

Analysis of Price Volatility of Cocoa and Its Implications for Farm Mechanisation Investment, Harvest Equipment Adoption, and Post-Harvest Technology in West Africa

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ABSTRACT

Cocoa price volatility remains a major challenge affecting the sustainability of the cocoa industry in West Africa, with significant implications for smallholder farmers, agricultural investment, and supply chain stability. This review examines the relationship between cocoa price volatility, farm mechanisation investment, harvest equipment adoption, and post-harvest technology, highlighting the role of agricultural engineering in enhancing supply stability. A narrative review methodology was adopted, drawing on published literature, cocoa production statistics, price trend data, engineering reports, and policy documents. The evidence was analysed using an interdisciplinary framework integrating supply and demand theory, the Cobweb Model, speculation theory, and agricultural engineering perspectives. The review found that persistent price volatility discourages investment in mechanisation and modern post-harvest technologies, resulting in low productivity, inefficient harvesting and processing, and post-harvest losses estimated at 15–40% of potential production value, thereby exacerbating supply instability and market price fluctuations. Engineering innovations such as mechanical pod breakers, motorised sprayers, automated fermentation systems, solar tunnel dryers, hermetic storage, and renewable energy-powered equipment were identified as viable solutions for improving productivity and reducing losses. The review concludes that mitigating cocoa price volatility requires integrating macroeconomic policies with investments in agricultural mechanisation and post-harvest engineering. It recommends strengthening technology adoption, rural infrastructure, extension services, and local equipment development to improve supply resilience and long-term price stability across West Africa.

1. INTRODUCTION

Cocoa is one of the most important agricultural products in the global market and serves as a primary raw material for chocolate and other confectionery products (Lazzarini *et al.*, 2022; Ogunwa *et al.*, 2026).

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Volatility in the product markets implies the extent to which prices deviate from the average over time. For cocoa, volatility is often attributed to disruptions to the supply side, such as climate change in major cocoa-producing countries like Côte d'Ivoire, Ghana, and Indonesia, plant diseases, and political instability (Buor, 2022). On the demand side, changes in economic development, consumer preferences, income levels, and in consumer markets such as Europe and North America also shift the market balance (Bermudez *et al.*, 2022; Bayoumi and Gagon, 2026). Yet, the cocoa market is plagued by ongoing and sometimes acute price volatility, which leaves all the stakeholders in the cocoa value chain from the farm gate to the international commodity exchange without any stability whatsoever (Brown, 2026). Understanding the drivers of this volatility and engineering-based solutions to mitigate it is very important not just for agricultural economists but also for agricultural engineers, agricultural machinery developers, and post-harvest technology specialists involved in cocoa systems in West Africa.

The price volatility of agricultural commodity markets is the number and size of price changes from an average price over a stated time period (Varzaru, 2025). This volatility in the cocoa market results from various interdependent factors on both the supply and demand sides. On the demand side, irregular climate, extended droughts, excessive rainfall, and the rampant occurrence of fungal diseases such as Black Pod and viral diseases such as Swollen Shoot virus have consistently reduced cocoa production across key cocoa-producing areas (Parthasarathy, 2025). The high share of cocoa production in Côte d'Ivoire and Ghana (combined) in global cocoa bean production and consumption (accounting for more than 60%) implies that cocoa production crises in the two countries can result in immediate and severe price shocks in international markets (Kalischek *et al.*, 2023). Meanwhile, chocolate's market price remains unpredictable due to changing consumer tastes, rising incomes in emerging nations, and the rise of alternative chocolate markets in developed regions like Europe and North America, which continually challenge the market balance (Bermudez *et al.*, 2022).

But it is often overlooked in standard economic studies of cocoa price volatility that farm mechanisation and the post-harvest technology infrastructure are not sufficiently developed to reduce supply-side volatility (Chidoko *et al.*, 2026). Cocoa in West Africa is overwhelmingly grown by smallholder farmers on less than five hectares of land, who use mainly manual labour for each step of the production process from land preparation, pruning to pod harvest, fermentation and drying (FAO, 2023). The reliance on manual processes significantly limits cocoa productivity, efficiency, and scalability. Lack of labour at peak harvest times results in pods left in the ground, reduced bean quality, and significant quantitative losses, effectively reducing the marketable crop of cocoa beans without altering overall production.

In addition to the farm, the final production stage, postharvest handling, is one of the most essential yet most underdeveloped engineering points in the cocoa value chain. Post-harvesting inefficiencies, such as inadequate fermentation practices, poor drying facilities, poor storage and physical damage during transportation (Ogunlade *et al.*, 2024), have been estimated to cost West African cocoa farmers between 15% and 40% of their potential production value (FAO, 2023; ICCO, 2022). Such losses are not only a direct cost to individual farmers but also lead to a loss of effective market supply, a structural decrease that gradually undermines the global cocoa price system. Poor fermentation control or mould growth during storage during the production process can render a significant proportion of physically produced cocoa unsuitable for international trade, leading to a supply shortage and, in turn, contributing directly to the emerging trend of high prices in recent years (Ramos-Neyra *et al.*, 2026). Additionally, the cocoa price increase in 2024 (which jumped by more than 169% from January to April) was partly due to the impact of systemic post-harvest losses on the available exportable quality cocoa that international buyers could purchase, as a result of the crop failure caused by climate change (Feyishola, 2025).

This report, therefore, takes an interdisciplinary perspective, bringing together the supply and demand economic analysis and an agricultural engineering view to comprehensively analyse cocoa price volatility in West Africa. In particular, the report looks into the impact of prevailing farm power situation and postharvest technology in major cocoa growing countries on supply side volatility and the potential for Olaniyan *et al.*: Analysis of Price Volatility of Cocoa and Its Implications for Farm Mechanisation Investment, Harvest Equipment Adoption, and Post-Harvest Technology in West Africa

supply side stability if their strategic adoption of suitable technologies for farm power, harvesting machinery, fermentation technology, drying equipment and hermetic storage solutions could deliver significant benefits in reducing postharvest losses, the effective market supply and mitigate the extreme price volatility threatening the economic well-being of millions of cocoa farmers in the region. This report seeks to contribute to a broader understanding of cocoa price volatility and to propose practical technology-based solutions for a stable, sustainable cocoa market in West Africa, to be implemented alongside economic market analysis.

