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Review Article

Mechanised Removal of Cocoa Beans from the Pod and Strategies to Optimize the Technique: A Review

Amuaku Randy[1, 2, *], Eric Amoah Asante[1], E. H. Y. Bobobee[1], Godwin Kwasi Amanor[2]

[1]Department Agricultural and Biosystems Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[2]Department of Mechanical Engineering, Faculty of Engineering, Koforidua Technical University, Koforidua, Ghana

Abstract

Confronted with problems associated with removing cocoa beans, methods, technologies and equipment have been developed and applied over the years. This paper comprehensively reviews the most effective method and technology to split cocoa pods and remove the beans. The working principle of the technique was explained with the cocoa pod opening mechanism, structures applicability and cost of the working method. The forces involved in opening cocoa pods are shearing, compressive, and impact depending on the machine type and the process used. The techniques applied in opening cocoa pods are grouped into traditional (manual) and improved (mechanised). The manual method of opening the cocoa pod is time-consuming and prone to accidents leading to injury to beans and farmers. The strength of the labour force available during harvest also affects the manual method. When cocoa beans are damaged, they deteriorate and are not appropriate for fermentation. The mechanised splitting has a high initial investment but very fast and reduced losses. Information gathered on cocoa pod mechanization shows that despite the countless efforts in developing various opening mechanisms. a high bean damage ratio and separation problems are still yet to be controlled. The current trends and techniques in cocoa pod opening mechanisms are also presented.

Keywords

Cocoa Pods, Opening Mechanism, Machine Design, Cocoa

1. Introduction

The dried, fully fermented bean of *Theobroma cacao*, often known as cocoa or cacao, is what is used as the primary ingredient in the production of chocolate. Due to the value and significance of its beans, the cocoa plant, which is a member of the family *Theobroma* and the genus *Theobroma*, is classified as a *Magnoliopsida* and belongs to the order *Malvales* [1]. The cocoa bean is greatly appreciated for its nutrients and smell. It contains nutrients such as magnesium, phosphorus, iron, zinc, copper, manganese, potassium, and vitamins B2 and B3 [2]. The cacao tree is native to the Amazon rainforest. Before being introduced to Central America by the Olmecs. It was initially domesticated 5,300 years ago in tropical South American tribes, with the Aztecs and Mayans being the most well-known of these indigenous peoples [3]. Globally, cocoa

*Corresponding author: amuaku.randy@ktu.edu.gh (Amuaku Randy)

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is grown in a narrow belt of around 20 degrees on either side of the equator, as it offers the perfect growing conditions. The cocoa tree needs high temperatures, humid conditions and plenty of rainfall to grow successfully. For these reasons, cocoa is produced predominantly in the hot and humid regions of Africa, but also in Asia, Central and South America and Australia [4]. Temperatures between 21 ℃ and 23 ℃ with fairly constant rainfall of 125 mm per year are needed for cocoa cultivation without the presence of hot dry winds and drought [4]. Currently, cocoa cultivation covers about 10.2 million hectares worldwide [5]. In Africa, especially West Africa, cocoa cultivation covers 6 million hectares of forest land [6]. Literature shows that nearly two-thirds of the world's cocoa production comes from West Africa, with Ivory Coast leading production at over 2.2 million tons, and Ghana, Nigeria, Cameroon and Togo producing an additional 1.55 million tons [7].

(a) (b)

Figure 1. *Cocoa Tree with fruits* [8].

The total area under cocoa cultivation in the year 2021 amounts to 4.3 Mha in Côte d'Ivoire and 2.7 Mha in Ghana [9], corresponding to 13.5 % and 11.3 % of Côte d'Ivoire's and Ghana's land area respectively. A cocoa fruit is a composite material composed of an external part namely a pod, placenta seeds/beans. The pod is the largest part of the cocoa fruit and occupies more than 70 % of the weight of the ripe cocoa fruit.

