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Development of a Cacao (*Theobroma cacao* L.) Bean Huller

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Abstract: *Cacao beans are a fundamental component of the global chocolate industry, and their quality and processing efficiency play a crucial role in determining the final product's taste and economic viability. Cacao beans are surrounded by a cacao hulls, and the manual removal of this husk is a labor-intensive and time-consuming process that poses significant challenges to cacao farmers and processors. This research focused on developing a cacao bean huller. The designed machine achieved a hulling efficiency of 91.83%. Additionally, the purity of the hulled nibs was measured at 96.31%. This innovation offers a valuable contribution to the cacao industry, particularly the cacao farmer producers.*

Keywords: Cacao huller, winnower, hulling efficiency

1. INTRODUCTION

The *Theobroma cacao* L., or cocoa variety, has three basic types- Criollo, Forastero, and Trinitario. It serves as the primary component in the manufacturing of chocolate, and there is no alternative crop or item that can take its place in chocolate production. Cacao beans yield six distinct intermediary products: cocoa nibs, cocoa liquor (also known as tablea in the Philippines), cocoa cake, cocoa butter, cocoa powder, and chocolate confectionery blocks. Its versatile applications, both in the food and non-food sectors, create wider market possibilities. From a health perspective, cacao is rich in vitamins such as proteins and amino acids [1] and antioxidants, making it a natural multivitamin.

On a global scale, cocoa farmers generate approximately five million metric tons of cocoa beans each year. According to the Department of Science and Technology (DOST), Côte d'Ivoire and Ghana are the primary cocoa-producing nations, contributing to more than 60% of the world's cocoa production. Ecuador follows with a 7% share. In Asia, Indonesia holds the title of the largest cocoa producer in the season of 2021-2022.

The Philippines, situated in Asia, is regarded as having a strong edge in cacao production due to its strategic geographical location and favorable climate. The country's two million hectares of coconut farms, which are suitable for cacao cultivation alongside coconuts, further enhance its competitive position in the industry. Although the Philippines possesses a competitive edge, its current cacao production is limited to a range of 10,000 to 12,000 metric tons, despite having an estimated 20,000 to 25,000 hectares of cacao-planted land in the industry. This estimate surpasses the data from 2015 provided by the Philippine Statistical Authority, which reported only 13,910 hectares cultivating cacao and yielding a production of 6,020 metric tons. the Davao Region plays a significant role in the national cacao production, accounting for 80% of it, with 19,769 hectares of cacao-planted land in 2015, according to LGU data. The remaining 10% is split between the rest of Mindanao, Luzon, and Visayas.

1.1. Cacao Bean Composition

Cacao, recognized globally as the fundamental ingredient for making chocolate, is classified within the Magnoliopsida class, Malvales order, Malvaceae family, *Theobroma* genus, and bears the species name *Cacao*. It stands out as the primary fruit within its genus that is cultivated, primarily because of the significant value and importance attributed to its seeds [2]-3]. Within the cocoa production process aimed at making chocolate, a substantial quantity of plant-based waste is created. Three types of byproducts emerge, namely, the husks of cocoa pods, the shells of cocoa beans, and the cocoa mucilage [4-7]. [5], [6], [7].

Cacao beans (Figure 1a) [8] are the essence of the cacao tree's fruit; formed by the coat, kernel, and germ, from which kernel also called "nib" serves as the sole economically significant component of the tree due to their role as the primary source of chocolate and other cocoa-based products [9], and is obtained by subjecting the beans to a process comprising harvesting, fermentation, heat treatment, winnowing, and roasting [10]. It is mainly constituted of water and fat [3]. Each cacao bean comprises two cotyledons, commonly referred to as nibs (Figure 1b) obtained from cracking and winnowing either the dried or roasted cacao bean and a small embryo, all enveloped within a protective shell (Figure 1c). The cotyledons are composed of two distinct cell types: storage cells, rich in fat globules, protein, and starch granules, and pigmented cells, which contain polyphenols and methylxanthine, contributing to their optimal flavor profile [11]. A fresh nib has a bitter taste and lacks the characteristic flavors, aromas, or tastes associated with various cocoa products in its raw state [12]. The cacao shell (Figure 1c) is separated from the germ either before or after roasting, and the resulting broken cotyledon fragments, known as nibs, which are devoid of the shell, are employed in the production of chocolate [13-14]. The cocoa shell is typically seen as an industrial byproduct of cocoa manufacturing, often overlooked, or regarded as waste.



