International Journal on Advanced Science Engineering Information Technology

Vol.15 (2025) No. 3
ISSN: 2088-5334

Experimental Investigation of The Tempering Effects on Chocolate Made by Vietnamese Cocoa

Van Lanh Nguyen [a], The Cuong Nguyen [b,*], Huy Bich Nguyen [a], Duy Lam Pham [a], Nam Quyen Nguyen [a]

[a] *Faculty of Engineering and Technology, Nong Lam University, Ho Chi Minh, Viet Nam*
[b] *Center of Testing and Calibration Region 3, Thu Duc city, Ho Chi Minh, Viet Nam*
*Corresponding author: *cuongnt.tdc@gmail.com*

Abstract —**Developing processing technology with suitable machine systems is one of the targets of diversified agricultural export products and sustainable economic development. Cocoa processing requires suitable technology to produce high-quality cocoa powder and delicious chocolate products. In the chocolate-making process, tempering is one of the crucial technological factors that significantly affects the quality of chocolate, including its physical and mechanical properties and appearance. Experimental investigation of the effects of tempering on the properties and the appearance of chocolate made from Vietnamese cocoa beans is the objective of this study. Cocoa beans from different provinces in Vietnam, such as Ben Tre, Dak Lak, and Dong Nai, are used for experimental investigations. The tensile strength, hardness, and color uniformity of chocolate are investigated. The results indicate that the optimal tempering conditions for chocolate processing are heating at 45°C, followed by cooling at 26°C, and then reheating at 30°C. The highest lightness (L), the hardness, and the tensile strength of chocolate are equal to 41.37, 179.2 ± 5.02 N, and 32.8 ± 1.05 N, respectively, under these tempering conditions. In contrast, the results also show that increased tempering temperatures may lead to a reduction in hardness, with lower tensile strength, and less desirable surface characteristics. The results verify that the tempering temperature is the key factor influencing the chocolate process. The study's results may provide valuable insights for the Vietnamese chocolate industry to enhance its global competitiveness.**

Keywords—**Chocolate tempering; chocolate properties; cocoa butter crystallization; Vietnamese cocoa.**

Manuscript received 5 Dec. 2024; revised 7 Feb. 2025; accepted 6 Apr. 2025. Date of publication 30 Jun. 2025.

I. INTRODUCTION

Vietnam is a tropical country that has a suitable climate, soil, and humidity for cocoa cultivation, and might be growing as a cocoa-producing country [1]. Recently, it might be rising as a contributor to the global cocoa industry [2], [3]. According to the International Cocoa Council Organization (ICCO), the Vietnamese cocoa beans have been recognized as one of the highest-quality cocoa beans in the world and are also one of the few Asian countries on the list as the world's best-tasting cocoa producers [4], [5]. It received huge international recognition after it won the International Cocoa Awards in 2013 and 2019, and was classified as Fine or Flavor Cocoa by the ICCO in 2015 [6]. One of the products made from cocoa beans is chocolate, a globally valued confectionery product prized for its smooth texture, rich color, and distinctive snap. The quality characteristics of chocolate, such as gloss, taste, snap, texture, heat resistance, and bloom resistance, are primarily influenced by the cocoa post-harvest processes and the physical properties of cocoa beans [7], [8]. Chocolate processing is a process strongly connected to the crystallization and polymorphic behavior of material from liquid to solid, and stops at the fat phase [7]. This requires a step to be satisfactorily processed, named tempering, which is a technique of controlled crystallization and plays a key role in inducing the most fixed solid form of cocoa butter in the finished product [8].

In order to develop a good chocolate adapting the market requirements and well heat resistance in a tropical environment condition, it is need to develop the particular chocolate processing techniques in which tempering is very important factor [9], [10], [11]. Tempering directly influences to the bloom resistance, physical properties, and overall appearance of chocolate [12], [13], [14]. This process involves carefully controlled cooling and reheating to achieve the desired crystalline structure of cocoa butter, resulting in a product with enhanced quality and shelf stability [15], [16], [17]. The microstructure of chocolate is crucial in determining its physical and mechanical properties, including texture and snap. Studies have shown that proper tempering results in a stable crystalline form (Form V) of cocoa butter, which is essential for a high-quality product [18], [19]. Furthermore, mechanical properties, including hardness and tensile strength, are also influenced by tempering conditions [20]. Appearance, another key attribute, is often judged by gloss and color uniformity, which are significantly impacted by the tempering process [21], [22], [23].