(a) (b) (c)

Figure 2. *Sample cocoa cultivars in Ghana [8].*

The percentage of cocoa beans is about 27 – 29 %, the remainder being the placenta which connects an average of 30 - 40 beans [10]. Generally, cocoa pods are oval-shaped and vary in size. The length of an average cocoa pod ranges between 20 and 32 cm and 7.5 to 10 cm in diameter. Its colour ranges from yellow or green to red-violet. The number of beans per pod varies depending on the cultivar.

Each bean consists of two convoluted cotyledons and is enclosed in the testa. The cotyledon has its colour varying from white to purple. The colour changes depending on the cocoa cultivar and prevailing environmental conditions [11]. Cocoa belongs to the genus Theobroma family which comprises three distinct groups within the species. The groups are divided into two namely; (1) Traditional (Criollo and Forastero); and (2) Derived (Trinitario). Criollo is native to Central America and is considered the best-flavoured cocoa [12]. This variety has white to pale yellow cotyledon with soft pods. It is easy to break and does not have the woody layer found in other varieties. Forastero is native to Venezuela and the Northern Amazon Basin [13]. However, it has its origin in Trinidad. It contains most of the cocoa commercially grown in Brazil, Central America, the Caribbean and West Africa (Ghana, Ivory Coast, and Nigeria, in particular). Forastero is noted for its precocity, superior growth vigour, high bean yields, and appreciable tolerance to West African virus strains. Cocoa constitutes a significant source of income for small-scale farmers who are responsible for the majority of worldwide production. Cocoa production is predominantly carried out by smallholders, as more than 90% of world cocoa farmers have plots of land between 2 ~ 5 hectares [14]. Cocoa production is also a source of foreign exchange for producing countries. In Ghana, cocoa production generates a livelihood for farmers and the country. In 2019, the Ghana Cocoa Board (COCOBOD) recorded 9.8 billion cedis, corresponding to roughly 1.3 billion U.S. dollars for the sale of cocoa beans [15]. Additionally, the same year's income from processed cocoa products amounted to 151 million cedis. The cocoa industry has recently contributed significantly to the economy, employing approximately 850,000 smallholder farmers and their families. It generates more than two billion dollars annually through the foreign exchange of exported cocoa beans and processed products [16]. The cocoa processing and mechanisation start immediately after harvesting. Harvesting starts approximately three years (hybrid/improved variety) or 4-5 years (traditional variety coming from the nursery) after planting [17]. Primary Cocoa processing includes harvesting, removal of beans, fermentation, and drying. Most of these processing operations have been successfully mechanized, resulting in technologies adopted by small and medium-scale levels of processing. Harvesting is done by cutting the stalk with a machete, a pruning pole, pruning shears or a sickle [18]. The processes involved in getting the beans for the production of products such as cocoa butter, cake, beverages etc., include the opening or breaking of the pods, extraction, fermentation, drying, dehulling and winnowing of the beans [12]. After the fermentation and drying of the beans, they are processed into paste, powder, granules etc., to produce a variety of products. The breaking of the pods whose aim is to extract the beans

from the pod is a major challenge to many farmers even though, it is an integral part of the production chain [19].

(a) (b)

Figure 3. *Harvesting ripe cocoa pods with (a) a long sword-like tool and (b) a cutlass* [8].