Figure 1. (a) Cacao Bean, (b) Cacao Shell, and (c) Cacao Nibs
Source: [8]

The chemical composition of the cacao beans differs according to the varieties. The following compositions ranges in percentages: Moisture content (5.12-6.63), lipids (36.81-45.50), cellulose (13.01-16.35), pigments (8.31-12.72), albumin (9.25-11.90), starch (3.81-6.37), glucose (0.42-2.76), sucrose (0.32-1.58), theobromine (0.85-1.16), and ash (3.31-8.73) [1].

1.2. Cacao Bean Hulling Process

Illustrated in Figure 2 is the processing of cocoa beans occurs in a two-part sequence, consisting of pre-processing and processing. The pre-processing stage encompasses activities performed in the field by the cocoa producer, which include harvesting, fruit opening, seed separation from the pulp, fermentation, bean drying, and storage. The typical industrial procedure comprises the second phase, which focuses on obtaining the key components to produce chocolate and its derivatives [13], [14-15].

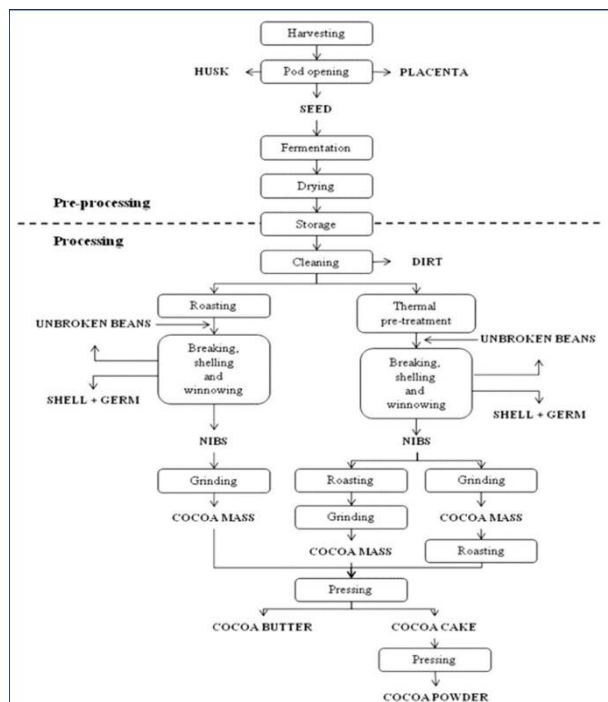


Figure 2. Cocoa bean processing and its byproducts and wastes
Source: [10]

Cacao beans are a fundamental component of the global chocolate industry, and their quality and processing efficiency play a crucial role in determining the final product's taste and economic viability. Cacao beans are surrounded by a protective husk, and the manual removal of this husk is a labor-intensive and time-consuming process that poses significant challenges to cacao farmers and processors.

The existing literature on cacao processing predominantly focuses on cultivation, fermentation, and drying, with limited emphasis on the development of cacao bean hullers. The main objective of this study is to develop a cacao bean huller and evaluate the performance of a hulling machine with the parameters of hulling efficiency, purity, and input capacity. In this study, the development of a cacao bean huller has the potential to revolutionize the cacao processing industry. It can significantly enhance the efficiency of cacao bean hulling, which is a critical stage in cocoa production. This study has the potential to benefit cacao farmer producers, the chocolate industry, and consumers, as well as contribute to the broader fields of agriculture and food technology.

2. MATERIALS AND METHODS

The cleaning of cocoa beans is a crucial stage in cocoa processing and typically encompasses methods like air separation, vibration, along with the use of various sieves and rotary magnets. Following this, the cocoa beans go through an additional processing step referred to as winnowing. Winnowing involves either pre-drying or subjecting the cocoa beans to heat treatment to facilitate the separation of shells from the cocoa nib. Subsequently, the cocoa beans are fragmented into sizable segments to disentangle the shells from the nibs. A technique called variable aspiration is frequently employed to achieve the highest possible removal of the shell while retaining the cocoa nibs [15].

The setup involving initial heat treatment followed by shell removal provides two significant benefits. Firstly, it causes water within the beans to evaporate, resulting in a puffing effect, and it enhances the shell's brittleness, making it simpler to remove later. Secondly, thermal pretreatment ensures a more uniform roasting process as the material undergoing the procedure becomes more consistent in size [13].