In addition, environmental issues such as temperature fluctuations in Southern Vietnam can easily damage chocolate, leading to reduced snap, appearance, or convenience in its use. Recently, studies on optimizing chocolate production using Vietnamese cocoa, particularly in terms of tempering techniques, are scarce and remain open. Therefore, a study focusing on how tempering affects the quality characteristics of chocolate made from Vietnamese cocoa beans, with the environmental conditions of the tropical region, is essential and needs to be researched to maximize its local market potential and improve its global competitiveness [13], [14], [24].

The objective of this study is to conduct an experimental investigation into the effects of tempering on the physical, mechanical, and appealing properties of chocolate made from Vietnamese cocoa beans. By analyzing these aspects, the research seeks to provide insights that can enhance the quality of locally produced chocolate. Moreover, it contributes to the broader understanding of how tempering impacts chocolate production globally, particularly for cocoa beans from non-traditional regions [25], [26]. The findings could support Vietnam's growing cocoa industry by promoting value-added products and strengthening its position in the international market [27], [28].

II. Materials and Method

A. The Cocoa Beans and Cocoa Butter

The cocoa beans and butter used in this experiment are sourced from three major cocoa-growing provinces in Vietnam, including Ben Tre, Dak Lak, and Dong Nai. These regions are selected for their unique climatic conditions and soil characteristics, which contribute to the distinct flavor and quality of the cocoa beans. The cocoa beans are fermented, dried, and roasted according to standard practices outlined in the literature on cocoa processing.

The chocolate samples used in the experimental investigation are prepared according to a standardized formulation, which includes cocoa nibs at 35%, cocoa butter at 15%, and sugar at 50%, calculated as a percentage of the chocolate shown in Figure 1. The chocolate samples are prepared using conventional refining and conching techniques.

Fig. 1 Cocoa nibs, 2. Cocoa butter

B. Tempering Machine

To conduct an experimental investigation of chocolate tempering, a tempering machine with a capacity ranging from 10 to 20 kg of chocolate mass per pack has been designed and manufactured. The machine operates in three temperature regimes for tempering processing, with temperature control automatically maintained. Figure 2 is the tempering machine that has been designed, and Figure 3 is the one manufactured at Nong Lam University, Ho Chi Minh City, Vietnam.

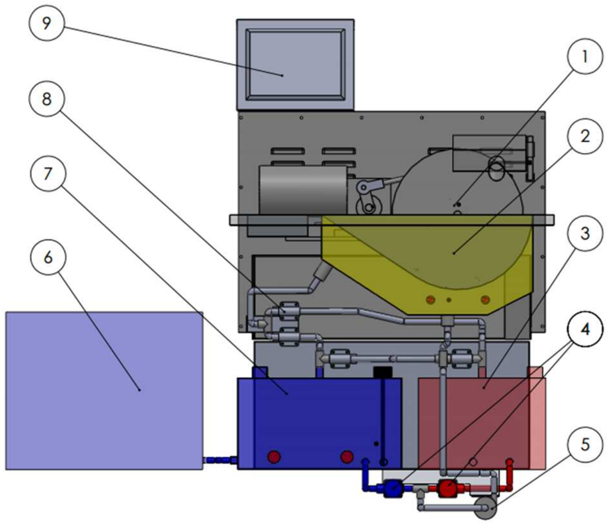

Fig. 2 The schematic of chocolate tempering machine designed

Notes:
1. Chocolate tank; 2. Tempering water tank; 3. Hot water tank; 4. Valve; 5. Water pump; 6. Chiller; 7. Cold water tank; 8. Valve; 9. Control panel.