This paper adopts a narrative review approach to synthesise existing knowledge on cocoa price volatility and its implications for farm mechanisation investment, harvest equipment adoption, and post-harvest technology in West Africa. Relevant literature was identified through a structured search of major academic databases, including Scopus, Web of Science, Google Scholar, ScienceDirect, SpringerLink, and the FAO and International Cocoa Organization (ICCO) repositories. The review considered peer-reviewed journal articles, books, conference proceedings, and authoritative institutional reports published between 2010 and 2026, with earlier seminal studies included where necessary for theoretical context. Literature was selected based on its relevance to cocoa price volatility, agricultural mechanisation, post-harvest technologies, supply-chain efficiency, and policy interventions, while studies lacking direct relevance or sufficient scientific credibility were excluded. The retrieved literature was analysed thematically, with evidence synthesised under key themes including drivers of cocoa price volatility, economic and market dynamics, farm mechanisation, post-harvest technology gaps, and policy implications. This methodological approach provides a comprehensive conceptual framework for integrating economic and engineering perspectives on cocoa price volatility and technology adoption in West Africa.

2. RELEVANT STATISTICS

Figure 1 shows the trend of the 10 best cocoa-producing countries from 2018 to 2023, highlighting Ivory Coast as the leading manufacturer after Ghana and Indonesia. WPR (2025) reflects the production volume, with some countries, like Ghana, experiencing a significant decline in recent years. Figure 2 shows the price of cocoa per kg from Quarter 1 2021 to Quarter 1 2025. The trend indicates a substantial increase from Q1 of 2021 to Q1 2025. A rapid rise in the prices of cocoa corresponds to ups and downs in production. It suggests a reverse relationship where production in large productive countries is declining, contributing to market volatility. Figure 3 shows the best cocoa-importing countries in 2024, with Malaysia, followed by US. Canada, Türkiye and Switzerland also show significant imports, inspired by chocolate and confectionery industry demand. European nations like UK and Switzerland maintain stable import levels, while Japan and Brazil have moderate imports. New Zealand records the lowest import price of \$ 13.26 million, reflecting a small cocoa market. The data distinguishes the demand for global cocoa affected by industrial and consumer needs.

Economic Analysis

a. Supply and Demand Framework

The volatility of cocoa prices can be analysed using the law of supply and demand, which states that prices fluctuate based on changes in supply and demand forces. Demand is driven by global chocolate consumption trends, income levels, and changing consumer preferences.

b. Law of Supply and Demand

Prices tend to rise when cocoa supply decreases due to poor harvests or disease outbreaks (e.g., Black Pod disease). Conversely, an oversupply due to favourable weather conditions or increased production leads to price drops. On the demand side, rising global consumption especially in emerging markets like China and India can push prices higher.

c. Elasticity of Cocoa Prices

The elasticity level of cocoa demand stays low since price changes barely affect consumer buying patterns. The limited availability of chocolate-making ingredients, such as cocoa, prevents elasticity changes in the

market demand. The cocoa supply exhibits elastic behaviour yet requires time due to the lengthy period required for cocoa farming. Data shows that consumers behave inelastically when cocoa prices rise by 10%, which leads to a 2% reduction in their buying behaviour. When prices increase by 5%, the cocoa supply generates a 5% volume increase because suppliers react to profits. The demand for cocoa increases by 3%, and supply decreases by 7% when prices fall by 10%, according to Table 1. Cocoa consumption shows stability because it serves an essential role in manufacturing, as observed in the supply market volatility, during which farmers adjust the supply levels according to price trends at a delayed rate, thereby causing fluctuations.

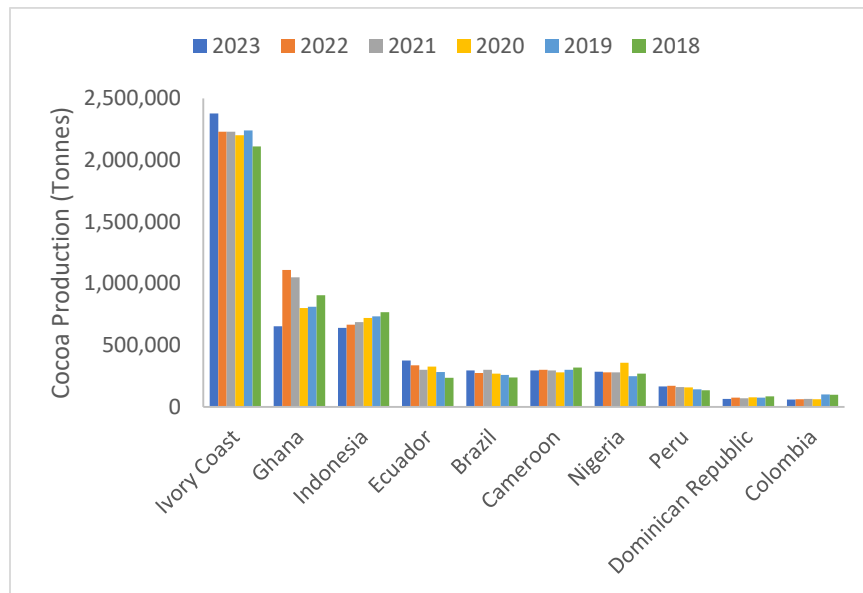


Figure 1: Cocoa Producing Countries (Data obtained from WPR, 2025)

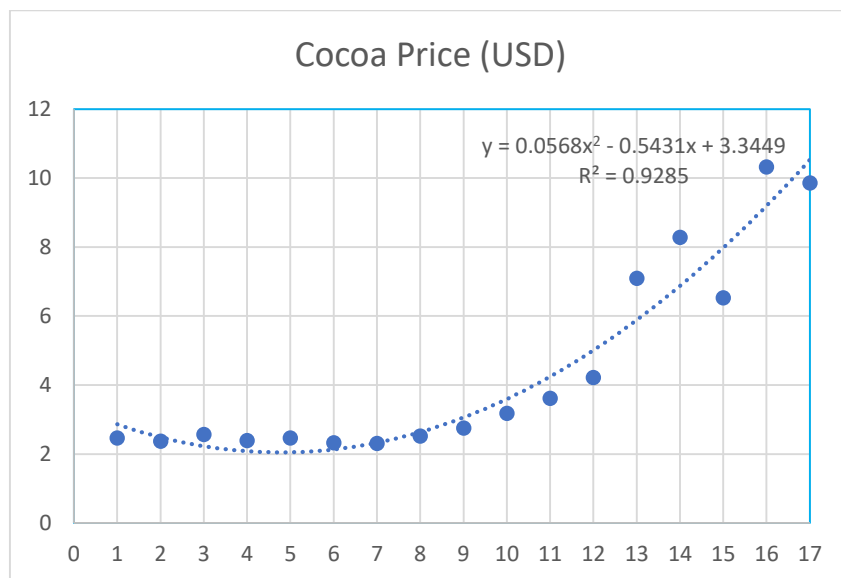


Figure 2: Cocoa Price/kg from Quarter 1, 2021 to Quarter 1, 2025 (Data Obtained from Ycharts, 2025)

