Original Research Article

On-farm Cocoa Fermentation Practices and their Effect on the Quality of Cocoa Beans in Three Agroecological Zones of Uganda

Abstract

Little attention has been paid to on-farm cocoa fermentation practices which have led to poor-quality cocoa beans. A cross-sectional study was conducted in three agroecological zones of Uganda (Lake Victoria Crescent, Western Rangelands, and Lake Albert Crescent) to investigate on-farm fermentation practices, the association between farmer training and adoption of recommended fermentation practices as well as the impact of fermentation practices on cocoa quality. Results revealed significant variation in fermentation practices used by farmers, with over 65% employing rudimentary methods such as sack, bucket, and *jerrycan*. Training of farmers did not increase the likelihood of farmers adopting the recommended fermentation practices. As a result, the quality of fermented cocoa beans was low with only 40-51% of the beans from all zones exhibiting the fully brown color, which is below the 60% threshold for commercial-grade cocoa beans. Furthermore, the fermentation index of cocoa beans from all zones ranged from 0.61-0.67, indicating a high percentage of under-fermented beans. Farmers who used the recommended practices (heap and box fermentation for 5-7 days while turning cocoa) in each zone produced cocoa with a significantly ($p<0.05$) higher percentage of fully fermented beans. The continued use of rudimentary postharvest handling practices among farmers leads to the production of poor-quality cocoa beans. It is important to strengthen the enforcement of recommended fermentation practices to improve the quality of cocoa beans and ensure a sustainable market.

Keywords: Farmer practices, Quality, Cocoa, Agroecological zones, Fermentation practices, On-farm

1.0 Introduction

Cocoa (*Theobroma cacao* L.) is a high-value crop worldwide and the primary raw material for chocolate manufacture (Ho et al., 2015). Cocoa ranks fourth after gold, coffee, and fish in terms of export earnings in Uganda with a reported steady increase from USD 7.2 million in 2004 to USD 112.9 million in 2022 (UBOS, 2023). This translates to an average growth rate of 18.2% per annum (World Atlas, 2024). Cocoa is mostly grown in three agroecological zones in Uganda namely; Western Rangelands which lies between 1200 to 2400 meters above sea level (MASL), Lake Victoria Crescent which lies between 1100 to 1400 MASL and Lake Albert Crescent which lies above 620 MASL (Kajobe et al., 2016). Owing to cocoa's contribution to household income, it has been identified by the Government of Uganda as a strategic crop to drive people out of poverty (UNPA, 2020).

In Uganda, cocoa beans are sold as fresh, dry fermented, or dry unfermented (Petithuguenin, 2000). Dry fermented cocoa undergoes several postharvest handling steps: pod breaking, fermenting, drying, sorting, and eventually bagging. Among these, fermentation has the most significant effect on the quality of cocoa beans (Meersman et al., 2016; Saidou et al., 2021). For desirable quality, cocoa fermentation is carried out using either heap or box fermentation method (Guehi et al., 2010), and turning every 24 or 48 hours for 5 to 7 days (Kadow et al., 2013). Fermenting cocoa beans for a shorter period below 5 days and without turning is reported to compromise the final quality of the cocoa beans (Afoakwa et al., 2014). The choice of fermentation practice is influenced by several factors including, cocoa variety, environmental conditions (Hernandez et al., 2016); and socio-economic factors such as local customs, knowledge, and available resources (Pokharel, 2023). According to the International Cocoa Organisation (ICCO) standards of 2011, a batch with 60% fully brown beans, less than 3% moldy beans, and moisture content between 7-8% is considered good quality (Lima & Nout, 2014). Good quality cocoa beans are further characterized by a slightly lower pHbetween 3-4 (Misnawi et al., 2003) and a fermentation index above 1 (Sulaiman, 2006).

To enhance Uganda's cocoa sector, the government and development partners designed training programs for farmers aimed at increasing yield and quality (MAAIF, 2022). However, the impact of the training programs has not been assessed and the quality of cocoa beans has not significantly improved overtime, remaining substandard and inconsistent.

Therefore, this study aimed to investigate; the on-farm fermentation practices used by farmers in the three agroecological zones where cocoa is grown, the likelihood of trained farmers adopting recommended fermentation methods, and the effect of on-farm cocoa fermentation practices on cocoa quality. The findings of this study are important in recommending practices that can be adopted by farmers to improve the quality of cocoa produced in Uganda.

2.0 Methodology

2.1 Study area

The study was conducted during July and October 2023 in three major cocoa-producing agroecological zones in Uganda: Western Rangelands, Lake Victoria Crescent, and Lake Albert Crescent (Kajobe et al., 2016). The agroecological zones are characterizedby bi-modal rainfall above 1,200 mm/year (Haneishi et al., 2013). In each agroecological zone, one district was purposively selected namely, Bundibugyo (Western Rangelands), Mukono (Lake Victoria Crescent), and Hoima (Lake Albert Crescent) (Figure 1). The districts selected in each agroecological zone have the highest cocoa production volumes (UBOS, 2023). From each district, farmers were sampled to provide cocoa beans for the study.