Fig. 3 The chocolate tempering machine is manufactured

C. The Experimental Parameters of Tempering

Depending on the type of chocolate manufactured, the tempering process must ensure that the chocolate has the correct melting temperature of 32-34 °C to achieve the stable form V (or β2) of cocoa butter [29]. This must be done because cocoa butter, as a simple triacylglycerol composition, can crystallize in several polymorphic forms, each with a distinct melting point and crystal structure [7]. Typically, this process is divided into three stages. The first step is the heating process of the chocolate mass until it reaches a maximum temperature of 50°C, which melts the fat crystals completely. The chocolate is then cooled, and the temperature is reduced to approximately 27 °C in the second stage. In the final stage, chocolate is reheated to raise the temperature to 32 °C [7]. Following this standard requirement, the chocolate samples in this study are tempered at three different precrystallization temperatures. After conching, the chocolate mass is divided into three batches, each of which is assigned to one of three cases. Each case undergoes tempering with one of three different tempering regimes, as presented in Table 1.

TABLE I
THE TEMPERING REGIMES

	Heating up to (^{0}C)	Cooling up to (^{0}C)	Reheating up to (0C)
Case 1	45	26	30
Case 2	47	27	31
Case 3	50	28	32

D. Physical and Mechanical Properties Testing Method

Mechanical properties, such as hardness and tensile strength, are assessed using the Mechanical and Physical Properties Testing Machines (Model: Zwick/Roell Z1.0, Germany) at the Advanced Biochemical Lab, Faculty of Chemical Engineering and Food Technology, Nong Lam University, Ho Chi Minh City.

1) Hardness testing of chocolate: These characteristics measure the resistance of chocolate to deformation under compression, which is tested step-by-step as follows:

- Preparing chocolate samples: The samples are prepared to have a dimension of 100 mm × 50 mm × 5 mm in length, width, and height, respectively. All samples are stored at standard conditions with a temperature of 20°C and a relative humidity RH of 50% for consistency.
- Loading the sample: The chocolate sample is placed on the compression stage and aligned correctly in the indenter.
- Selecting test method: Use a cylinder with a 5 mm steel head.
- Setting test parameters: The compression force ranges from about 200 N, the speed is 0.5 mm/s, and the deformation depth is up to 50% of the sample thickness, equivalent to 2.5 mm.
- Running testing: Start the machine with an increased compressing force gradually until a failure of the sample occurs. Recording the maximum force (N) at failure.
- Analyzing results: Hardness is determined by the force-displacement curve, and the results are compared with standard values for different chocolate types.
- Each sample is tested three times to ensure consistency.

2) Tensile strength testing of chocolate: The resistance of chocolate to break under tension is evaluated by tensile strength. It is calculated through a three-point bending test with some steps as follows:

- Preparing chocolate samples: it is done similarly to the sample hardness testing above.
- Loading the sample: locating the sample in tensile grips and ensuring proper alignment.
- Setting test parameters: running the machine at a speed of 0.5 mm/s, loading cell is 200 N, and gauge length is 10 mm.
- Running the test: Start the machine by pulling the chocolate until it fractures and record the maximum force (N).
- Analyzing results: Tensile strength is the maximum force (N), and determines brittleness and ductility by analyzing the stress-strain curve.
- Each sample is tested three times to ensure consistency.

E. Appearance Evaluation Method

The appearance of chocolate samples is mainly evaluated by color uniformity. The color of the chocolate is evaluated by using a chromameter (Konica Minolta CR-400, which is equipped at the Faculty of Chemical Engineering and Food Technology, Nong Lam University, Ho Chi Minh City). The System of Commission Internationale de l'Eclairage (CIE) L* a* b* is used [30].

- L* indicates lightness level, ranging from 0 (black) to 100 (white), which means a low number (0-50) indicates dark, and a high number (51-100) indicates light.
- a* indicates the level of green to red, where a positive number indicates red, and a negative number indicates green, and
- b * indicates the level of blue to yellow, where a positive number indicates yellow, and a negative number indicates blue.
- ΔL* (L* sample minus L* standard) = difference in lightness and darkness (+ = lighter, – = darker).
- Δa* (a* sample minus a* standard) = difference in red and green (+ = redder, – = greener)
- Δb* (b* sample minus b* standard) = difference in yellow and blue (+ = yellower, – = bluer)
- ΔL*, Δa*, and Δb* may be positive (+) or negative (-).
- The total color difference ΔE* is counted by the formula:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (1)$$