Beans are typically fragmented using a swing-hammer-type breaker that employs centrifugal force to strike the beans against an impact plate. The wheel's rotation, in combination with the processing capacity, dictates the particle size distribution for a given bean quality. This distribution should ideally be as uniform as possible to facilitate the efficient separation of the shell from the nibs. After the shell is broken, winnowing is used to separate the nibs, while unbroken beans are returned for further processing. In the winnowing process, the shattered beans are segregated into multiple fractions using sieves and an air classifier, or sifter classifier, to distinguish the shell from the nib particles. Each section (sifter) has its own optimal airflow, which is contingent on the size fraction it is processing [12-17]. [16], [17].

2.1. Preparation of Samples

Locally available dried and fermented cacao beans, specifically sourced from Davao City, were selected as samples for the testing and evaluation of the hulling machine. These beans were chosen due to their high quality and consistency, which are representative of the region's renowned cacao production.

To prepare the beans for hulling, a food-grade material was used to manually roast them for 30 to 35 minutes.

This process involved heating the beans, ensuring even roasting to enhance the flavor and texture. During roasting, the beans began to crack, a sign that they were reaching the optimal roast level. Another indicator that the samples are roasted is the color change of the beans, from light brown to a darkened shade.

2.2. Machine Design Criteria

Designing a cocoa bean huller machine using mechanical rollers involves several important criteria to ensure efficiency, effectiveness, and reliability. The performance requirements must be established, including the machine's capacity, typically measured in kilograms per hour, hulling efficiency to ensure a significant percentage of beans are hulled without damage, and the integrity of the beans to minimize breakage and maximize the quality of the cocoa nibs. The clearance of the roller design must be adjustable to give the option which the most appropriate hulling clearance is desirable during the operation. The feeding mechanism for consistent and even bean distribution to the rollers, along with adjustable roller spacing or clearance and pressure to handle different beans sizes and conditions. An integrated separation system through blowers is also necessary to segregate the hulls from the nibs effectively. Sufficient power of the prime mover (gear motor) to drive the roller under load conditions. The use of roller chain and sprockets will be essential for transferring reliable transmission components at very low speed and high torque. Safety and ergonomics of the machine to protect the operators and seamless in operation as well ease access during maintenance.

2.3. Operational Block Diagram

The operational block diagram is depicted in Figure 3, commencing with the loading of cacao beans into a hopper. The initial phase involves hulling, where the cacao beans undergo cracking and removal of the outer husk. Subsequently, the winnowing process separates the husks, designated as waste,

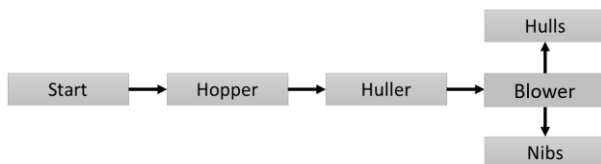


Figure 3. Operational Block Diagram

2.4. Machine Design Consideration

The design of the roller-type cacao huller machine involves some design considerations. Key mechanical components include rollers, ideally made of stainless steel or other corrosion-resistant metals. The frame must be durable to withstand operational stresses. The drive mechanism should be an electric motor at very low speed with the use of roller chains and sprockets as the transmission system. The hulling mechanism must feature adjustable roller gaps or clearance to handle different bean sizes, with an efficient feeding mechanism to ensure a steady flow of roasted cacao beans into the rollers. Safety considerations are the top mechanism for quick halting operations. Maintenance and durability aspects are included in the design for easy disassembly and cleaning.

Table 1. Materials used in fabrication

Materials	Quantity	Unit
G.I. Plain Sheet (16mmx4x8)	1	sheet
Pillow Block 205 (1")	2	pcs
Flange Bearing UCF-205 (1")	2	pcs
Cold Rolled Steel (CRS) (1")	1	15 in
G.I. Pipe (3")	1	18 in
Nuts and Bolts 3/8" x 1 1/2"	12	pcs
Plain Washer	12	pcs
Lock Washer	12	pcs
Electric Motor 3phase 0.75 hp	1	unit
Angle Bar (1 1/2")	2	length
Chain		pitch
Sprocket (21 & 24)	2	teeth
Variable Speed Blower	1	pc
Round Bar (6mm)	1	length
Set Screw	2	pcs
Contact	1	pc
Switch On/Off	1	pc