Traditionally, cocoa pods are broken to extract the wet beans within 3 - 7 days after harvesting depending on the size of the farm and labour availability [20]. Subsequently, fermentation and drying follow before export or use locally. Recently, some farmers and companies have used sophisticated equipment such as ovens, solar dryers, etc., to remove moisture from the beans. Traditionally smallholder farmers sun dry cocoa beans after fermentation. There are several techniques by which the pod can be broken with the main objective of carefully generating a crack to aid in the removal of the wet beans. These include using a wooden or any blunt object to hit the pod hitting two pods against each other or using a cutlass to split the pod open [21]. However, using the cutlass to split the pod open is the most prevalent traditional technique among the lot. Though the process is carefully and skillfully carried out, there is always the tendency to cut through the pod and damage the beans reducing the number of beans suitable for fermentation [22]. The manual cocoa-breaking technique is time-consuming, prone to accidents leading to injury and dependent on the strength of manpower [23], as a result, this method or technique of opening the cocoa pod is not advisable. However, some farmers still believe the method is faster and more convenient. To eliminate the drudgery, and reduce bean loss and risk involved in extracting cocoa beans, many efforts have been put in place over the years to mechanize and simplify the process. For instance, the Cocoa Research Institute of Nigeria (CRIN) which is an active producer of cocoa beans in West Africa constructed a cocoa pod splitter and reported a good performance [24]. A similar machine was built by Messers Christy and Norris Limited of England and tested at Cadbury Brothers Cocoa Plantation at Ikiliwindi, Cameroon [25]. This machine required two people to operate. The pod is split open using a revolving ribbed wooden cone mounted vertically inside a ribbed cylindrical metal drum. The authors reported that an impact energy of 30.9 J is required to break one cocoa pod while 78.6 J is required for five pods at a time for a hammer speed of 3.13 m/s. In another study, the existence of the Zinke cocoa-splitting machine which used several rotary jaws or toothed rollers was reported [24]. The performance evaluation showed a bad result because the jaw crushes the husks into tiny portions, making separation difficult. Subsequently, [25] assessed the performance of an impact-type hand-operated cocoa pod breaker operating at 3.13 m/s hammer speed and reported 93-100% efficiency with less than 1% seed damage. Similarly, [26] evaluated an electrically powered cocoa pod-breaking machine with an operating 6.6 m/s belt speed and reported 93 % efficiency with no seed damage. Further research work on the extraction of cocoa beans showed that the forces involved in opening cocoa pods are shearing, compressive, and impact forces depending on the machine type and the process used [27]. In a similar research [28] designed and developed a cocoa-splitting machine which had the potential to split open five cocoa pods at a time. The splitting knives were actuated by simple hydraulic mechanisms devoid of any major stresses and forces acting on them. These mechanisms were powered by simple hydrostatic hydraulic pumps with an 87.5 kW power rating. However, the machine can also operate on simple two-stroke internal combustion Engines. To automate the production process, a Pinhalense cocoa pod breaker was developed in Brazil [29]. The machine consists of the breaker which includes an agitator that starts the process of separating the beans from the husk, a conveyor belt, a cocoa bean pulp agitator and a pulper. The machine works automatically from the cocoa pod received through the splitting process, fermentation, drying and bean bagging. Findings have in that several attempts have been made over the years to mechanize the process of cocoa pod opening. Therefore, this paper reviews existing techniques, machines and equipment used for opening cocoa pods. The gaps in mechanized cocoa pod opening have been highlighted and projections for future machine development have been made [30]. Information and data on cocoa pod opening by way of procedure were obtained from scientific papers published globally on the subject from various search engines and databases like Google Scholar, Scopus, web of Science etc. The search focused on techniques for opening cocoa pods, machine development, machine efficiency, and the merits and limitations of developed machines.

2. Literature on Cocoa Pod Mechanisation

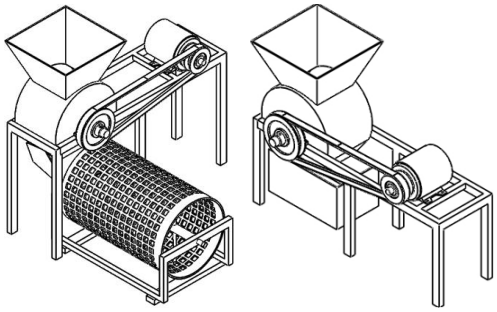
2.1. Techniques in Cocoa Pod Opening

The techniques in the process of opening matured ripped cocoa pods can be grouped into two namely; (1) Traditional and (2) Modern / Improved methods. After cocoa pods have been harvested, they are mostly broken within three (3) days

with the sole aim of extracting the beans. The traditional method is still practised by smallholder farmers in various parts of cocoa-growing areas in Africa including Ghana. Visits to some cocoa farms in Ghana show that smallholder farmers use tools and implements such as cutlasses, knives, wooden clubs etc., to break open the cocoa pod with the sole aim of extracting the beans for processing. Some smallholder farmers also use wooden handles of hoes or cutlass to hit the pod in an attempt to open them. Some hit the cocoa pods against each other or stationary blunt surfaces.