Therefore, it is always positive. Measurements are performed in triplicate. The color evaluation steps are as follows:

- Ensure the Konica Minolta CR-400 colorimeter is fully charged or connected to a power source for proper operation, and verify the accessories, including the white calibration plate. Cleaning the measurement surface of the device and the experimental samples to avoid interfering with the results.
- Calibration: Turn on the device and boot it completely. Attach the white calibration plate to the measuring head. Perform calibration following the on-screen instructions or the user manual. Calibration ensures high measurement accuracy.

- Setting Measurement Mode*:* Choose the *required* color space (Product Development Pilot Plant). Set the average mode to calculate the average value of 9 times of measuring for each sample.
- Measuring color for each experimental sample: Repeat the following steps for each experimental sample (case 1, 2, and 3). Taking 9 measurements for each sample.
- Position the device on the sample: Place the measuring head firmly against the sample surface to ensure there are no gaps or slopes. Ensure the sample is evenly illuminated and not affected by ambient light.
- Performing the measurement: Press the MEASURE button on the device to take a measurement. Repeat this process 9 times for each sample.
- After each measurement, the device displays the color values on the screen (L*, a*, b*, ΔL*, Δa*, and Δb*) and then calculates the ΔE* using the Excel program.
- Recording the measurement values
- Measuring other samples: repeating the same steps for the second and third samples.

III. Results and discussion

A. Mechanical Properties

The experimental investigation results for the hardness and tensile strength of chocolate tempered at different regimes, designated as Case 1, Case 2, and Case 3, are presented in Figs. 4–7. Each chocolate sample is tested three times.

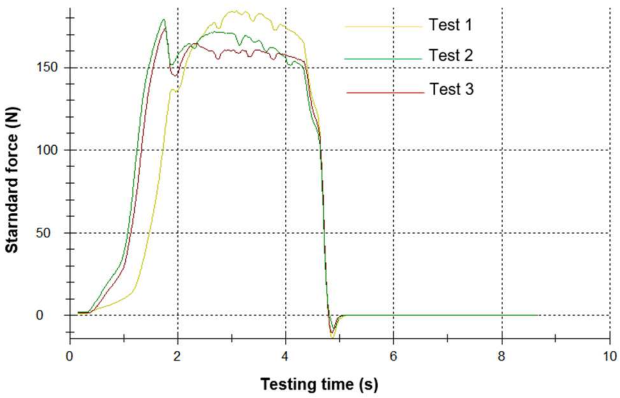

Fig. 4 The hardness of the chocolate tempered in case 1.

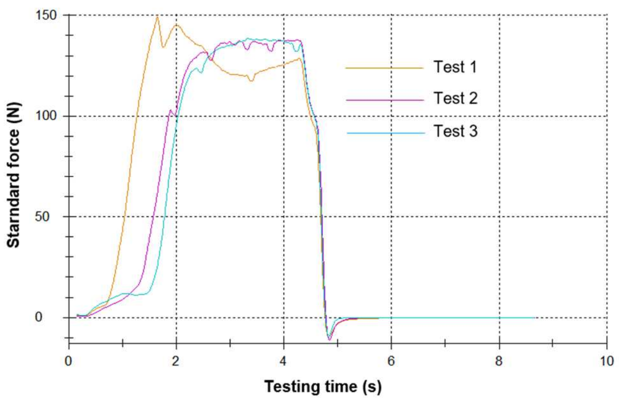

Fig. 5 The hardness of the chocolate tempered in case 2.

The hardness of the chocolate tempered in cases 1, 2, and 3 is shown in Figs. 4, 5, and 6, respectively. It can be seen that the highest hardness values for cases 1, 2, and 3 are 179.2 ± 5.02 N, 142.5 ± 6.08 N, and 131.7 ± 8.19 N, respectively. The results indicate that the hardness of tempered chocolate decreases from Case 1 to Case 3. In Case 1, the chocolate exhibits a well-formed crystalline structure, resulting in minimal voids and more efficient molecular packing, which contributes to higher hardness and better texture. In Case 2, the structure is less stable, likely due to the presence of mixed crystalline forms, including unstable Form IV crystals. In Case 3, the chocolate exhibits a disordered crystalline structure with a high proportion of amorphous regions, resulting in reduced hardness and inferior texture, as confirmed by microstructural analysis.