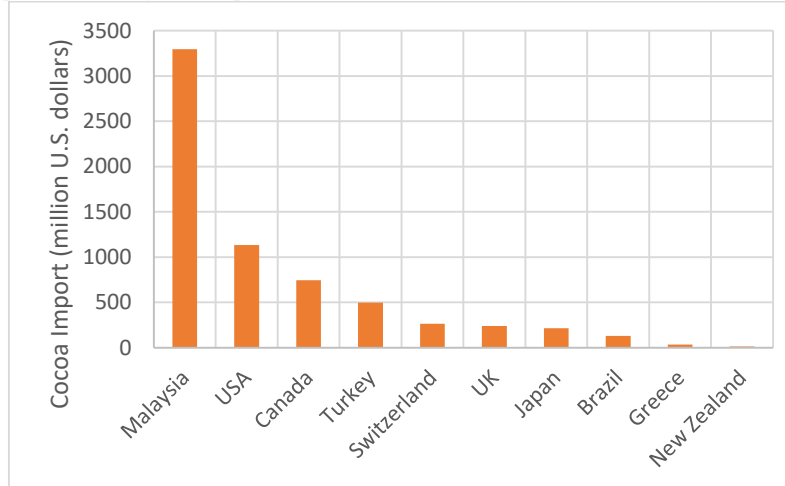


Figure 3: Top Demand and Import of Cocoa/Country
(Data obtained from Statistica, 2025)

Table 1: Effect of Changes in Price on Cocoa Demand and Supply

Change in Price (%)	Fluctuation in Cocoa Demand (%) (Inelastic)	Fluctuation in Cocoa Supply (%) (Elastic)
+10% (Increase)	-2%	+5%
-10% (Decrease)	+3%	-7%

(Data obtained from ICCO, 2012)

Market Equilibrium

Cocoa market balance is determined where the amount delivered equals the amount demanded. If the offer is reduced due to climate shock, the balance price (shift to the left) increases. Contrary to this, if production increases due to technical improvement, the balance price falls (shift right). In 2024, the global cocoa market experienced a significant price increase due to a lack of offers and unfavourable weather conditions as shown in Table 2.

Table 2: Cocoa Price Surge in 2024

Month	Average Price (USD/ton)	Percentage Increase (%)
January	4,453	-
April	12,000	169.5
December	10,353	132.5

(Source: Feyishola, 2025)

2.1 Price Volatility and Market Dynamics

Figure 4 shows the prices of cocoa over time. The cocoa market shows significant price instability because various supply and demand elements have shaped market dynamics in recent years.

a. Impact of Supply Shocks

Production difficulties in major cocoa territories, including Côte d'Ivoire and Ghana, emerged because of El Niño climate phenomena, which diminished crop numbers and triggered marketplace inflation. According to ICCO the El Niño event triggered an 11% loss in global cocoa production during the 2023-24 season (Myers, 2024).

b. Role of Speculation and Futures Markets

The speculative trades conducted in cocoa futures markets contribute to market price changes. February 2024 brought about a 25% surge in cocoa futures prices that stands as the most incredible monthly jump since 2001, as speculative traders joined the market because of supply worries (Myers, 2024).

c. Currency Exchange Rate Fluctuations

Major cocoa-producing countries suffered more market effects because of their currency exchange rate declines. About 160,000 tons of cocoa were smuggled from Ghana into the market during the 2023/24 season because the country's currency earned a lower exchange value than international markets (McFarland, 2024).

d. Cocoa Prices Over Time

Various economic forces have caused significant price changes in the cocoa market. The price of cocoa futures reached \$11,600 per tonne on January 22, 2025 since supplies contracted and inventories dropped, according to Figure 4 (Trading Economics, 2025)

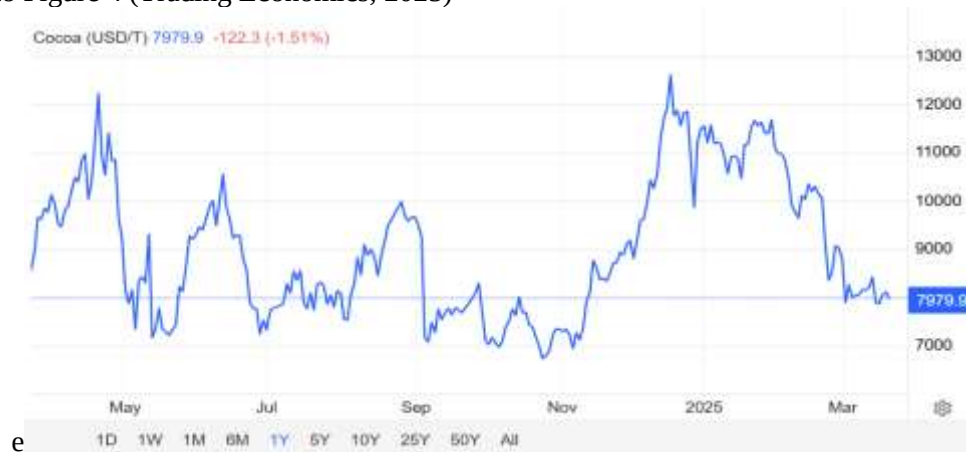


Figure 4: Prices of Cocoa over time (Trading Economics, 2025)

2.2 Economic Theories

- Cobweb Model:** this demonstrates how delays between product choices and their production result in price instability, mainly when applied to agricultural markets (Triatmojo *et al.*, 2025). The development of cocoa trees takes numerous years before they become harvestable. Additional tree planting by farmers who expect high prices will produce future market oversupply that ultimately drives prices downward. Plenty of farmers will avoid establishing cocoa plantations when prices remain low which then creates predictable cocoa shortages that drive prices up. Continuous price volatility occurs as part of this repeating market pattern.
- Theory of Speculation:** Commodity market speculators utilize the strategy of purchasing at low prices to achieve profits through high-price sales (Adhikari *et al.*, 2025). Excessive speculative activity and supply boost price movements even above the natural forces of market supply and demand dynamics. From 2024, cocoa futures prices rose by 25% throughout a solitary month due to speculative market actions that considered upcoming supply limitations.

3. ADOPTING FARM MECHANISATION IN COCOA SYSTEMS

It is well known that farm mechanisation is linked to the stability of agricultural supplies in various agricultural systems worldwide. This is a poorly developed link, however, for West African cocoa production and one of the greatest under-researched causes of price volatility in international cocoa markets. The availability of farm power and machines in cocoa production affects supply of cocoa beans to international markets in terms of quantity, quality and frequency. Where mechanisation is not available, production is inefficient, losses occur at various stages and the marketable supply of cocoa reduces, this leading to the type of supply side shocks that give rise to a high degree of price volatility. The status of mechanisation in West African cocoa farming, its analysis and effect on the cocoa supply instability, as well as the critical relationship between the decisions on cocoa mechanisation investment and cocoa price volatility cycles are discussed in this section.