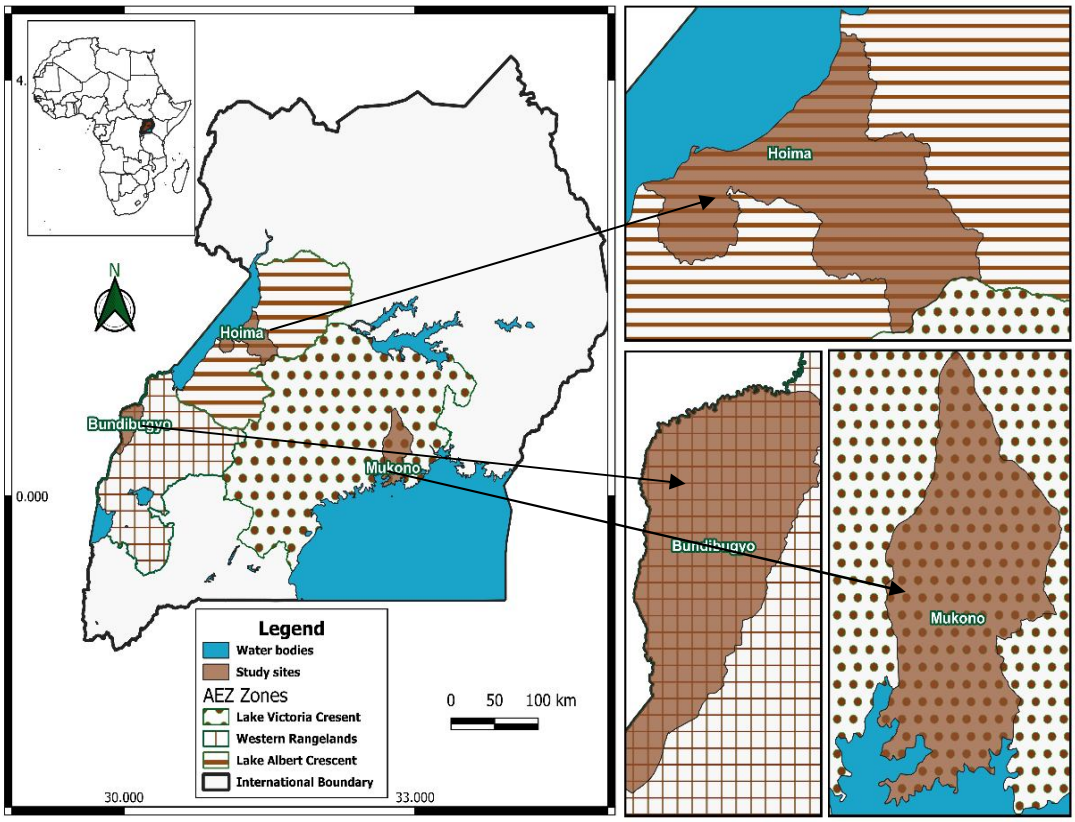

Figure 1: Selected study districts from the three agroecological zones

2.2 Farmer sample size calculation

The total sample size of farmers who participated in the study was determined using Equation 1 (Daniel, 1999).

Sample size: $n = p(1-p)\left(\frac{Z}{E}\right) \wedge 2(1)$

Where; n=sample size; Z=the value from the standard normal distribution reflecting the confidence level (1.96 for95%); E=the desired margin of error (0.05); p=population proportion ratio (0.5);∧2=power2.

The final estimated sample size (n) was 300 cocoa farmers

2.3 Study design

A cross-sectional study design was used according to Agyemang *et al.* (2014). Five major cocoa-producing villages per district were purposely selected based on production and number of farming households. From Bundibugyo, 121 farmers were interviewed, 113 in Hoima, and 66 in Mukono, making 300 farmers.

2.4 Establishment of on-farm cocoa fermentation practices used by farmers

Information on cocoa fermentation practices used by farmers from the 3 agroecological zones was obtained using a semi-structured questionnaire. Information gathered included; whether farmers received training, fermentation methods used, duration of fermentation, and turning frequency of the fermenting cocoa.

2.5 Categorization of on-farm fermentation practices and the likelihood of trained farmers to adopt and use recommended practices

The on-farm fermentation practices were categorized into recommended and rudimentary fermentation practices based on descriptions by Camu *et al*. (2016) and De Vuyst &Weckx (2015). The use ofthe heap or box method to ferment the beans for 5-7 days and turning the fermenting cocoa mass at an interval of 24 or 48 hours were categorized as recommended practices. In contrast, rudimentary practices included using other fermenting methods (sacks, baskets, saucepans, *jerrycans,* or buckets), fermenting for less than 5 days and not turning fermenting cocoa beans.