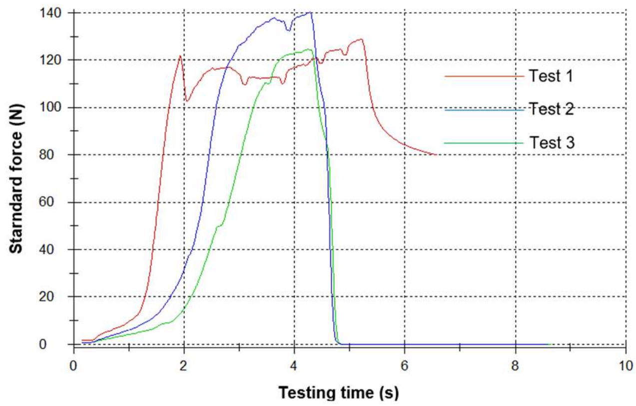

Fig. 6 The hardness of the chocolate tempered in case 3.

The findings could support Vietnam's growing cocoa industry by promoting value-added products and strengthening its position in the international market. To achieve optimal hardness and a smooth, glossy finish, producers should adopt tempering conditions similar to those in Case 1. Specifically, controlling temperature precisely during the tempering process is crucial to promoting the formation of stable Form V crystals while avoiding unstable or amorphous structures. By optimizing tempering protocols based on these insights, householders can enhance the sensory qualities and market value of their chocolate products.

Figure 7 presents the tensile strength of the tempered chocolate at different regimes, named Case 1, 2, and 3, with the values of this parameter being 32.8 ± 1.05 N, 22.5 ± 2.04 N, and 18.2 ± 2.07 N, respectively. Similar to the hardness, the results remain the same as the decrease from case 1 to case 3. The sample of case 1 exhibits the highest tensile strength, followed by a reduction in case 2, and is finally the lowest in case 3. The results indicate that the regimes of tempering play an essential role in the tempering stage of chocolate production.

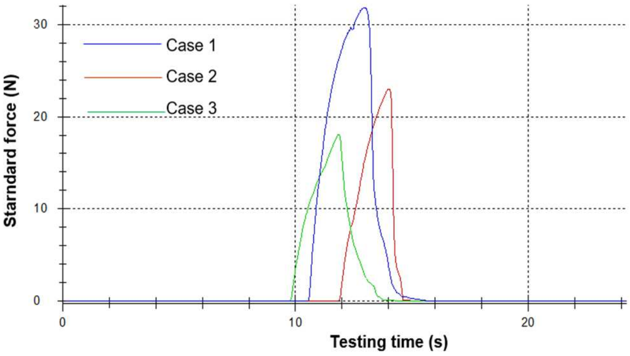

Fig. 7 Tensile strength of tempered chocolate in cases 1, 2, and 3

B. *Chocolate Appearance*

The appearance of the chocolate is primarily assessed by the uniformity of color at the fat phase. Due to the limitations of measurement devices, the gloss of chocolate has not yet been evaluated and is not shown. Figure 8 illustrates the pictures of chocolate tempered at different regimes, as cases 1, 2, and 3.

The indicators of chocolate color following the CIE system, as L*, a*, and b*, and their differences Δ, L*, Δa*, and Δb*, of the three cases are measured and presented in Table 2. The mean and standard deviation for each sample are also calculated and presented.

a. Sample 1 (case 1)

b. Sample 2 (case 2)

c. Sample 3 (case 3)

Fig. 8 The tempered chocolate samples in three cases.

The results in Fig. 8 and Table 2 indicate that the color values following the CIE system, with an average lightness (L*) of the chocolate tempered in cases 1, 2, and 3, are 41.37, 39.98, and 38.75, respectively. Similarly, they are 6.36, 6.06, and 6.09 for the level of green to red (a*), and 4.06, 3.68, and 3.67 for the level of blue to yellow (b*). The lightness of chocolate in case 1 has the highest value, tending to a redder and yellower color. This might be beneficial for the appearance of chocolate, as it is adaptable to market requirements.