3.1 Current State of Mechanisation in West African Cocoa Farming

Overall, the smallholder farming system, with its subsistence-based production practices, limited capital investment and low level of mechanisation throughout the entire production cycle, continues to dominate cocoa production in West Africa. Tractor density is one of the lowest in the agriculture sector in Ghana and Côte d'Ivoire, which combined produce more than 60% of the world's cocoa crop (FAO, 2023). The average number of tractors per agricultural hectare in Ghana is about 1, which is lower than the recommended density for efficient mechanised farming (World Bank, 2022). In Côte d'Ivoire, the situation is similar, as the majority of cocoa farmers use handheld cutlasses, manual knapsack sprayers and traditional wooden fermentation boxes as their main production equipment. Limited mechanisation is experienced in all vital activities of the cocoa production chain. Improved fungicide application to control Black Pod disease using power sprayers, which has the potential to significantly enhance the efficacy of disease control, is still uncommon on smallholder cocoa farms (Alvarado *et al.*, 2026).

Although mechanical pod breakers exist, they are not widely used on the farm and can cut the time and manpower needed to process harvested pods. Likewise, motorised pruning equipment is underutilised, which is vital to promote tree health and maximise light penetration to increase yield. The majority of West African cocoa is produced on smallholder farms and is not used in mechanical and controlled fermentation systems which could be used to standardise the quality of the beans and minimise losses during fermentation (Kongor and Rahadian, 2024). This technological gap is not only an issue of farmer preference but also a question of deep structural issues such as lack of access to rural credit, lack of agricultural machinery supply chains in cocoa growing areas, low technical training among farmers and extension service providers and the constant economic instability caused by the volatile cocoa prices, which makes it difficult for farmers who operate on thin margins to invest in their farms in the long term.

3.2 How Poor Mechanisation Contributes to Supply Volatility

Inadequate farm mechanisation has direct and pervasive implications for cocoa supply stability. Crops are mostly harvested manually, which leads to acute labour shortages in peak harvesting seasons when cocoa pods mature at the same time over extensive cocoa growing areas, resulting in delays and insufficient harvest. If pods are not picked in time, beans can over-ripen on the tree, which lowers the quality of the beans for premium chocolate production. Unharvested pods in severe cases rot on the tree to produce breeding grounds for Black Pod disease inoculum which can potentially reduce subsequent seasons' production (Gupta, 2022). Manual harvesting is also slower and less effective than mechanised harvesting, so even if adequate labour exists, harvesting may not be able to catch up with the pods reaching and passing peak maturity. This can lead to systemic delays in the supply as volume of cocoa that is physically available is not able to be processed into marketable product in the optimum timeframe, hence reduced supply of quality cocoa to export markets during critical supply windows.

In addition, manual farming systems are structurally weak for their lack of capacity to increase production quickly during periods of high cocoa prices. In mechanised agriculture, the significant increases in international cocoa prices in 2024 could stimulate farmers to increase their production efforts, invest in more machines, and process more beans to benefit from the high prices (Adams *et al.*, 2025). In West Africa, where the availability of manual labour is physically limiting, it is not possible to implement this supply response and price signals are unable to lead to the necessary increases in supply to dampen the resulting price increases as would typically happen in a more mechanised production context. Table 3 clearly shows that mechanisation development in all the various operations of cocoa farms brings significant benefits in terms of efficiency and quality of the cocoa product. Taken together, these improvements would result in a more substantial and stable supply of export quality cocoa to international markets, resolving one of the fundamental causes of price volatility in the cocoa market.

Table 3: Current vs Recommended Mechanisation in Cocoa Farming Operations

Farm Operation	Current Method	Recommended Machinery	Potential Yield/Efficiency Improvement	References
Pod Harvesting	Manual cutlass and hand picking	Mechanical harvesting poles and ergonomic cutting tools	20-30% faster harvesting rate	Randy <i>et al.</i> (2024)
Pod Breaking	Manual breaking by hand/cutlass	Mechanical pod breaker machine	40% reduction in labour requirement	Arhsad <i>et al.</i> (2026)
Fermentation	Traditional wooden boxes	Controlled fermentation tanks with temperature regulation	15% improvement in bean quality grade	Amissah <i>et al.</i> (2025)
Drying	Open-air sun drying on mats	Solar tunnel dryers / mechanical forced-air dryers	25% reduction in drying-stage losses	Elwakeel <i>et al.</i> (2026)
Disease Spraying	Manual knapsack sprayer	Motorised backpack sprayers / agricultural drone sprayers	35% improvement in spray coverage and efficacy	Asif (2025)

3.3 Mechanisation Investment and Price Volatility: A Reinforcing Cycle

The most difficult aspect of the mechanisation deficit in West African cocoa production is perhaps the self-reinforcing nature of the relationship between investment capacity and price volatility. However, when cocoa prices are not stable and consistent, smallholder farmers without financial safety nets or access to cheap, rural credit are unable to make a strong case for heavy investment in farm machinery. If the farmer's income is highly variable from one season to the next, he is not certain that he will be able to pay the tractor repayments or the mechanical pod breakers or the motorised spraying equipment, because if one season has a low price or poor yield, the debt will be unserviceable for the season. This means that the mechanisation levels are still very low, which further limits yield and leads to high post-harvest losses, thereby causing high price volatility, which initially deterred investments. The cycle depicted below is one of the most intractable structural challenges to the stability of the cocoa supply in West Africa this cycle. Table 4 presents the mechanisation-volatility cycle and its effects.

Table 4: The Mechanisation-Volatility Cycle and Its Effects

Stage of Cycle	Description	Market Impact
Price Volatility	Unpredictable cocoa prices reduce farmer income certainty	Farmers unable to plan long-term investments
Low Mechanisation Investment	Farmers cannot access credit or justify machinery purchase	Production remains manual and inefficient
Yield Inefficiency	Manual systems create harvest delays, losses and quality problems	Effective marketable supply is reduced
Supply Shortfall	Reduced export-quality cocoa reaches international markets	Upward pressure on cocoa prices
Increased Price Volatility	Supply shortfall triggers further price spikes and instability	Cycle restarts with greater intensity

In order to break the vicious circle, a coordinated action involving the government-sponsored mechanisation programmes, availability of rural machinery finance, and appropriate agricultural engineering extension services is required, in which farmers would be provided with relevant working and maintenance skills for modern cocoa farm machinery. If deliberate attempts are not made to boost the mechanisation of West African smallholder cocoa farmers, supply-side volatility will persist to continue to jeopardise market stability and farmer welfare in West Africa.