The likelihood of adoption was determined based on the 2x2 table (Riffenburgh, 2012), where two categories of fermentation practices were considered (recommended or rudimentary practices) and either a farmer being trained or not trained.

2.6 Cocoa beans sample collection

One (1) kg of fermented dry cocoa beans was collected from the interviewed farmers in each district. The samples were double-packed in black polyethylene bags and labeled according to the district, village, and farmer-assigned identification tag. The samples were transported to Makerere University, Department of Food Technology and Nutrition, and stored in the Chemistry laboratory at ambient temperature until analysis.

2.6.1Sample preparation for quality tests

The samples were re-dried under the sun to achieve the recommended moisture content (7-8%) for storage (Lima & Nout, 2014). The samples were analyzed for bean cut test, fermentation index, pH, and titratable acidity following standard methods.

2.6.2Bean cut test evaluation

The degree of cocoa bean fermentation was performed following the procedure described by Hii *et al*. (2006). Briefly, 350 beans were randomly selected and cut lengthwise using a secateur. Both halves of each bean were fully viewed under well-lit environment. Using visual observations, the color of the cocoa bean cotyledon was categorized as; fully brown, partially purple, fully purple, and moldy.

2.6.3 Fermentation Index

The method described by Gur'eva and Tserevitinov (1979) was used. Dried cocoa beans were crushed to separate husks from nibs. The nibs were ground using an electrical grinder (Pascal Engineering, UK). 0.5 g of the ground nibs were added to a 50 ml mixture of methanol and HCl (concentration 37%) at a volume ratio of 97:3 and homogenized. The mixture was stored at 4^{o}C for 16-18 hours and filtered using Whatman No. 2 filter paper to obtain a clear extract. The absorbance of filtrate at 460 nm and 530 nm was determined using a UV-visible spectrophotometer (Shimadzu, Japan). The Fermentation index (FI) ratio was determined using Equation 2.

$$FI = absorbance\ at\ \frac{460nm}{530nm} \quad (2)$$

2.6.4 pH of cocoa nibs

Using Nazaruddin*et al*. (2006) method, 5 g of the ground cocoa nibs were dissolved in 45 ml of boiled distilled water. The mixture was filtered with Whatman No. 4 filter paper and cooled to 20-25^{0}C and pH were read in triplicates using a pH meter (Mettler Toledo, Columbus, OH, USA model MP 230).

2.6.5 Titratable acidity

The non-volatile acidity of the cocoa nibs was determined according to the AOAC (2005) method and expressed as the percentage of acetic acid. Five-gram samples were homogenized for 30s in 100 ml of hot distilled water and filtered through Whatman filter paper No.4. A 25 ml aliquot of the filtrate was titrated to an end point pH of 8.1 with 0.01 N NaOH and the titratable acidity values were reported as moles of sodium hydroxide (MNaOH) per g of dry cocoa nibs.

2.7 Establishing the effect of on-farm fermentation practices on cocoa quality

To understand the effect of fermentation practices, cocoa beans' quality data was grouped into two categories of cocoa fermentation practices that is; recommended and rudimentary fermentation practices.

2.8 Data analysis

Data from the survey responses was analyzed using SPSS Statistical Package (Version 21). The proportion of farmers' fermentation practices was presented as percentages in tables. The likelihood of trained farmers adopting recommended fermentation practices was performed using odds ratio. The difference in the quality of cocoa produced from different agroecological zones was established using ANOVA and the means were significant at $P<.05$. The effects of fermentation practices on cocoa bean quality were analyzed by factorial ANOVA using GenStat (12th Edition) and means were considered significant at $P<.05$.

3 Results

3.1 On-farm fermentation practices used by farmers in the three agroecological zones

3.1.1 Fermentation methods

The fermentation methods used by the farmers in the three agroecological zones studied are summarized in Table 1. The results showed that farmers in Western Rangelands used three methods (heap, box, and sack) to ferment cocoa, with the heap (56%) being the most used followed by the box (32%) method. The majority of the farmers in L. Victoria Crescent (38%) and L. Albert Crescent (55%) used the sack method.

Table 1: Cocoa fermentation methods used in the three agroecological zones of Uganda

	Respondents using method (%)		
	Agroecological zone		
Fermentation method	Western Rangelands	L. Victoria Crescent	L. Albert Crescent
Box	32	16	5
Heap	56	25	8
Sack	12	38	55
Bucket	0	7	11
Jerrycan	0	11	15
Baskets	0	3	5
Saucepan	0	0	1

3.1.2 Fermentation duration

The fermentation duration as practiced by farmers in the three agroecological zones studied is summarized in Table 2. The results showed thatthe majority (85%) of farmers in Western Rangelands fermented cocoa for the recommended 7-8 days, with only a few (8%) fermenting for 5-6 days and shorter periods of 3-4 days (7%). In the L. Victoria Crescent, only 50% of the farmers fermented for the recommended timeframe, and even less in L. Albert Crescent (30%).