The differences ΔL*, Δa*, and Δb* also show that the ΔL* of case 1 has a higher value compared to that of cases 2 and 3. Moreover, the Δa* and Δb* values for the three cases do not show a significant difference; case 1 exhibits a slightly larger change. This confirms that there is a greater lightness difference and clearer colors in case 1, with a tendency towards red and yellow compared to other cases. The differences in lightness among samples in the three cases are remarkable.

TABLE II
COLOR UNIFORMITY OF TEMPERED CHOCOLATE

Sample (case)	L*		a*		b*	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**
1	41.37	0.54	6.36	0.38	4.06	0.42
2	39.98	0.43	6.06	0.27	3.68	0.30
3	38.75	0.27	6.09	0.79	3.67	0.37
Sample (case)	**ΔL***		**Δa***		**Δb***	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**
1	-10.88	0.56	6.78	0.38	-5.34	0.42
2	-12.25	0.43	6.49	0.27	-5.71	0.30
3	-13.47	0.27	6.29	0.27	-5.72	0.36

The analysis of ΔE* for three cases may reveal insights into total color difference and help identify its influencing factors on chocolate color, such as lightness (L*), chromaticity (a*, b*), and their respective deviations (ΔL*, Δa*, Δb*). The total color difference ΔE* of the three cases is presented in Figure 9. It demonstrates that the highest lightness (L* = 41.37) and the lowest total color difference (ΔE* = 13.90) are observed in case 1. This implies that the higher lightness corresponds to the lower total color difference. This case also exhibits moderate stability, with a standard deviation (Std ΔE*) of 0.48, indicating minor fluctuations in color across measurements. Similarly, the total color difference of case 2 and case 3 is higher than that of case 1, at 15.00 and 15.94, respectively. This reconfirms that high lightness has low total color differences.

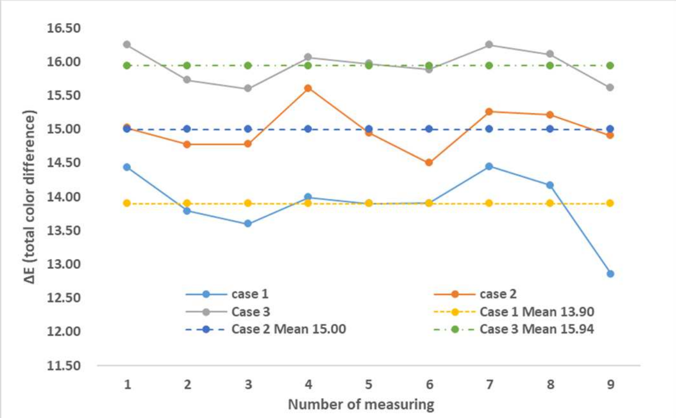

Fig. 9 The total color difference ΔE* in three cases

The results indicate that the lower lightness contributes to higher total color difference, while the stability of ΔE* depends on variations in chromaticity. Case 3 exhibits a significant difference in total color, necessitating process control improvements to minimize deviations. Case 1 exhibits satisfactory characteristics in terms of maintaining color uniformity. Adjustments in material selection and production conditions might also optimize the color consistency across the three cases.

IV. Conclusion

The effects of tempering conditions on the physical, mechanical properties, and appearance of chocolate made from Vietnamese cocoa have been experimentally investigated. Some of the key qualities of tempered chocolate, including its crystalline structure, hardness, tensile strength, and total color difference, are presented. The well-formed β(V) crystal structure of chocolate with the highest hardness is 179.2 ± 5.02 N, the tensile strength is 32.8 ± 1.05 N, and the highest lightness is 41.37. The lowest total color difference is 13.90, which was found through experimental investigation under the tempering regimes of heating temperatures up to 450 °C, cooling temperatures up to 260 °C, and reheating temperatures up to 300 °C. The reheating temperature of up to 30°C is found to be the highest in the tempering process. It is also found that when the tempering temperature exceeds the one mentioned above, incomplete crystal formation leads to duller surfaces, and the total color difference increases. The higher lightness leads to a lower total color difference that depends on variations in chromaticity. Regime parameters of tempering play a crucial role and must be controlled strictly to achieve stable β(V) crystal formation. The microstructure and gloss of tempered chocolate require further investigation using microscopic analysis and gloss measurement devices to ensure more accurate tempering regimes.