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4. POST-HARVEST LOSSES AS A DRIVER OF COCOA SUPPLY VOLATILITY

In the larger study of cocoa price volatility, the cocoa postharvest phase of the supply chain is one of the very important, yet often overlooked, factors driving volatility from the supply side (Konar *et al.*, 2026). Although, significant resources and efforts are devoted to analysing climate variability, disease epidemics and geopolitical events as causes of cocoa supply shocks, the losses inherent between harvest and export are just as significant and much more preventable. It is estimated that the three main reasons for the losses of cocoa farmers in West Africa are due to poor fermentation control, poor drying practices, and losses on the way to storage, accounting for 15% to 40% of their potential gains (FAO 2023, ICCO 2022). Such losses are not just an economic hit on consumers' finances these losses are a systematic and ongoing occurrence of the availability of export-quality cocoa that faces international markets, contributing towards price volatility throughout the cocoa value chain. This section reviews the postharvest processing of cocoa beans, discusses the losses at various post-harvest cocoa processing stages and the available technology solution to deal with losses systematically.

4.1 Stages of Post-Harvest Cocoa Processing

A first step to combating postharvest losses is to be aware of both the quantity and location of the losses through the sequential processes that the cocoa bean undergoes from harvest to export (Mori-Mestanza *et al.*, 2026). The postharvest processing chain has a number of components which have their own set of technologies that can create technology challenges and other areas where engineering can be of assistance. The cocoa postharvest processing chain is shown Figure 5. Each of these stages has the potential of creating quantitative losses in cocoa volume, qualitative loss in bean characteristics or quantitative loss along with loss in bean characteristics. This cascading decline at each successive processing step is a hallmark of the postharvest dilemma in West Africa's cocoa industry and it is why investments in enabling cocoa supplies to be more stable and less volatile is a tall order that hinges on solving the some of the major challenges in the postharvest phase.

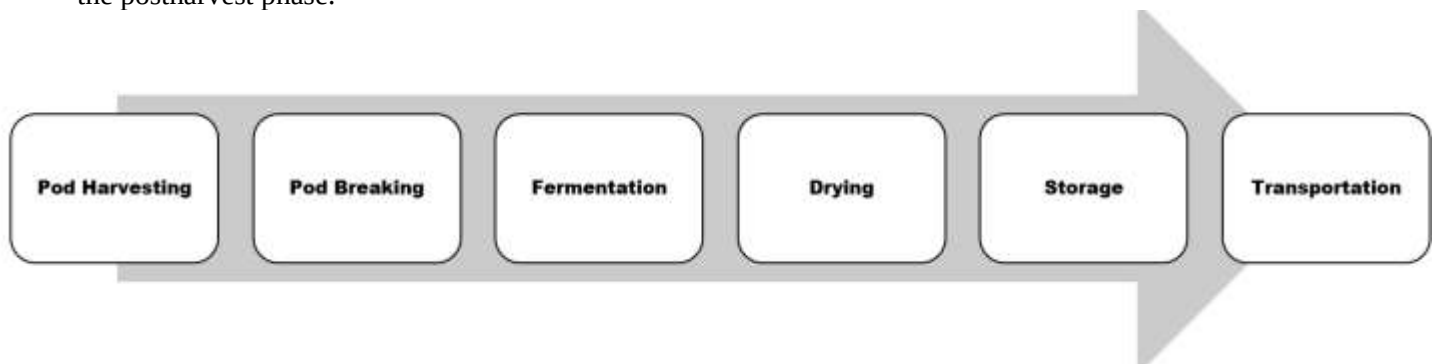


Figure 5: Cocoa Postharvest Processing Chain

4.2 Post-Harvest Loss Analysis

a. Fermentation Problems

The first, and perhaps most important, quality determining phase in cocoa postharvest is fermentation. The sugary pulp that remains around fresh cocoa beans after extraction is broken down by microbial activity for a few days to create biochemical precursors necessary for the formation of the characteristic compounds of cocoa flavour and aroma during roasting. If fermentation doesn't happen properly, whether it's for a short period of time, because not enough of the mass is being turned over, or because the fermenting beans aren't in the correct temperature, then they don't become the biochemical complexity needed for producing good quality chocolates. Beans that have been poorly fermented are downgraded or turned down in bulk at export inspection stations and in the worst affected seasons as much as 1 in every 5 consignment of beans is rejected at Ghanaian and Ivorian points of inspection (ICCO, 2022). There are ramifications besides just

the loss of volume associated with the failures of fermentation. Rejected beans at export are cocoa beans that have already been exhaustively labour, land and post-harvest-processed but without the earnings of exports. This rejection of 'bad' fermented cocoa, overall, will significantly diminish the volume of physically produced cocoa available for market sale, adding to the effect of shortfalls from seemingly sufficient gross production that drive the prices higher in the international markets.

b. Drying Inadequacies

After fermentation, the cocoa beans must be dried to around 7.5% moisture to guarantee safe storage in the long run without deteriorating (Khaled et al., 2026). However, the smallholder system of Africa generally, and West Africa specifically, has very few alternative options to the sun drying method and is entirely weather dependent, with no technology for moisture control during cloudy conditions, rain or high ambient humidity. The effects are bad and immediate when beans are not sufficiently dried and when moisture content is above the safe level when they enter the storage facilities. Moulds grow most readily in situations of excess moisture, which occurs during storage in bean masses in a similar way to how they grow in the field at a time of Black Pod disease, leading to further loss of quality within the consignment and making it commercially unfit for sale. In West Africa cocoa systems losses and quality downgrades due to drying are estimated to range from 8% to 15% of the post-harvest value loss during high humidity seasons (FAO, 2023).

c. Storage Losses

Despite good initial fermentation and adequate drying of cocoa, mismatched storage facilities are still a serious quality and quantity problem. Most farm and village level cocoa stores in West Africa are simple stores in which very little is done to prevent the damaging effects of fluctuations in humidity, infestation by insects and rodents. The moisture reabsorbed by the dried cocoa beans during prolonged periods of storage in uncovered or inadequately closed storage areas may overcome the desirable effect of a proper dried product and mould growth may be encouraged. Meanwhile, insect damage such as that from cocoa storage beetles diminishes stored beans' weight and market value, while simultaneously damaging the beans physically (Tonin et al., 2026). The precise magnitude of the losses in the West African cocoa sector caused by storage is elusive, but is thought to represent another 5–10% of the post harvest value loss each year (ICCO 2022).

d. Transportation Losses

The final stages of the post-production stage puts the produce at risk of additional damages resulting from handling and transport by car, and increases the quality degradation resulting from extended transport durations over sub-below standard road surfaces. Roads leading to the cocoa growing centres in the rural areas of both Côte d'Ivoire and Ghana are frequently crushed, poorly maintained or unsurfaced, causing mechanical damage to loaded vehicles as well as compression damage resulting in better loaded vehicle damage due to ruptured bags and spilled beans, and adversely affecting the process of commercial grading through consignment rejection. Because of the lack of controlled and/or humidity controlled transport vehicles, beans can become moist during longer road trips in humid weather conditions and thus nullify the effect of the drying process on the farm. The losses in cocoa value chain (CVC) related to transportation from the farm to the point of sale already amount up to 3% - 7% loss in quality of cocoa beans. (FAO, 2023).

e. Engineering Solutions for Post-Harvest Losses

The losses mentioned above are not from cocoa biology or West African geography, but are avoidable and preventable. Their fundamental character of being engineering problems with engineering solutions is an established fact. Studies in the post-harvest processing chain have shown that suitable and appropriate technology and interventions at every step can cause a dramatic reduction in quantitative volume losses, as well as qualitative losses of cocoa beans, enhancing the capacity to provide export-quality cocoa to

international marketplaces, thus reducing supply-side cocoa price volatility. The engineering solutions for the reduction of postharvest losses in cocoa is presented in Table 5.