2.5. Cacao Hulling Machine Working Principle

The cacao hulling machine Figure 4 operates on a series of coordinated mechanical actions to efficiently separate the hull from the nibs of cocoa beans. The process begins with loading cocoa beans into a hopper, designed to hold a significant quantity and feed them steadily into the machine. Consistent feed rate regulation is crucial to prevent blockages and ensure smooth operation. The machine hulling comprises two rollers positioned parallel to each other with an adjustable gap. These rollers, often textured (groove) to enhance their grip, crack the beans through mechanical pressure and shearing action. Precise gap adjustment is essential to break the hull without too much crushing the nibs. Following the cracking process, the mixture of the hull and nibs undergoes separation through the blower. The cracked mixture is directed through a system where lighter hull fragments are blown away by air, while heavier nibs fall through the nib's outlet chute and are collected separately. Operators can adjust various machine parameters, such as the roller gap, feed rate, and airflow intensity, to optimize performance for different types and sizes of cocoa beans. Control systems are easily accessible to allow operators to adjust and allow fine-tuning for maximum hulling efficiency.

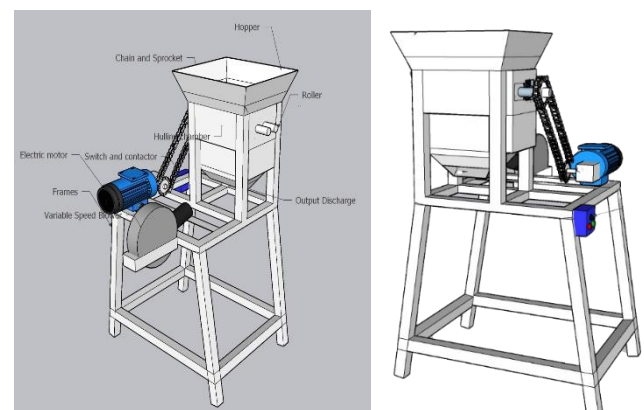


Figure 4. Cacao Bean Huller Design

2.6. Machine Testing

The machine was tested by adapting the standard testing protocols from Philippine Agricultural Engineering

Standards PAES 254:2018 Agricultural Machinery-Cacao Huller- Methods of Test. Prior to the conduct of the test, running-in and preliminary adjustments were done to ensure seamless operation during the final testing of the machine. The testing and evaluation protocols of a cacao huller using the methods of test in PAES 254 involve several steps. The cacao huller is operated at recommended settings for speed and feeding rate during the test run. The research team opted to utilize the available resources to test the machine. Thus, the maximum blower speed of 6 m/s was tested during the test. In addition, single roller clearance was used about 4 mm (about 0.16 in) wide between two rollers during the test. There were three test trials where each trial contained 1.18 kg of cacao beans samples. The duration of the test each test trial started from the feeding of the test materials into the hopper (first drop) and ends at the last drop of the test material into the hopper.

Samples are collected at different outlets during each test trial for evaluation. The performance of the machine is assessed based on its operation, ease of handling, safety features, and overall efficiency. The results of the tests, including the bean count and hulling efficiency, are reported following specific formulas outlined in the standard. A hand-held laser-contact tachometer was used to measure the motor speed, an air velocity meter was used to measure the blower, and a sound level meter was used to measure the noise level of the machine.

2.7. Laboratory Analysis

Laboratory analysis was done to determine the moisture content, purity, blower loss, bean count, input cacao nibs, and hulling efficiency. The moisture content of the roasted cacao beans was determined using the digital grain moisture meter of the Agricultural Machinery Testing and Evaluation Center (AMTEC UPLB). For blower loss determination, the three 100-g samples were taken from the shell outlet and cleaned manually by separating the mixed nibs and hulls. Similarly, another three 100-g samples of roasted cacao beans were manually hulled and weighed the nibs for the computation of the theoretical cacao nibs' input and recovery index. Finally, hulling efficiency was determined by manually separating the three 100-g samples of cacao nibs and unhulled beans collected at the nibs outlet. A digital weighing scale (0.01 g resolution), sample bags, aluminum cans, and labeling tags were used for the laboratory analysis.

2.8. Performance Evaluation

The performance test of the machine will follow the PAES Methods of Test for the huller. A minimum of three (3) test trials, with a duration of at least fifteen (15) minutes per trial, shall be adopted. The duration of each test trial shall start from the feeding of the test materials into the hopper (first drop) and end at the last drop of the test materials into the hopper. During the test, all operation data from input to output must be recorded for analysis. Table 1 shows the indicators for the performance evaluation of the machine.