Acknowledgement

We sincerely express our gratitude to the Vietnam Ministry of Education and Training for providing funding support for this study under the project code B2023-NLS-01. We would also like to appreciate Nong Lam University, Ho Chi Minh City, Vietnam, for providing essential facilities and our colleagues for their assistance during the conduct of this project.

References

[1] H. Everaert et al., "Molecular characterization of Vietnamese cocoa genotypes (Theobroma cacao L.) using microsatellite markers," *Tree Genet. Genomes*, vol. 13, no. 5, 2017, doi: 10.1007/s11295-017-1180-6.

[2] H. B. Nguyen, D. L. Pham, and V. L. Nguyen, "A study on the breaking and winnowing machine for cocoa beans at small industrial scale in Vietnam," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 9, no. 1, pp. 329-335, 2019, doi: 10.18517/ijaseit.9.1.7765.

[3] F. Goletti, *Study on Suitability, Feasibility, and Socioeconomic Benefits of Cocoa Production in Viet Nam*, Nov. 2008.

[4] A. J. Daymond et al., *A Global Review of Cocoa Farming Systems*, Int. Cocoa Organ. Swiss Found. Cocoa Choc. Econ., 2022.

[5] International Cocoa Organization, "ICCO panel recognizes 23 countries as fine and flavour cocoa exporters." [Online]. Available: https://www.icco.org/icco-panel-recognizes-23-countries-as-fine-and-flavour-cocoa-exporters/.

[6] Vietnam Investment Review, "Excellent cocoa beans originating from Vietnam," Oct. 13, 2022. [Online]. Available: https://vir.com.vn/excellent-cocoa-beans-originating-from-vietnam-97092.html.

[7] S. T. Beckett, *Industrial Chocolate Manufacture and Use*, 4th ed., 2009, doi: 10.1002/9781444301588.

[8] A. Torbica, B. Pajin, and R. Omorjan, "Influence of soft cocoa butter equivalents on color and other physical attributes of chocolate," *J. Am. Oil Chem. Soc.*, vol. 88, no. 7, pp. 937-947, 2011, doi:10.1007/s11746-011-1763-6.

[9] D. Bikos et al., "A micromechanical based finite element model approach to accurately predict the effective thermal properties of micro-aerated chocolate," *Innov. Food Sci. Emerg. Technol.*, vol. 83, p. 103227, 2023, doi: 10.1016/j.ifset.2022.103227.

[10] M. Mokbul, Y. L. Cheow, and L. F. Siow, "Physical properties, sensory profile and storage stability of compound chocolates made with cocoa butter replacer consisting of mango kernel fat and rice bran oil," *Food Chem. Adv.*, vol. 3, p. 100515, 2023, doi:10.1016/j.focha.2023.100515.

[11] V. Abe-Inge et al., "Physico-chemical and chemometric analysis of milk chocolate sold in Ghana using NIR spectroscopy," *Futur. Foods*, vol. 10, p. 100427, 2024, doi: 10.1016/j.fufo.2024.100427.

[12] G. S. Silva et al., "Bioaccessibility of bioactive amines in dark chocolates made with different proportions of under-fermented and fermented cocoa beans," *Food Chem.*, vol. 404, p. 134725, 2023, doi:10.1016/j.foodchem.2022.134725.

[13] Y. Guckenbiehl et al., "Conching of dark chocolate - Processing impacts on aroma-active volatiles and viscosity of plastic masses," *Curr. Res. Food Sci.*, vol. 9, p. 100909, 2024, doi:10.1016/j.crfs.2024.100909.