Table 5: Engineering Solutions for Post-Harvest Cocoa Loss Reduction

Post-Harvest Stage	Primary Problem	Engineering Solution	Expected Impact
Fermentation	Inconsistent temperature control and inadequate turning	Automated fermentation boxes with embedded temperature sensors and timed turning mechanisms	Standardised fermentation quality; reduction in export rejection rates by up to 20%
Drying	Weather-dependent open-air sun drying causing incomplete or inconsistent moisture reduction	Solar tunnel dryers and mechanical forced-air dryers providing controlled drying environment	25% reduction in drying-stage losses; consistent moisture content achievement regardless of weather
Storage	Humidity fluctuation, insect infestation, and moisture reabsorption in inadequate warehouse facilities	Hermetic storage systems and controlled atmosphere storage with humidity regulation	Elimination of moisture reabsorption losses; 90% reduction in insect damage to stored beans
Transportation	Physical damage from poor roads and moisture absorption during transit	Improved rural road infrastructure investment and mechanised sealed-container loading systems	3-7% recovery of currently lost post-harvest value; improved bean integrity at export inspection
Quality Testing	Manual visual grading errors leading to inconsistent quality classification and unnecessary rejection	Electronic moisture meters and near-infrared spectroscopic analysers for objective quality assessment	Reduction in grading errors; improved accuracy of export consignment quality certification

As demonstrated in Table 3, engineering interventions are available and technically proven for every critical stage of the cocoa post-harvest chain. The collective implementation of these solutions across West African cocoa producing regions would generate a substantial increase in the volume and consistency of export-quality cocoa supply reaching international markets. By addressing post-harvest losses that currently remove between 15% and 40% of potential supply from the marketable pool, these engineering interventions would effectively shift the cocoa supply curve rightward without requiring any expansion of farmland or increase in the number of trees under cultivation. This supply-enhancing effect, achieved purely through improved post-harvest technology, represents one of the most cost-effective and immediately actionable pathways available for reducing cocoa price volatility and improving the economic security of West African cocoa farming communities.

5. FARM MECHANISATION DEFICITS, POST-HARVEST TECHNOLOGY GAPS, AND THEIR ROLE IN COCOA SUPPLY VOLATILITY: EVIDENCE FROM WEST AFRICA

The world's cocoa price reacts to global production activities and consumer buying behaviour alongside speculation activities and economic and political events outside cocoa markets (Kaestner *et al.*, 2026). Research studies that examine price variations of cocoa analyse these market dynamics from a financial standpoint, considering supply and demand theories (Talero-Sarmiento *et al.*, 2023). Parthasarathy (2025) demonstrates that cocoa yield outcomes suffer substantially from supply disturbances, including droughts, heavy precipitation events, and the propagation of black pod disease and swollen shoot virus infections. The prices of cocoa increase during periods of reduced supply because of adverse weather and disease outbreaks, reflecting the scarcity effect according to the law of supply (Fountain and Hutz-Adams, 2024).

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Cocoa production exists in mainly two countries because Côte d'Ivoire and Ghana together produce more than 60% of all cocoa worldwide (Kalischek *et al.*, 2023). The physical concentration of cocoa production makes the supply chain susceptible to disturbances, including government actions, worker stoppages, and civil disturbances. Supply shocks in the prime cocoa-producing countries create rapid price volatility, according to the International Cocoa Organisation (ICCO), because short-term cocoa production is not elastic (Leissle, 2018).

Price determination for cocoa depends heavily on three demand-side factors: consumer preferences, economic conditions, and income levels in major cocoa-consuming regions. Gilbert (2016) studies speculative trading effects and consumer demand modifications in Europe and North America as the top markets for chocolate products (Coral *et al.*, 2024). Quartey-Papafio *et al.* (2021) demonstrated in their studies that cocoa product demand remains comparatively constant throughout the first run of the business year, which translates to minimal price fluctuations in consumption levels. Long-term trends, including growing consumer health awareness or economic recession signals, result in changes in market demand. During economic downturns, when people earn less money, the demand for luxury chocolate products weakens, and cocoa prices fall (Coral *et al.*, 2024). The volatility level within the commodity futures market grows worse because traders base their decisions on future supply and demand expectations rather than actual market data (Lasisi *et al.*, 2025). The Ghanaian cedi and Ivorian franc fall against the dollar, which enhances export competition, forcing higher market supply and price reduction (Gilbert, 2024). The literature review confirms that cocoa price volatility originates from multiple factors: supply constraints, market demand variations, and speculative market practices.

In addition to macroeconomic and climatic factors influencing cocoa price volatility, the growing literature on cocoa agriculture reveals that the lack of farm mechanisation and post-harvest technology infrastructure is also an important, yet under-researched dimension and source of supply instability in West Africa cocoa systems. Tresserras *et al.* (2022) argue that the lack of dynamic flexibility in cocoa production, required at different stages of production, in smallholder farming systems represents inherent productivity ceilings and is not conducive to the elasticity of supply that is necessary for the self-correcting mechanisms assumed in commodity market theory to be working. Producers would be expected to become more responsive to this high price of cocoa due to the mechanised system which would enable them to expand production rates to supply the market on a larger scale, thereby curbing the price. Yet in both Côte d'Ivoire and Ghana, the prevailing manual supply-response systems lack the ability to perform this action within what is commercially achievable turnaround time producing for a period of time with greater normal demand that lead to greater price increases than simply market fundamentals would dictate.

Many international agricultural development institutions have reported on the role of postharvest losses in magnifying cocoa prices volatility. Fermentation, poor drying practices, poor storage facilities and transportation related cocoa quality losses are cited to destroy between 15 per cent and 40 per cent of potential cocoa income in West Africa, according to the Food and Agriculture Organisation (FAO, 2023). In theoretical research, Awua (2002) has identified several cases where beans fail in quality systems due to poor fermentation processes and his theory suggests as the percentage of such beans selling increases in the country, the quality decline becomes unnoticed. This leaves significant quantities of cocoa beans unmarketable, hidden in the market data, as there is no corresponding decrease in cocoa volume figures, which are published by the gross production, but only becomes apparent in the international price fluctuations.