Table 2. Performance Evaluation of the machine

Indicator	Description	Equation
Hulling Efficiency	The ratio of the weight of the cacao nibs collected at the cacao nib outlet/s to the weight of the unhulled beans and cacao nibs collected at the cacao nib outlet, expressed in percentage (%)	$E_h = \frac{W_{cn}}{W_{ub+cn}} \quad (1)$ where, E_h is the hulling efficiency. W_{cn} is the weight of cacao nibs collected at cacao nibs outlet/s (kg) W_{ub+cn} is the weight of unhulled beans and cacao nibs at cacao nibs outlet/s (kg)
	The amount of cacao nibs free from foreign matter to the total weight of uncleaned cacao nibs, expressed in percent (%)	$P = \frac{W_{cn}}{W_h} \quad (2)$ where, P is the purity (%) W_{cn} is the weight of cacao nibs (g) W_h is the weight of hull/testa (g)
Input Capacity	The weight of dry cacao or roasted cacao beans fed into the huller per unit time, expressed in kilogram per hour (kg/h)	$C_i = \frac{W_{rc}}{T_i} \quad (3)$ where, C_i is the input capacity (kg/h) W_{rc} is the weight of dry cacao or roasted cacao bean (kg) T_i is the input time (h)

3. RESULTS AND DISCUSSION

3.1. Machine Design and Working Principle

The cacao bean huller comprises the following main components: a cracking mechanism, a hulling chamber, and a blower. The cracking mechanism is a roller-type cracker. The hulls and nibs will be separated using a blower. The machine is powered by an electric gear motor. Figure 4 shows the actual machine design. The following components are the following: 1. hopper, 2. roller, 3. hulling chamber, 4. blower, 5. electric motor, 6. sprocket, 7. chain, 8. controller, 9. frames, and 10. nibs and hulls outlet.

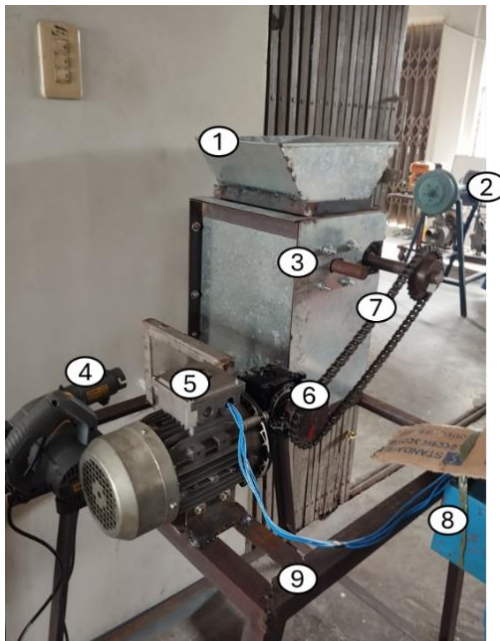


Figure 5. Cacao Huller Machine

3.2. Hulling Performance

Table 2 shows the performance test results of a cocoa huller machine, comparing various parameters against the Philippine Agricultural Engineering Standards (PAES) minimum requirements. The moisture content of the cocoa beans processed was relatively low at 2.37%, which is favorable for hulling efficiency. The machine's hulling efficiency was 91.83%. The purity of the hulled product is 96.31%. Regarding capacity, the machine processes cocoa beans at an input rate of 64.41 kg/hr.

Table 3. Performance test of the cacao huller machine

Parameters	Trial 1	Trial 2	Trial 3	Average
Moisture	2.7	2.2	2.2	2.37
Content				
Hulling	89.31	91.00	95.18	91.83
Efficiency				
Purity	93.88	97.58	97.48	96.31
Input	65.56	62.11	65.66	64.40
Capacity				

Table 4 shows the roller clearance, speed, and blower speed. Stated the actual design and the remarks and observations during the testing and analysis.