[14] S. Schroeder et al., "Influence of PET as single-use contact material on gloss and surface properties of chocolate," *Food Struct.*, vol. 40, p. 100375, 2024, doi: 10.1016/j.foostr.2024.100375.

[15] E. O. Afoakwa, A. Paterson, M. Fowler, and J. Vieira, "Influence of tempering and fat crystallization behaviours on microstructural and melting properties in dark chocolate systems," *Food Res. Int.*, vol. 42, no. 1, pp. 200-209, 2009, doi: 10.1016/j.foodres.2008.10.007.

[16] H. R. Pirouzian et al., "Pre-crystallization process in chocolate: Mechanism, importance and novel aspects," *Food Chem.*, vol. 321, p. 126718, 2020, doi: 10.1016/j.foodchem.2020.126718.

[17] P. T. de S. Silveira et al., "Influence of variety and harvest on the sensory characteristics of chocolate made from cocoa fermented with different pulp contents," *LWT*, vol. 210, 2024, doi:10.1016/j.lwt.2024.116768.

[18] E. O. Afoakwa, A. Paterson, M. Fowler, and J. Vieira, "Modelling tempering behaviour of dark chocolates from varying particle size distribution and fat content using response surface methodology," *Innov. Food Sci. Emerg. Technol.*, vol. 9, no. 4, pp. 527-533, 2008, doi: 10.1016/j.ifset.2008.02.002.

[19] J. Cheragheshahi et al., "Optimization of dark chocolate formulation with roasted coriander cake as cocoa substitute," *Food Chem. X*, vol. 25, p. 102166, 2025, doi: 10.1016/j.fochx.2025.102166.

[20] G. Califano and C. Spence, "Consumer preference and willingness to pay for 3D-printed chocolates: A discrete choice experiment," *Futur. Foods*, vol. 9, p. 100378, 2024, doi: 10.1016/j.fufo.2024.100378.

[21] S. Schroeder et al., "Influencing chocolate gloss inhomogeneities by the choice of surface-active substance and contact material," *Food Struct.*, vol. 40, p. 100373, 2024, doi: 10.1016/j.foostr.2024.100373.

[22] F. Debaste et al., "Contribution to the modelling of chocolate tempering process," *J. Food Eng.*, vol. 88, no. 4, pp. 568-575, 2008, doi: 10.1016/j.jfoodeng.2008.03.019.

[23] E. M. Castro-Alayo et al., "Effect of tempering and cocoa butter equivalents on crystallization kinetics, polymorphism, melting, and physical properties of dark chocolates," *LWT*, vol. 173, 2023, doi:10.1016/j.lwt.2022.114402.

[24] T. V. P. H. T. A. Ngoc et al., "A study on tempering of chocolate processing in Viet Nam," in *Proc. 9th Int. Conf. Appl. New Technol. Green Build.*, 2024, pp. 150-155.

[25] I. Quintero et al., "Dry cacao pulp in chocolate bars: A sustainable, nutrient-rich sweetener with enhanced sensory quality through refractance windows drying," *Appl. Food Res.*, vol. 5, no. 1, 2025, doi:10.1016/j.afres.2025.100700.

[26] A. Astuti et al., "The optimization of cocoa processing on small and medium enterprises in South Sulawesi," *AIP Conf. Proc.*, vol. 2957, no. 1, 2024, doi: 10.1063/5.0183918.

[27] C. Marchioretto et al., "Nutritional value and acceptability of chocolate with high cocoa content and green banana biomass," *LWT*, vol. 191, 2024, doi: 10.1016/j.lwt.2023.115667.

[28] V. Abe-Inge et al., "Assessment of chocolate retail in Ghana and willingness to use cooling devices," *Heliyon*, vol. 10, no. 17, p. e36961, 2024, doi: 10.1016/j.heliyon.2024.e36961.

[29] J. Kurniasari et al., "The use of oven as a device to temper molten dark chocolate," *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 355, no. 1, 2019, doi: 10.1088/1755-1315/355/1/012042.

[30] Konica Minolta, "Chroma meter CR-400/410," 2013. [Online]. Available: https://www.konicaminolta.com/instruments/download/instruction_manual/color/pdf/cr-400-410_instruction_eng.pdf.