Additionally, Afoakwa *et al.* (2013) showed that the quality of the beans handled during the post-harvest process influence the final quality of the beans, with an inadequate process resulting in the beans being devalued in premium markets for chocolate production. At the same time as quantitative volume losses do, this quality-driven supply reduction reinforces the reduction in supply and its effect on the market value of the final product by impacting both quantity and quality available on the international market. Agro-feasible Olaniyan *et al.*: Analysis of Price Volatility of Cocoa and Its Implications for Farm Mechanisation Investment, Harvest Equipment Adoption, and Post-Harvest Technology in West Africa

improvements, such as better-dried fermentation box designs, higher drying platforms for better drying conditions and hermetic storage bags to improve post-harvest operations, had been identified by Bart-Plange and Baryeh (2003) as having the potential to reduce post-harvest losses of between 20% and 35% on a smallholder cocoa farm basis in West Africa without additional crop production.

The study also analysed the link between investment in mechanisation and cocoa price volatility in the context of the agricultural technology adoption theory. Nin-Pratt and McBride (2014) have shown that price volatility is a very important constraint on the adoption of mechanisation by small farmer households, because small farmers will be unwilling or unable to invest in machinery. This produces the vicious circle described in all parts of this report: More price volatility means less mechanisation investment, less mechanisation means less yield efficiency and post-harvest losses, less moving market supply means more price volatility, etc. To break the cycle requires coordinated policy action, incentivizing the sale or hire of modern cocoa processing machinery on agricultural credit facilities, and providing agricultural engineering extension services to enhance farmer technical capacity to operate and maintain modern cocoa-processing machinery effectively, Dorward *et al.* (2009) wrote. The literature thus shares a single clear-cut understanding: the solutions to cocoa price volatility comprehensively demand not macroeconomic responses, but the targeted investments of cocoa producing regions in WA in farm mechanisation and in the infrastructure of post-harvest technology.

6. FARM POWER REQUIREMENTS AND ENERGY ANALYSIS FOR COCOA MECHANISATION

Mechanisation is an inevitable reality for the sustainable production of cocoa, and will play crucial roles in the efficient use of labour, product quality and post-harvest losses, while helping to mitigate the farm labour problem amid rising costs. The development of the success of mechanisation will require in addition to the availability of suitable equipment, the knowledge of the power availability and energy requirement for each step of cocoa production. The mechanical power and energy input requirements vary from one operation to the other and land preparation, crop establishment, harvesting and post harvesting processing are few such operations. Allocation of appropriate energy requires farmers to decide upon the use of energy-efficient technologies, reduce the cost of operations and boost farm productivity. Mechanical pod breaking is one of the significant opportunities for mechanisation in cocoa production (Arulmari *et al.*, 2021). In the past, pods are opened by hand with cutluses or wooden beaters which are labor intensive, time consuming and potentially destructive of beans due to inexperienced operators. Automated mechanical pod breakers have been designed to break the pods without compromising the integrity of the bean.

The electric motor power ranges typically from 1.5 to 3.0 kW in most small and medium scale pod breaking machines, whereas all diesel powered machines require electric motors between 3.0 to 3.75 kW. The machines can process several hundred kilograms of cocoa pods per hour, greatly reducing labour needs and helping to improve processing efficiency. Slightly lower power consumption also allows a reliable operation with small generators or photovoltaic power systems in the rural areas. Another high energy-consuming phase of cocoa processing is the drying stage. With proper drying, the moisture content of the manure beans is lowered to around 6-7%, which helps to eliminate the growth of fungus and meet international quality specifications. Conventionally, cocoa beans are spread on raised platforms or concrete floors and directly dried in the sun. Solar drying is actually example of virtually zero external energy consumption and relies on favourable weather conditions, and can be rather lengthy, especially in rainy seasons, which can require several days of drying.

This is overcome by the use of a solar tunnel dryer which surrounds the drying chamber with transparent covers that are capable of trapping the sun's radiation and still keeping beans dry from rain, insects and contaminants. They are mainly passive solar energy, with very low operating energy requirement, so they are very appropriate for smallholder farmers with the intention of using sustainable and environmental

processing means. Mechanical dryers provide more consistent and rapid drying, however, elements of the weather are not a problem. Electrical, diesel burners, biomass furnaces, or gas-fired dryers are generally used for these systems and produce drying capacity of 5 to 20 kW depending upon drying capacity and airflow. Mechanical dryers are more expensive to operate than fan-and-fire dryers, but offer greater variety, control and flexibility in temperature and humidity drying resulting in better bean quality and fewer post-harvest losses.

The operations of land preparation for establishment of new cocoa plantations/farm rehabilitation demand a much larger power than post-harvest operations. For locations where mechanical land-clearing equipment can be used, agricultural tractors fitted with ploughs, harrows, or subsoilers are generally used. For Cocoa farm development, tractors from 45 to 75 kW are suitable, considering the type of tractor, its slope, soil texture and vegetation density. Medium powered tractors can till the land effectively and also conduct secondary tillage in short time durations, thereby minimizing the labor as well as time needed for land tillage. Mechanised land preparation is good for large plantations, especially those run by commercial farmers, but in smallerhousehold farming operations, adoption has been hindered by lack of capital and land size. Harvesting renewable energy resources into cocoa farming processes is undeniably beneficial and has a tremendous potential for decreasing fossil fuel consumption and promoting environmental stewardship. Cocoa produced in certain parts of the world including the cocoa-producing regions of Nigeria are increasingly being dried using a drying system powered by solar energy, which is prevalent in this area due to the availability of the solar energy and its low operational requirements. PV systems can be used to provide electricity for mechanical pod breakers, moisture meters, fermentation monitoring devices, lighting and water pumping systems in addition to drying.

The increasing role of solar-powered irrigation pumps (SIPS) in cocoa nurseries and young plantations (YP) is also significant, especially in the context of the changing climatic conditions, which include longer dry seasons. Modern solar pumping systems not only do away with fuel expenses but can also help lower the amount of Green House Gases that are emitted, and are also less maintenance intensive than diesel powered pumps. Operational flexibility is further improved through battery storage systems, which enable irrigation to be carried out throughout the day even when the solar radiation is low. Energy integration within the cocoa mechanisation therefore helps to support the climate-smart food production approach whilst reducing the longer-term production cost. The use of more recent technologies in cocoa processing has also brought about devices to measure electronic monitoring. The automated fermentation controller comes with a relatively small amount of electrical power, typically about 0.5 kW, and with a temperature and humidity sensor, it will be able to optimize the fermentation process, key to achieving a more consistent process. These technologies can lower the intra-batch variability in quality and improve the quality attributes that the cultured chocolate producers are asking for, internationally. Table 6 shows typical farm power and energy requirements for cocoa mechanisation.