Table 4. Roller clearance, roller speed and blower speed

Component	Type	Actual Design	Remarks/ Observation
Roller Clearance, mm	Adjustable	2 to 5	•Varying from 2 mm to 5 mm. •Actual clearance applied is only 4 mm
Roller Speed, rpm	Fixed	320	•Applied roller speed is high
Blower speed, m/s	Variable Speed		•Blower can be change up to 5 variable speed. Single speed was applied during machine test at an

average of (6.24 m/s)

•Applied blower speed is high

4. CONCLUSION AND RECOMMENDATION

This project was developed to improve the efficiency and effectiveness of the cacao bean hulling process. The designed cacao huller machine is mainly composed of a roller-type cracker, a variable speed blower, and a prime mover of an electric motor. The hulling efficiency is 91.83%. A purity of 96.31% and an input capacity of 64.41 kg/hr. The motor's speed and blower capacity are 320 rpm and 6.24 m/s, respectively. Based on the performance and findings of the designed cacao hulling machine. The researchers highly recommend to conduct test optimization by applying the different roller clearance and blower speeds. Adjust the desired roller speed. An adjustable knob is necessary for ease in roller clearance adjustments. Add a cyclone separator or oscillating sieve bed for better separation of hulls and nib and use food-grade materials. It is also recommended to test the samples based on sizes of the beans.

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6. REFERENCES

- [1] A. Bertazzo, S. Comai, F. Mangiarini, and S. Chen, "Composition of cacao beans," in *Chocolate in Health and Nutrition*, Humana Press Inc., 2013, pp. 105–117. doi: 10.1007/978-1-61779-803-0_8.
- [2] X. Argout *et al.*, "The genome of *Theobroma cacao*," *Nat Genet*, vol. 43, no. 2, pp. 101–108, 2011, doi: 10.1038/ng.736.
- [3] J. E. Kongor, M. Hanneh, D. Van de Walle, E. O. Afoakwa, P. Boeckx, and K. Dewettinck, "Factors influencing quality variation in cocoa (*Theobroma cacao*) bean flavour profile — A review," *Food Research International*, vol. 82, pp. 44–52, Apr. 2016, doi: 10.1016/j.foodres.2016.01.012.
- [4] J. P. Balentic *et al.*, "Cocoa shell: A by-product with great potential for wide application," *Molecules*, vol. 23, no. 6. MDPI, 2018. doi: 10.3390/molecules23061404.
- [5] O. A. Lessa *et al.*, "New biodegradable film produced from cocoa shell nanofibrils containing bioactive compounds," *J Coat Technol Res*, vol. 18, no. 6, pp. 1613–1624, Nov. 2021, doi: 10.1007/s11998-021-00519-4.
- [6] F. Lu *et al.*, "Valorisation strategies for cocoa pod husk and its fractions," *Current Opinion in Green and Sustainable Chemistry*, vol. 14. Elsevier B.V., pp. 80–88, Dec. 01, 2018. doi: 10.1016/j.cogsc.2018.07.007.
- [7] R. Martínez, P. Torres, M. A. Meneses, J. G. Figueroa, J. A. Pérez-Álvarez, and M. Viuda-Martos, "Chemical, technological and in vitro antioxidant properties of cocoa (*Theobroma*

- cacao L.) co-products,” *Food Research International*, vol. 49, no. 1, pp. 39–45, Nov. 2012, doi: 10.1016/j.foodres.2012.08.005.
- [8] “PNS/BAFS PAES 253:2018,” 2018. [Online]. Available: www.bafs.da.gov.ph
- [9] Z. S. Vásquez *et al.*, “Biotechnological approaches for cocoa waste management: A review,” *Waste Management*, vol. 90. Elsevier Ltd, pp. 72–83, May 01, 2019. doi: 10.1016/j.wasman.2019.04.030.
- [10] D. C. G. Okiyama, S. L. B. Navarro, and C. E. C. Rodrigues, “Cocoa shell and its compounds: Applications in the food industry,” *Trends in Food Science and Technology*, vol. 63. Elsevier Ltd, pp. 103–112, May 01, 2017. doi: 10.1016/j.tifs.2017.03.007.
- [11] A. Caligiani, A. Marseglia, and G. Palla, “Cocoa: Production, Chemistry, and Use,” in *Encyclopedia of Food and Health*, Elsevier Inc., 2015, pp. 185–190. doi: 10.1016/B978-0-12-384947-2.00177-X.
- [12] K. P. P. Nair, “Cocoa (*Theobroma cacao* L.),” in *The Agronomy and Economy of Important Tree Crops of the Developing World*, Elsevier, 2010, pp. 131–180. doi: 10.1016/b978-0-12-384677-8.00005-9.
- [13] S. T. Beckett, *Industrial chocolate manufacture and use*, 4th ed. Wiley-Blackwell, 2009.
- [14] S. T. Beckett, *The science of chocolate*, Second. Cambridge: RSCPublishing, 2008.
- [15] R. Dand, *The international cocoa trade*. Woodhead Publishing, 1999.