(a) (b) (c) (d)

Figure 4. *Traditional Methods of Opening Cocoa Pod [8].*



(a) (b)

Figure 5. *Samples of modern machines for opening cocoa pods.*

The traditional method of opening the cocoa pod is full of drudgery, dangerous, nonproductive, has a high bean damage ratio, is time-consuming, is prone to accidents leading to injury and is dependent on the strength of manpower.

Injury to cocoa beans results in spoilage, making them unsuitable for fermentation [31]. The man-hours required for this manual operation vary and depend on crop factors such as variety and worker's attitude and supervision. However, some farmers still believe the method is fast, effective and more convenient even though the process is challenging and significantly slow. Modern/improved method of cocoa pod opening uses equipment or implements such as knives, rotary blades, splitting cutters, crush rollers etc., manually or powered with fuel or electricity. These machines have proven over the years to be effective and efficient in the processing of cocoa, however, they come with additional costs in terms of maintenance and the purchase of spare parts to replace faulty and broken-down parts. Some machines are prone to high seed damage, this is because the Ghanaian scale of machine design and development is still artisanal [32].

2.2. Working Principles of Cocoa Opening Machines

Cocoa pod-opening machines are both manual and power-driven machines developed to support the process of extracting beans from the pod. The prime movers for these machines mostly include electric motors; transmission coupled shafts, belts, pulley arrangements etc. The machines are mostly used after harvesting ripe cocoa pods from the farm. The cocoa pod opening can be achieved by methods such as impact, rotating action and sharp edge incision. Most of the developed machines have feeding units, an opening mechanism (impact hammers, rotating jaws with spiked teeth or beaters, crushing plates etc.) and separation units [33]. The mechanization process starts with the feeding of the cocoa pods into the opening mechanism unit through manual feeding with the hand, attached hoppers or in some cases motor-driven conveyors. The feeding mechanism in some cases is inclined at specific angles to aid an easy flow of the cocoa pod into the opening mechanism unit mostly embedded in a cascaded housing (cylinder). The cocoa pod is fed along with the direction of motion of the opening mechanism [34]. The housing for the opening mechanism is either stationary or rotating at specific speeds. In the case of rotating cylinders, they serve as agitators in separating the broken pods and the beans. Some machines are developed with enhanced separation units operated by electric motors and vibrators with lined sieves or mesh units to serve as collectors of the beans [12] reported on a rotary sieve mechanism in their research developed by Are and Gwynee-Jove, 1974. However, the working principle of some opening mechanisms such as those that crush the entire cocoa pod forming a mixture of pod fragments and wet beans poses a huge strain in separation [35] which is an integral part of the cocoa pod mechanization process. Over the past decades, several researchers have attempted to mechanise the process of cocoa pod opening (Table 1). The technique ranges from

manual to powered machine development for optimal cocoa pod opening mechanisms.

Table 1. Summary of selected research papers on cocoa pod opening automation.

Author	Year	Objective
Jabagun	1965	To design and fabricate a cocoa pod shelling machine
Are and Gwynee-Jove	1974	To design a cocoa pod machine which breaks the pods utilizing a revolving ribbed wooden cone mounted vertically inside a ribbed cylindrical metal drum.
Faborode and Oladosun et al.	1991	Design, fabrication and evaluation of a cocoa pod-breaking machine operating on several rotary jaws or toothed roller mechanisms.
Maduako and Faborode	1993	To determine the mechanical breaking behaviour of cocoa pods for machinery development.
Adewumi and Fatusin	2006	To design, fabricate and test a simple hand-operated impact-type cocoa pod-breaking machine for peasant farmers in rural areas.
O. K. Owolarafe et al.	2007	Application of coefficient of friction in the separation of cocoa beans-husk mixture.
Adzimah and Asiam	2010	Development of a cocoa pod splitting machine to reduce bean losses and increase profits.
Asante Eric et al.	2015	Design and develop a cocoa pod-breaking machine using two rotating cylinder mechanisms operating in the reverse direction.
Josue Dzudie Fonsso, Wolfgang Nzie, Guy Edgar Ntamach, Bienvenu Kenmeugne	2016	To improve the productivity of cocoa pod breaker predicting the necessary rapture forces
M. O Iyanda et al.	2018	Design, fabricate and evaluate a cocoa deppoder to address the challenge of manual depodding of cocoa pods.
Arivu. Y et al.	2018	Design of an efficient, highly productive, cost-effective and environmentally friendly cocoa-splitting machine
Dzudie Fonsso Josue et al.	2019	Determine the physical and mechanical properties of cocoa pods for effective equipment design and improve the quality of cocoa products.
Choudary, Udayramu Pujari, Padma Priya and Burri Madhuri	2019	Design and evaluation of a pedal-operated cocoa pod breaker
R. Arulmari et al.	2021	To determine the physical properties of cocoa pods for essential development of equipment to mechanize farm-level processing.
Osoteo, Pajaron, and Paque	2021	To develop a cocoa crushing machine to mechanize cocoa processing and improve cocoa production.
Amuaku, R et al.	2023	To develop a mechanical model to assess the opening force required to break a cocoa pod under continuous compressive loading.