Table 6: Typical Farm Power and Energy Requirements for Cocoa Mechanisation

Equipment	Power Requirement	Fuel/Energy Type	Operational Cost Estimate
Mechanical pod breaker	1.5–3.0 kW	Electricity/Diesel	Low
Solar tunnel dryer	0 kW (passive)	Solar energy	Very low
Mechanical cocoa dryer	5–20 kW	Electricity/Diesel/Biomass	Medium–High
Motorised sprayer	2–5 kW	Petrol	Medium
Tractor (land preparation)	45–75 kW	Diesel	High
Fermentation controller	0.5 kW	Electricity	Low
Solar irrigation pump	0.5–2.5 kW	Solar energy	Very low

The Economic advantages of mechanisation will be based on comparing the cost of the machines to their ability to save labour, enhance product quality and increase productivity. The manual cocoa production involves a lot of labour effort in harvesting, pod breaking, managing the fermentation process, drying and transportation. The shortage of labour by many cocoa producers' countries has also made the production of cocoa expensive and less efficient. Mechanisation allows workers to reduce reliance on man power, reduces processing time and increases product quality consistency. The capital investment involved in the initial acquisition of machinery, like tractor, pod breaker and mechanical dryers can be large, but over the life of the machine, reduced labour will be an economic advantage, increased production will be an advantage, and reduced post-harvest losses will be an advantage. There is potential in cooperative ownership models, equipment hire services and government-funded mechanisation centres for smallholder farmers to address financial constraints related to purchasing machinery. Renewable Energy Systems also boost economic efficiency by lowering recurring fuel costs and maintenance expenses, and help fight against environmental impact.

7. REAL-WORLD IMPLICATIONS

The unpredictable nature of cocoa prices generates multiple adverse effects on all participants in the supply chain. Cocoa produces a financially unstable condition for Ghanaian and Cote d'Ivoire's major cocoa farm owners because this sector provides their main financial support, and declining prices create poverty and result in limited farming investment. The consumer market responds to cocoa price changes through their effect on chocolate manufacturers since these price fluctuations control production expenses and retail pricing levels. Market changes have led some businesses to look for substitute ingredients or resize their products to keep costs in check. The cocoa market receives support through stabilisation strategies from governments and worldwide organisations that include trading price floors alongside subsidy funds and fairtrade and living income differential sustainability initiatives. The schemes implement protective measures to shield farmers from price plunges, ensuring continued sustainability for the cocoa production industry.

Policy interventions need to strike a balance between market forces to prevent unreasonable market anomalies that might include excessive production and improper smuggling from price differences. From an agricultural engineering perspective, the real-world implications of cocoa price volatility extend deeply into the technical and infrastructural dimensions of cocoa production systems across West Africa. The persistent financial instability experienced by smallholder farmers directly suppresses investment in farm machinery, post-harvest processing equipment, and renewable energy systems that could otherwise transform production efficiency and supply consistency. When farmers cannot afford mechanical pod breakers, solar tunnel dryers, or motorised sprayers, the technological gap between West African cocoa systems and international quality standards widens progressively, making it increasingly difficult for smallholder-produced cocoa to meet the stringent grading requirements of premium chocolate manufacturers in Europe and North America.

Furthermore, the absence of adequate post-harvest engineering infrastructure, including hermetic storage facilities, controlled fermentation systems, and mechanised transportation loading equipment, means that a significant proportion of physically harvested cocoa is lost or degraded before reaching export markets. These engineering-driven supply losses directly translate into reduced farm incomes, weakened national export revenues for Ghana and Côte d'Ivoire, and persistent upward pressure on international cocoa prices that ultimately harms both producers and consumers simultaneously. Agricultural engineering interventions therefore represent not merely a technical improvement opportunity but a critical economic stabilisation mechanism whose implementation could generate measurable and sustained reductions in the price volatility that currently destabilises the entire global cocoa value chain. Prioritising engineering investment in West African cocoa systems is therefore both an agricultural and an economic imperative.

8. ENGINEERING POLICY RECOMMENDATIONS

To promote the pace of cocoa mechanization, coordinated engineering actions or interventions are needed, which can be facilitated by enabling government policy. Public mechanisation schemes should have a preference towards providing mechanised access for smallholder farmers on a scale and through mechanisms that are applicable, such as providing subsidised access to solar panels, mechanical pod breakers, motorised sprayers and other implements on a small scale. This would minimize capital constraints and increase efficiencies in production in cocoa producing communities through these programmes. Strengthen agricultural extension services and continue training farmers on the operation of the machinery, preventive maintenance, appropriate method of managing the fermentation processes, efficient drying methods etc. Raising farmers' technical skill will help increase the productivity and life cycle of the equipment used. Investment in rural infrastructure remains equally important. The construction and rehabilitation of feeder roads, bridges, and transportation networks will facilitate timely movement of cocoa pods and dried beans, thereby reducing transportation delays, quality deterioration, and post-harvest losses while improving market accessibility.

Greater investment in engineering research and development is also required to design affordable, durable, and locally manufactured cocoa-processing equipment suited to the small farm sizes that dominate cocoa production in many developing countries. Innovations should focus on low-cost mechanical pod breakers, energy-efficient dryers, modular fermentation systems, and renewable energy technologies that can be fabricated and maintained using locally available materials. Finally, digital technologies should be integrated into cocoa production to enhance precision agriculture and improve farm management. Mobile soil sensors, weather forecasting applications, GPS-enabled machinery, drone-assisted crop monitoring and spraying, and digital decision-support systems can provide farmers with real-time information for optimising irrigation, fertiliser application, disease management, and harvesting schedules. The combination of mechanisation, renewable energy, and digital agriculture will significantly improve productivity, profitability, environmental sustainability, and resilience within the cocoa value chain.

9. CONCLUSION

Cocoa price volatility in West Africa is a multidimensional challenge rooted not only in macroeconomic forces, climate variability, and speculative market behaviour, but critically in the structural engineering deficits of farm mechanisation and post-harvest technology infrastructure that systematically undermine effective cocoa supply. This report has demonstrated that inadequate mechanisation across harvesting, pod breaking, fermentation, drying, and disease management operations creates productivity ceilings that prevent supply from responding elastically to market signals, perpetuating the self-reinforcing cycle of volatility, underinvestment, and yield inefficiency. Simultaneously, post-harvest losses accounting for 15% to 40% of potential production value represent a preventable and recurring supply reduction that amplifies international price instability far beyond what climate or demand factors alone would generate. Engineering interventions including mechanical pod breakers, solar tunnel dryers, automated fermentation controllers, hermetic storage systems, and renewable energy-powered farm equipment offer technically proven and economically viable pathways to dramatically reduce these losses and stabilise cocoa supply. Realising these benefits requires coordinated policy action combining government-subsidised mechanisation programmes, rural infrastructure investment, agricultural engineering extension services, and research into locally manufacturable appropriate technology. Addressing cocoa price volatility sustainably demands that agricultural engineering solutions occupy a central rather than peripheral role in the policy response.

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