Table 2: Fermentation duration used in the three agroecological zones of Uganda

	Respondents (%)		
Fermentation duration	Agroecological zone		
(days)	Western Rangelands	L. Victoria Crescent	L. Albert Crescent
7-8	85	50	30
5-6	8	20	25
3-4	7	30	45

3.1.3 Turning frequency of cocoa

The turning frequency of fermenting cocoa as practiced by the farmers in the three agroecological zones of Uganda is shown in Table 3. The results showed that, in all three zones, the majority of the farmers

(68-87%) turned their cocoa every 48 hours during fermentation. The second largest proportion of farmers in all the zones turned their cocoa every 24 hours. A small proportion of farmers in Western Rangelands (9%) and L. Albert Crescent (3%) did not turn the cocoa during fermentation.

Table 3: Turning frequency of cocoa as practiced in the three agroecological zones

	% Respondent		
	Agroecological zone		
Turning frequency	Western Rangelands	L. Victoria Crescent	L. Albert Crescent
Every after 24 hours	23	13	26
Every after 48 hours	68	87	71
Don't turn	9	0	3

3.2 Likelihood of farmers adopting recommended fermentation practices

3.2.1 Categorization of on-farm fermentation practices used by farmers

The categories of on-farm fermentation practices and their adoption are presented in Table 4. Rudimentary fermentation practices were the most adopted by farmers (90%) in L. Albert Crescent followed by farmers (65%) in L. Victoria Crescent. Western Rangelands had the highest proportion of farmers (67%) that adopted recommended practices.

Table 4: Category of on-farm fermentation practices used by farmers in the three agroecological zones of Uganda

	Respondents (%)		
	Agroecological zone		
Category	Western Rangelands	L.Albert Crescent	L.Victoria Crescent
Recommended fermentation practice	67	10	35
Rudimentary fermentation practice	33	90	65

3.2.2 Trained farmers and their adoption of recommended cocoa fermentation practices

Table 5 shows the proportion of trained farmers andtheir adoption of recommendedcocoa fermentation practices. More farmers (93%) from Western Rangelands were trained in fermentation followed by farmers from L. Victoria Crescent (68%) while in L. Albert Crescent 64% were trained. Western Rangelands had the highest number of trained farmers (67%) who adopted recommended fermentation practices, followed by L. Victoria Crescent(40%) and L. Albert Crescent (15%). Odds ratio (*OR*) results (Table 5) showed that there was a 0.851 (Western Rangelands), 0.469 (L. Victoria Crescent), and 0.130 (L. Albert Crescent) likelihood of trained farmers adopting recommended fermentation practices. However, in all the agroecologicalzones, the likelihood was low and insignificant at 95% *CI*(0.016-3.097).

Table 5: Farmers trained in fermentation and their adoption of recommended fermentation practices in the three agroecological zones

Agroecological zone	Respondents (%)		
	Trained in fermentation	Adopted recommended fermentation practices	*OR (CI at 95%)*
Western Rangelands	93	67	0.851(0.234, 3.097)
L. Victoria Crescent	68	40	0.469 (0.146, 1.507)
L. Albert Crescent	64	15	0.130 (0.016, 1.042)

Note: *OR*= Odds Ratio; *CI*= Confidence Interval.

OR is not statistically significant if *CI* includes 1.000.

3.3 Quality attributes of cocoa beans produced in the studied zones

The physical and chemical quality attributes of cocoa beans from farmers in the three agroecological zones studied are summarized in Table 6. The results showed that cocoa from farmers in L. Victoria Crescent and WesternRangelands had a significantly higher percentage (*P*<.05) of fully brown cocoa beans (51% and 48% respectively) compared to L. Albert Crescent (40%). L. Victoria Crescent had a significantly (*P*<.05) higher percentage of partially purple cocoa beans (26%) compared to the other two zones. On the other hand, L. Albert Crescent had a significantly higher percentage (34%) of fully purple and moldycocoa beans (8%). The cocoa beans from Western Rangelands were slightly acidic (pH 5.62) with a higher titratable acidity (TA) value (0.34 MNaOH/g of cocoa nibs) compared to cocoa beans from L. Victoria and L. Albert Crescent (pH range 5.91-6.01, and TA value 0.3-0.32NaOH/g of cocoa nibs). The fermentation index (FI) of cocoa from all zones ranged between 0.61-0.67 but was not significantly different (*P*>.05).