2.3. Mechanisms in Cocoa Pod Opening

Findings have it that several machines have been developed over the years and operate under different opening mechanisms. The most common opening mechanisms applied in machines used for processing cocoa pods include; (1) Manual hand operation, (2) Crushing, (3) knife cutting and (4) Rotary mechanism.

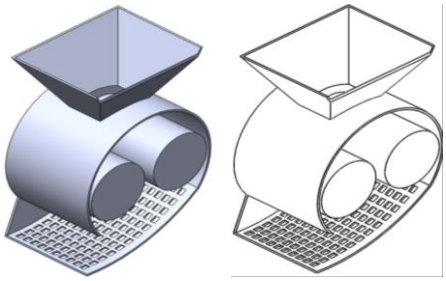
2.3.1. Manual Hand Operation Mechanism

The mechanization of cocoa pod opening has been researched over the years. [36] report on machines developed for processing cocoa pods, and further details extensively on experiments conducted to determine the extent to which broken cocoa pods and beans mixed during opening can be separated. Documentary sources report on a cocoa pod crusher designed, fabricated, tested and operated by hand [27].

This machine was designed purposely for cocoa farmers in rural areas where there is no electrical power source. An advantage of using a manual hand-opening mechanism is the absence of a power source making the operation less expensive compared to other mechanisms. However, it is limited to rural areas and small-holder farmers with minimal resources. [37] report that the first cocoa pod opening machine developed in Nigeria was built at the Cocoa Research Institute Nigeria (CRIN). A similar machine developed and operating under the same mechanism was developed by a British company Messers Christy. Their machine was evaluated at the Cadbury brother's cocoa plantation in Ikiliwindi, Cameroon. The operating principle and mechanism of these machines require two people; one feeds the cocoa pods into the machine while the other collects the beans after opening [34]. Cocoa pods introduced into the hopper drop into the bombardment section due to gravity. The cocoa pods are broken while moving through a vertically mounted rotating wooden rib cone inside a cylindrical drum with metal ribs. The seeds pass through the meshes in a collection of wooden boxes, while the shell or shell fragments are left at the open end of the rotating sieve. [25] developed a hand-operated impact-type machine composed of a frame, rail, hammer, pulley, bearings and rope for opening cocoa pods. They report less than 1% seed damage with efficiency and capacity ranging from 93 to 100 % and 377 to 738 kg^{-1} respectively.

