopt a 7-day fermentation period because it consistently produced balanced pH and moisture outcomes that support cacao bean quality.

A drying duration of 6 to 7 days is recommended, provided that beans are turned regularly, protected from rainfall, and dried with adequate airflow to reach safe moisture levels without excessive weight loss.

Fermentation and drying should be managed as connected stages. Proper fermentation improves drying behavior, while appropriate drying preserves the quality developed during fermentation.

Farmer training programs should emphasize quality-based processing, including proper turning, aeration, moisture monitoring, cut-test evaluation, and grading based on ISO 2451:2017 and PNS/BAFS 58:2019 standards.

Future studies may include sensory evaluation, detailed chemical analysis, different cacao varieties, and controlled temperature or humidity treatments to further validate and refine the recommended local processing protocol.

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