Table 6: Quality of dry fermented cocoa beans from the three agroecological zones of Uganda

Agroecological zone	Physico-chemical attributes of the cocoa beans						
	FB (%)	PP (%)	FP (%)	Mouldness (%)	pH	TA (MNaOH/g of cocoa nibs)	FI
Western Rangelands	48^{a}±1.157	17^{a}±0.854	30^{a}±1.129	5^{a}±0.697	5.62^{a}±0.037	0.34^{a}±0.007	0.67^{a}±0.019
L. Albert Crescent	40^{b}±1.194	18^{a}±0.882	34^{b}±1.165	8^{b}±0.719	6.01^{b}±0.039	0.30^{b}±0.007	0.61^{a}±0.019
L. Victoria Crescent	51^{a}±1.479	26^{b}±1.092	22^{c}±1.443	1^{c}±0.891	5.91^{b}±0.048	0.32^{ab}±0.009	0.64^{a}±0.024
Lsd	3.645	2.693	3.557	2.198	0.119	0.023	0.060

Note:
1. Values are means ±SE. Mean values in a column with the same subscript letter are not significantly different at *P*<.05
2. FB= fully brown, PP=Partially purple, FP=fully purple, TA=titratable acidity, FI=fermentation index
3. *Lsd*= least significant difference

3.4 Effect of on-farm Fermentation Practices on the QualityAttributes of Cocoa Beans

3.4.1 Physical quality

The mean values of the physical quality of cocoa beans from each agroecological zone produced using recommended and rudimentary fermentation practices are summarized in Figure 2 (a, b, c, and d). The results indicated that cocoa beans produced using recommended fermentation practices had a significantly (*P*<.05) higher percentage of fully fermented beans across the three zones compared to cocoa beans produced using the rudimentary fermentation methods (Figure 2a). A significantly (*P*<.05) high percentage of partially purple cocoa beans were produced using recommended fermentation practices (25-32%) compared to those produced using rudimentary fermentation practices (14-24%) (Figure 2b). On the other hand, a significantly (*P*<.05) higher percentage of fully purple (non-fermented) cocoa beans was reported in all zones amongst farmers who used rudimentary methods (28-40%) compared to those who used recommended practices (12-24%) (Figure 2c). There was no significant difference (p>0.05) in the percentage of moldy beans across all zones regardless of the on-farm fermentation practices (Figure 2d).