2.3.2. Crushing Mechanism

The crushing mechanism of opening cocoa pods applies loading either at the lateral or longitudinal positions on the pods. Loading is simply introducing a force (impact, compression or shear) either manually or automatically on the surface of the cocoa pod [38]. [20] reports that forces required to open cocoa pods are impact, compression or shear and are dependent on the type of machine. However, the impact, compression or shear forces are not well assessed in the literature. The modelling of these compression or shear forces is very relevant for the cocoa pod opening mechanism design. Literature shows that two types of machines using crushing mechanisms have been developed over the years. The first type of machine operates by completely crushing the cocoa pods through impact or compression forces [39]. The separation of the beans and the broken pods is usually by screening. The major disadvantage of this operational method is that a considerable amount of cocoa pod husk mixes with the beans. The second type of machine cuts the cocoa pod husk through shear force before manually separating the beans or tumbling [10]. As part of research to mechanise the cocoa pod opening process, machines have been developed to operate under the crushing mechanism. For instance, [25] designed, fabricated and tested a machine to open cocoa pods and extract wet beans. The machine components included a hopper, metering plate, hammer and reciprocating sieve. The hammer which generates the crushing impact breaks the cocoa pods while the vibrating screen separates the husk. The wet beans are collected through a discharge chute; however, the machine is characterized by low efficiency and bulkiness. The developed machine also has a problem crushing the husks into small portions that mix with wet beans and pose a problem during separation. Also, [40], designed a machine consisting of a hopper, depodding unit and frame. The machine had a top and layers which formed the deposition unit where breakage of the cocoa pods occurs. The developed machine employs both impact and compression forces for its depodding operation. In the machining process, ripe harvested cocoa pods are manually introduced into the hopper which falls by gravity into a depodding unit where the action of compression results in reduced pod size and seed separation. The unit of depodding is divided into two layers, upper and lower (screen). The upper layer allows the cocoa pods to fall into the drum, then breaks them by impact and the broken pods are further forced to the lower layer where the broken pods and the beans pass through a screen for efficient separation. Similarly, [36] developed an electrically operated cocoa breaker with manual feeding of cocoa pods through a hopper. The crushing mechanism is provided by a hammer which comprises a sheet plate that moves in a vertical direction allowing cocoa pods to roll between a hammer and a fixed angle welded horizontally to the frame directly under the flat hammer. When the hammer goes down, it compresses the cocoa pods against the horizontal corner bars, which breaks the cocoa pod into smaller pieces, both the beans and the broken pods fall by gravity into the collector. The process continues to repeat until all cocoa pods are completely crushed or opened. Another research, [12] reports a designed, fabricated and evaluated machine named Zinke. This machine model uses several toothed jaws or rotating cylinders which serve as impact hammers. The hammer breaks the cocoa pods while a vibrating sieve separates the hull. The beans are collected by the evacuation chute. Typical of most machines operating under a crushing mechanism, smaller portions of the cocoa pod husk mix with moist cocoa beans, posing a problem during separation. Subsequently, [27] designed and developed a cocoa pod-breaking and beans extraction machine. It consists of a cocoa pod opening system, hopper, 4 mainframes, speed reducer, guiding wheel, support wheel, motor, and motor unit pulley. The designed machine uses the principle of compression force along the lateral axis of the pod. The main factor considered in the design of the machine was to use locally available materials to reduce cost while meeting all material resistance requirements. The machine was developed to have a maximum capacity of 3.5 tons/day (08 hours) so that it can be affordable for farmers.



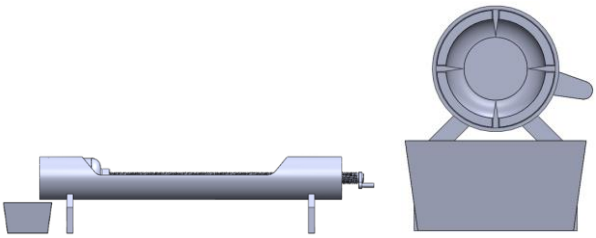
(a) (b)

Figure 6. *Cylindrical rollers applied in cocoa pod crushing mechanism.*

2.3.3. Knife-Cutting Mechanism

Knife cutting mechanism involves the use of sharp-edged blades oriented at specific angles to open cocoa pods at both lateral and horizontal positions. The cocoa pods are mostly placed between the blades (knives) and a support handle is pressed to split the pod into two halves. Information gathered from the literature shows that several machines have been developed using a knife-cutting mechanism, however, several inventions relating to pod opening into halves and bean extraction have been developed, but none have been widely adopted. This is because excessive breakage of the pod shell leading to contamination of wet beans is still a major problem in most designs. Literature shows that [10] designed a pod splitter that uses knives to divide cocoa pods by the action of a hydraulic mechanism.