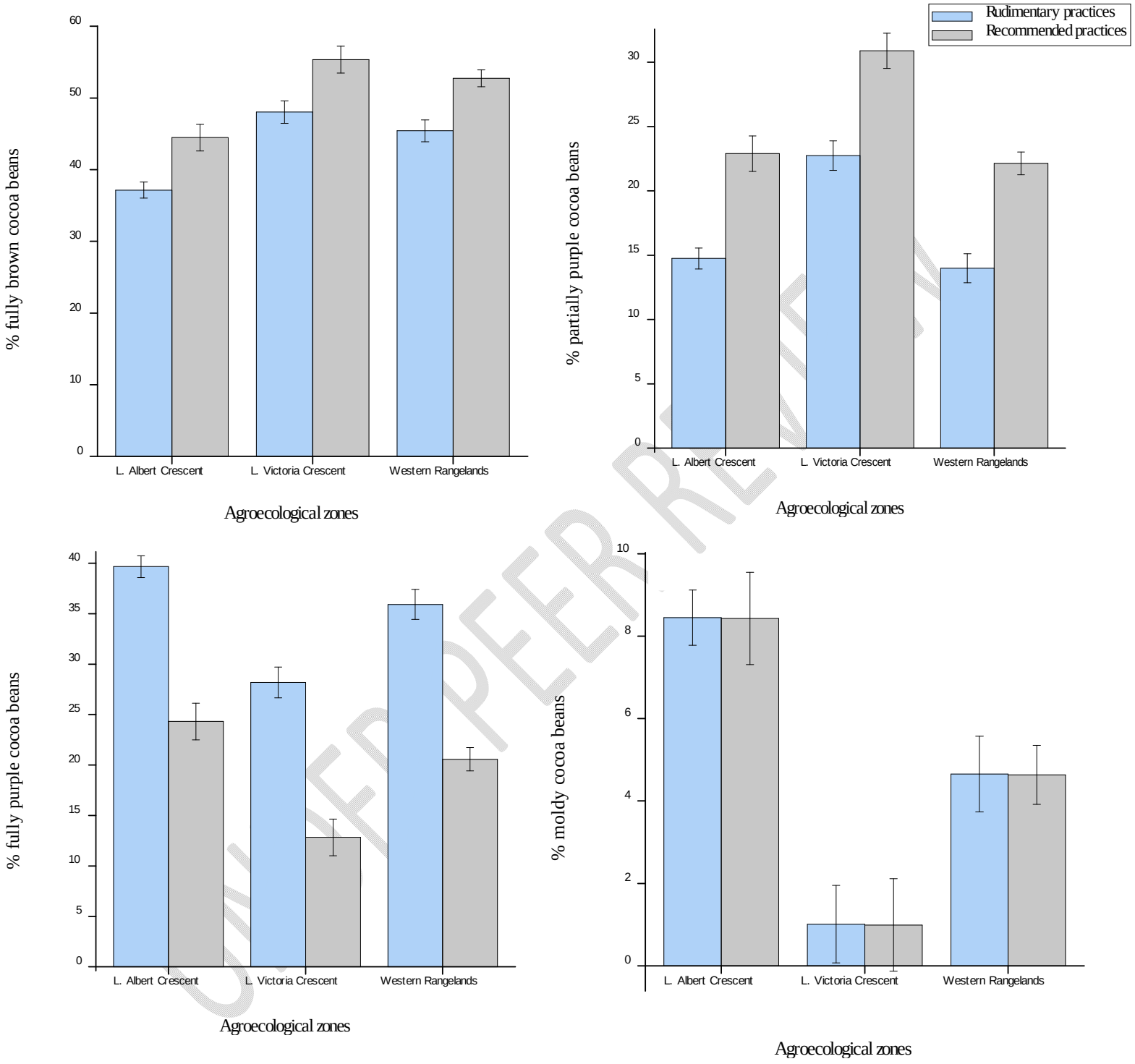

Figure 2: Percentages of; a) fully fermented, b) partially purple, c) fully purple, and d) moldy cocoa beans from the three agroecological zones produced using different fermentation practices

3.4.2 Chemical quality

The mean values of the chemical quality of cocoa beans from each agroecological zone produced using recommended and rudimentary fermentation practices are presented in Figure 3 (a, b, and c). The results showed that cocoa beans fermented using recommended practices in all zones were slightly acidic but not significantly different from cocoa fermented using rudimentary methods (Figure 3a). The results however showed significantly (P<.05) higher titratable acidity values and fermentation index for cocoa fermented using recommended fermentation practices as opposed to cocoa beans fermented using rudimentary practices (Figure 2b and 2c).