The developed machine comprises an inclined rectangular container divided into five temporary compartments. The operating mechanism is such that cocoa pods move progressively by gravity along the inclined paths in the corresponding cavities. A pair of knives cut the placentas of cocoa pods. Separation of the pods along the sides is performed by another pair of knives. After splitting laterally into two halves the beans are separated from the empty cocoa pods at the bottom of the collector beneath the machine.



(a) (b)

Figure 7. *Manual hand-operated knife-cutting mechanism.*

2.3.4. Rotary Drum Mechanism

The rotating mechanism applied in the cocoa pod opening machines design mostly comprises two rolling cylinders moving in an anticlockwise or reverse orientation. The rolling cylinders serve as the main opening mechanism. Due to their orientation, they can break open cocoa pods moving directly towards them. Machines developed under this mechanism have proven to be effective. A typical example is research conducted by [39] who designed and developed a cocoa pod-breaking mechanism. In their machine design, breaking happens between two rotating cylinders in the reverse direction. The two cylinders are of the same size, viz. 150 mm in diameter and 250 mm in length, and rotated in a reversed direction at a speed of 20 - 25 rpm. The torque for the cylinder movement was provided by a Spark Ignition Engine (gasoline engine) of 5.5 hp. Cocoa fruit is fed manually into the breaker cylinder by setting the sliding feeding port of the hopper with a feeding rate between 8,000 - 10,000 cocoa fruit per hour. Cocoa pods, kernels, and placenta move through two levels of a vibration-sieving machine. In another research, [41] developed a cocoa pod breaker consisting of a cocoa pod breaking unit and a cocoa bean separation unit. The cocoa pod breaking unit and cocoa bean separation unit comprise a hopper, metal rollers, chute and rotating cylindrical strainers, frame, prime mover, and pulleys respectively. The operating mechanism is such that cocoa fruits are fed manually into a breaker unit through a hopper. The breaker unit comprises two rollers with a set gap between them. The purpose of the gap is to reduce bean damage during the breaking of cocoa pods. A tangential force is induced in the rollers as a result of their orientation and pushes the cocoa pod towards the gap resulting in breakage. Cocoa pod, kernels and placenta are then discharged to a strainer through a chute. Rotation of the strainer separates the beans from the cocoa pod through pores created in the strainer. The cocoa beans go through the strainer while the broken pods remain above the strainer.

2.3.5. Effects of Opening Mechanism on Cocoa Beans

The quality of beans is an integral aspect of cocoa pod mechanisation. Beans with injury (cuts, scratched surfaces etc.) during pod opening are prone to chemical, biological and microbiological deterioration resulting in damage. Some researchers over the years have reported bean damage as a result of the cocoa pod opening mechanism applied. Similarly, [42] reports that manual processes and some developed machines have been found to cause damage to the cocoa beans, making them unsuitable for fermentation, thereby resulting in losses. Another research conducted by [36] reported that the manual breaking of the cocoa pod leads to bean damage, increases the percentage of losses and reduces profits. In a recent study, [12, 37] reported that the manual means of cocoa pod opening results in fatigue, risk of injury and damage to the beans through the use of the machete and other implements leading to low productivity. Subsequently, [24, 40] reported on a cocoa depodding machine whose speed affected the performance of some parameters such as throughput capacity, efficiency and percentage bean damage. They further reported that operating the machine at 219 rpm produced the highest efficiency of 89.29%, throughput capacity of 469.87 kg/h and bean damage of 0.037 kg. Further research conducted by [12]

reports on the development and performance evaluation of a cocoa pod breaker cum bean extractor recorded a bean damage rate of 1%. Another research by [10] reports of cocoa pod opening mechanism which operates by a pedal system attached to a splitting knife, trommel, a pedal drive and a frame. They further report a successful operation with bean damage of 0.67 % with the inclusion of 0.3 % pod chips. Literature shows that present machines and equipment developed for cocoa pod opening consider seed damage ratios in the machine operations. Improvement in equipment and machinery for cocoa pod opening is leading to reduced bean damage ratios and increased bean quality.