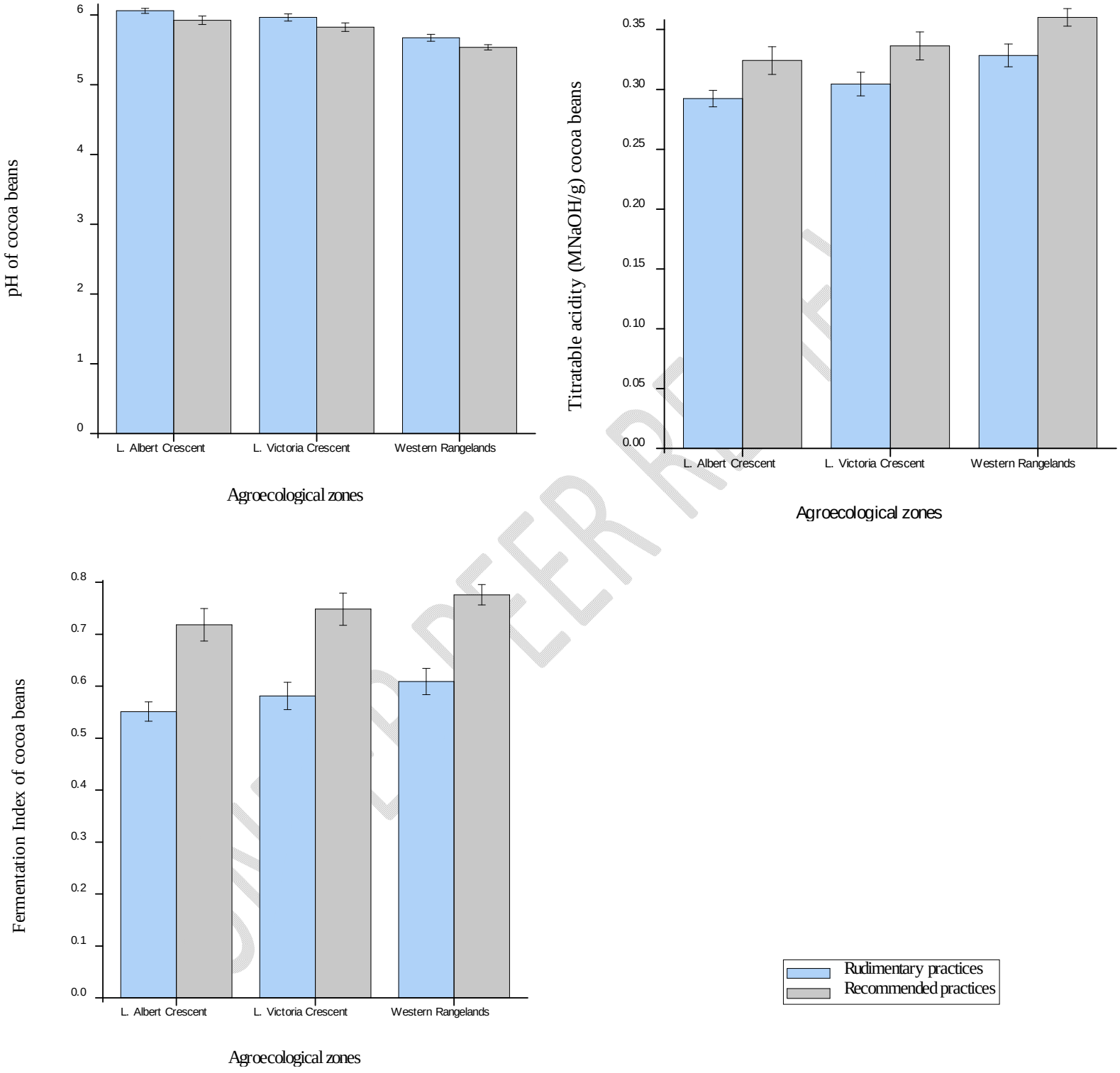

Figure 3: Mean values of; a) pH, b) titratable acidity, and c) fermentation index of cocoa beans from the three agroecological zones produced using different fermentation practices

4 Discussion of results

4.1 On-farm cocoa fermentation practices

Cocoa fermentation involves concurrent practices aimed at achieving market-desired bean quality (Guehi et al., 2010). Fermentation practices include fermentation methods, duration, and turning frequency. Heap and box fermentation methods are recommended for the production of good-quality cocoa beans (De Vuyst &Weckx, 2015; Camu et al., 2016; Guzman-Alvarez & Marquez-Ramos, 2021; Kim-Ngoc et al., 2022). Camu *et al*. (2016) stressed that it is difficult to turn cocoa and there is usually poor pulp drainage (Guehi et al., 2010)when using fermenting methods like sacks, "*jerrycans*", buckets, and saucepans. The current study showed that the majority of farmers in Western Rangelands used heap and box methods compared to other zones. This could be attributed to training programs focused on Western Rangelands (MAAIF, 2022), exposing farmers to a better knowledge of cocoa fermentation. With regards to the fermentation period, fermenting cocoa for 7 days is the most recommended duration (Camu et al., 2016; Figueroa-Hernandez et al., 2019). Although the number of days may vary between 5-7 depending on season, variety, and pulp quality of cocoa mass (Rodrigues-Campos et al., 2011). Fermentation conducted for a shorter duration below 5 days is sub-optimal and gives consistently poor-quality beans (Guehi et al., 2010). A turning frequency of 24- or 48 hours to improve oxygenation and metabolism is recommended (Camu et al., 2008; Guehi et al., 2016).The effect of the use of rudimentary practices (shorter fermentation time and poor fermenting methods) on cocoa bean quality is confirmed in the current study by the low percentages of fully brown (36-47%) and partially purple (14-23%) cocoa beans in each agroecological zone compared to cocoa beans produced using the recommended fermentation practices (Figure 2a and 2b).

In the current study, unlike L. Albert Crescent, farmers from other zones used appropriate fermenting time and turning frequency. The high diversity observed in fermentation duration among farmers from L. Albert Crescent and L. Victoria Crescent could be attributed to limited training opportunities (MARKUP, 2023). In Western Rangelands, there are functional local government bylaws that regulate cocoa activities[6], and this could further explain why the majority of farmers follow recommended practices of fermentation method, duration, and turning frequency.

4.2 Likelihood of adopting and using recommended fermentation practices

It was noted in the current study that a high proportion of farmers from all the agroecological zones turned cocoa during fermentation although, the fermentation method and duration used were poor. This resulted in a high proportion of farmers being categorized as using rudimentary practices especially those from L. Albert Crescent. The high proportion of farmers using rudimentary fermentation practices reported in the study could be due to high labor, time, and resource requirements as was reported in the study conducted by Saidou *et al*. (2021) among Cameroon cocoa farmers.

A high proportion of farmers received training on cocoa fermentation in all three production zones. This could be attributed to the fact that quite often, training related to production and postharvest handling of cash crops in Uganda are directly coordinated by buyers hence the wide coverage to deliver these services closer to farmers (Midamba&Kizito, 2022). With the promise of better prices, farmers are willing to participate, and bulkers assume that farmers adopt good practices thus producing good quality cocoa beans as was noted by Levai *et al*. (2015). Western Rangelands had the highest proportion of trained farmers (93%), likely due to the high concentration of cocoa buyers in this zone (Opoka, 2016). Government programs such as the Market Access Upgrade Program (MARKUP) I and II and Operation Wealth Creation (OWC) have concentrated cocoa activities in Western Rangelands (MAAIF, 2022) and this could further explain the high number of trained farmers. Despite training farmers on cocoa fermentation in all three production zones, their likelihood of adopting recommended fermentation practices was low and insignificant. The low adoption could be due to inadequate regulations and enforcement in the sector (MARKUP, 2023), allowing farmers to ignore good practices despite knowing about them.

4.3 Quality attributes of fermented cocoa beans

The cut test is an industry standard for monitoring the quality of fermented cocoa beans (ITC, 2001). Fermentation and consequential drying go along with subsequent changes in the color of the cotyledons. Fresh cocoa beans are violet or pink depending on the genetic variations (Rohsius, 2007). With

fermentation, the color of cotyledon starts to turn brownish, often from the center of the seed. Upon completion of the fermentation process, the cotyledons turn fully brown (Rohsius). The current study revealed that the cocoa beans from all three zones failed to meet the ICCO's commercial standards for market-grade cocoa, which requires a minimum of 60% fully brown beans (ICCO, 2023) and less than 3% moldy beans (Lima & Nout, 2014). Further, the prevalence of fully purple and partially purple beans across the zones suggests a widespread reliance on rudimentary fermentation practices, consistent with findings by Mounjouenpou et al. (2010) and Ganeswari et al. (2015).

The fermentation index, a chemical method, confirmed the bean cut test results (0.61-0.67), indicating under-fermentation in all the production zones studied. According to Khairul (2014) and Sulaiman (2006), a fermentation index below 1.0 suggests a high percentage of fully purple beans. This is indicative of the high content of anthocyanins which impart the purple coloration (Caligiani et al., 2007; Hernandez et al., 2016). The findings of Caligiani*et al*. (2007), further confirm the observations in the current study where fairly high fermentation index values were reported for cocoa fermented using recommended fermentation practices (0.71-0.80) compared to rudimentary practices (0.54-0.60) (Figure 3c). The significantly lower values of the fermentation index (Figure 3c) for cocoa beans fermented using rudimentary practices are indicative of the high concentration of anthocyanin content (Caligiani et al., 2007) which is also reflected in the high percentage of fully purple cocoa beans produced using rudimentary fermentation methods (Figure 2c).

The pH values (5.61-6.01) reported during the current study were within the acceptable range (5.4-6.2) (Rohsius, 2007), but contradicted another study's recommendation range (4.4-4.7) by Nazaruddin et al. (2006). The titratable acidity increased as pH decreased, reflecting the presence of organic acids as was reported by Camu et al. (2008) and Mbonomo et al. (2016). The differences in the cocoa quality among the studied zones may be attributed to varying fermentation practices used by farmers.

4.4 Effect of on-farm fermentation practices on the physicochemical quality of cocoa beans

On-farm cocoa fermentation practices strongly determine the quality of beans produced (Guehi et al., 2010). The use of recommended fermentation methods such as heap and box, facilitates optimal microbial activity through the effective turning of cocoa for aeration and even heat distribution (Papalexandratou et al., 2013). These methods also enable efficient drainage of mucilage from fermenting cocoa, regulating pulp acidity (Guehi et al., 2010). Using the heap or box method to ferment cocoa for a duration of 5-7 days also allow sufficient time for microbial action and bioconversion of compounds into desirable color and flavor bioactive compounds (Ardhana & Fleet, 2003; Adeyeye et al., 2010; Papalexandratou et al., 2013). In contrast, rudimentary practices like the use of sacks, buckets, basins, and *jerrycans*, have poor heat retention and hinder easy turning and drainage of mucilage during fermentation (Camu et al., 2016; Guehi et al., 2010). This phenomenon explains the observed trend of significantly high percentages of fully brown(well-fermented) cocoa beans fermented using recommended practices compared to the use of rudimentary practices (Figure 2a).

It was observed that the use of rudimentary practices gave a significantly higher percentage of fully purple (non-fermented) beans (28-40%) compared to the use of recommended practices (12-24%) (Figure 2c). The observed differences in the fermentation degree could be due to the ambient conditions and time which favors brown color development when using recommended practices as was noted by Caligiani et al. (2007), and retention of purple pigmentation for poorly fermented cocoa confirmed with low fermentation index values (Figure 3c). Notably, the difference in moldiness of cocoa beans was not influenced by the fermentation practices, consistent with Renaud's (1954) findings that mold growth primarily depends on drying efficacy. This suggests that drying is a critical factor in controlling mold growth, regardless of the fermentation methods employed.

5 Conclusion

Rudimentary fermentation practices (sacks method, fermenting for 3-4 days and not turning cocoa) are the most used by farmers to ferment cocoa in Uganda. Training of the farmers on recommended fermentation practices did not significantly influence their adoption and a high proportion of farmers persistently used rudimentary practices. The quality of cocoa beans produced in the three agroecological zones fell short of the acceptable commercial grade, with less than 60% fully brown (well fermented) and more than 3% moldy beans. Farmers who used recommended fermentation practices produced a

significantly higher percentage of fully brown(fermented fermented) cocoa beans. Enforcing the adoption and use of recommended fermentation practices specifically, heap or box fermentation methods, for 5-7 days and turning frequencies of 24 or 48 hours, will significantly improve the quality of fermented cocoa beans. This approach will help bridge the gap between current practices and commercial-grade cocoa production, ultimately enhancing the quality and market competitiveness of Uganda's cocoa beans.

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