2.3.6. Cost, Efficiency, and Adoption of Cocoa Pod Opening Mechanism

The production volume, the resources at hand, and financial concerns are some of the variables that influence the choice of the cocoa pod opening mechanism. Table 2, provides a brief comparison of the various opening mechanism about some selected factors.

Table 2. *Comparing cost, efficiency and adoption of cocoa pod opening mechanism.*

Mechanism	Cost	Performance efficiency	Adoption
Manual hand operation	Low initial cost, but labour intensive which increases operational cost over time	Relatively low efficiency compared to mechanised methods, as it relies on human strength and speed.	Common in small-scale or traditional settings where machinery is limited
Crushing	Higher initial investment in machinery, but efficiency gains lower long-term operational cost	Highly efficient but comes with separation problems	Large-scale processing facilities where increased efficiency justifies investment
Knife cutting	Moderate cost for the knife cutters	More efficient than the manual hand method	Common in small to medium-scale operations
Rotary drum	High investment in machinery, but has a potential for increased throughput	High efficiency due to automation, resulting in rapid processing	Common in large-scale settings where mechanised processing is economically viable

Depending on the intended level of mechanization and the size of the operation, industrialization may or may not incorporate cocoa pod-breaking methods. While rotary drum and crushing mechanisms are more common in larger-scale industrial facilities where increased efficiency and throughput are crucial, knife-cutting mechanisms are frequently preferred in smaller industrial settings. The optimum opening technique depends on a variety of factors, such as processing volume, resources available, and the equipment's economic feasibility.

3. Conclusion

The mechanization of cocoa pods is a valuable tool in the processing of cocoa. Although presently, there are several ongoing studies in the area of cocoa pod mechanization there is still a lot of work that needs to be done to optimize the process. Research on the mechanization of cocoa pods is still lacking to some extent. Among the frequent gaps found in the literature are (1) optimization of existing mechanised processes and opening techniques, (2) cost-effectiveness and affordability of mechanised cocoa pod-breaking techniques, (3) smallholder farmer adoption of existing cocoa pod opening techniques considering aspects such as cost, ease of operation, (4) introduction of innovative technologies such as artificial intelligence to further advance mechanization efficiency, and (5) preservation of cocoa bean quality while taking into account the effects of automated pod opening methods to reduce seed damage. However, in this review, four common opening mechanisms namely manual, crushing, knife cutting and rotary were identified as the frequently used methods in cocoa pod processing. The manual method of cocoa pod opening though efficient is time-consuming, prone to accidents and involves much drudgery; hence, not favourable for the commercial processing of cocoa pods. Presently, equipment, techniques, and machines are developed to be efficient. They are divided into groups according to the kind of opening mechanism (crushing, knife cutting, and rotating) and the way the cocoa pods are fed (single or continuous). While machine creation takes operation efficiency into account, some of the chosen opening mechanisms have drawbacks. The crushing mechanism for instance has been criticized for its poor performance because it has a problem separating broken pod mixtures from wet beans; this is the reason it has not been adopted on a commercial scale. Due to the ease with which broken pods and wet beans are separated, in addition to the low bean damage ratio, the knife and rotating drum opening mechanism is recognized as having satis-

factory performance and is adopted for commercial-scale purposes. Based on these inferences, it is recommended that even though a massive contribution has been made by various researchers and machine developers, the research for an effective and widely acceptable cocoa pod opening mechanism continues and further research is required. Future research may focus on measuring the force required to open a cocoa pod considering different post-harvest delays for different cocoa cultivars, the data acquired from such research can be a vital additive for machine parameter optimization and development for the efficient opening of cocoa pods.

Abbreviations

CRIG	Cocoa Research Institute Ghana
hp	horsepower
CRIN	Cocoa Research Institute Nigeria
COCOBOD	Ghana Cocoa Board

Author Contributions

Amuaku Randy: Conceptualization, Writing – original draft

Eric Amoah Asante: Methodology, Project administration, Supervision

E. H. Y. Bobobee: Project administration, Supervision

Godwin K. Amanor: Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

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