Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter reviews the previous research works carried out by research workers, scientists and students. Reviews related to cocoa production, unit operations of chocolate production, preparation of compound chocolate, chocolate enrobing process and machinery involved for enrobing process are included in this chapter.

2.1 COCOA PRODUCTION

2.1.1. Cocoa

The cocoa tree (*Theobroma cacao L.*) is native to the tropical regions of South America. It can grow up to 12 meters in height and starts producing fruit after about five years, reaching its full yield in approximately ten years. The fruit, known as a pod or cabosside, contains 30 to 40 seeds, referred as cocoa beans. Along with the plant variety, factors such as soil composition, temperature, sunlight and rainfall influence the flavour of cocoa beans (Verna, 2013).

Cocoa plants respond well to relatively high temperatures, ranging from an annual average maximum of 30–32°C to a minimum average of 18–21°C. They also require consistently high relative humidity, often reaching up to 100% during the day and dropping to 70–80% at night. The ideal soil for cocoa cultivation is forest soil rich in humus, which facilitates root penetration, retains moisture during summer and allows proper air and moisture circulation. The depth of the soil should be at least 1.5m. Cocoa grows well in soils with a pH range of 6–7.5, ensuring the availability of essential nutrients and trace elements (DCCD, 2022).

2.1.2. Cocoa background

The history of chocolate began with the Maya, who were the first people in South America to cultivate the cocoa plant. For the Maya, chocolate was a drink made from cocoa, mixed with hot water and often flavoured with cinnamon and pepper. They referred to it as the "Food of the Gods." In 1502, Christopher Columbus became the first European to encounter cocoa. He seized a vessel carrying cocoa beans, which were described as "mysterious-looking almonds" and were used as currency in Mesoamerica. Cocoa was introduced to Europe in 1528 when Spanish conquistador Hernán Cortés brought cocoa samples to King Charles of Spain and popularized the beverage made from this 'brown gold.'" In 1753, Swedish scientist Carl Linnaeus officially named the cocoa plant *Theobroma cacao*, derived from the Latin word *Theobroma*, meaning "food of the Gods." The tree was likely domesticated in the upper Amazon region and then spread northward. Over 3,000 years ago, it was widely grown by the Maya, Toltec and Aztec civilizations. These cultures not only used cocoa beans to prepare beverages (sometimes for ceremonial purposes) but also as a form of currency (Montagna *et al*., 2019). Cocoa was introduced to India in the early 20th century (DCCD, 2022).

2.1.3. Nutritional composition of cocoa

The main ingredient in chocolate, which is cocoa, contains a substantial amount of fat (40–50% cocoa butter, with approximately 33% oleic acid, 25% palmitic acid and 33% stearic acid). It also contains polyphenols, which constitute about 10% of the dry weight of a whole cocoa bean. Cocoa beans are among the top sources of dietary polyphenols, offering more phenolic antioxidants than most other foods. The polyphenols/flavonoids in cocoa can be categorized into three main groups: catechins (37%), anthocyanidins (4%) and proanthocyanidins (58%). Cocoa also contains nitrogenous compounds, including proteins and methylxanthines (theobromine and caffeine). Additionally, cocoa is rich in essential minerals such as potassium, phosphorus, copper, iron, zinc and magnesium (Montagna *et al*., 2019). The nutritional values of cocoa is tabulated Table 2.1.

Table 2.1. Nutritional values per 100 g of cocoa (Source : Montagna *et al*., 2019)

Chemical Composition	Cocoa
Water (g)	2.5
Protein (g)	20.4
Lipid (g)	25.6
Cholesterol(mg)	0
Carbohydrate (g)	11.5
Sugar (g)	Traces
Iron(mg)	14.3
Calcium(mg)	51
Phosphorus (mg)	685
Thiamin (mg)	0.08
Riboflavin (mg)	0.3
Niacin (mg)	1.7
Vitamin A (µg)	7
Phenolics (mg)	996 – 3781
Energy(kcal)	355
Energy(kJ)	1486

2.2. UNIT OPERATIONS IN CHOCOLATE PRODUCTION

The production of chocolate involves a comprehensive post-harvest process, which includes the fermentation, drying, roasting and grinding of cocoa beans, followed by mixing of ingredients, conching and tempering (Barišić *et al*., 2019). A schematic diagram of the chocolate making process is presented in Fig. 2.1.

2.2.1. Harvesting and pod breaking

Cocoa pods are generally harvested, when their colour changes from green to yellow or orange. In West Africa, harvesting is usually done in the last quarter of the year. The pods are broken using machete, uncovering a cluster of beans, typically 30 to

40 seeds, covered with white slime. Before being fermented and dried, the beans are separated from the pulp (Talbot, 2012).

The development of the cocoa pod takes 5 to 6 months, from fertilization of the flower to full ripening. Harvesting involves removing the ripe pods from the trees and opening them to extract the beans. Only ripe pods should be harvested, ensuring that the flower cushions are not damaged, which is done by cutting the stalk with a knife. Harvesting is usually performed at regular intervals of 10 to 15 days (DCCD, 2022).

2.2.2. Fermentation

Cocoa beans are usually fermented by naturally occurring microorganisms over a period of 4 to 7 days, reaching temperatures of up to 50ºC and a pH below 4. During fermentation, enzymes produced by the beans contribute to the formation of flavour precursors and the breakdown of pigments (Hansen *et al.*, 1998). Fermented cocoa beans are abundant in free amino acids and metabolites that result from microbial peptidase activity during the process (Ardhana and Fleet, 2003 ; Rohsius *et al.*, 2006).

The ripe pods are cut from the trees and split open using machetes. The beans, along with their surrounding pulp are gathered into heaps, covered with leaves and placed in holes lined with leaves in the ground or stored in shallow boxes with perforated bottoms to facilitate proper drainage of mucilage. Frequent turning of the beans helps to release excess heat and ensures the fermentation process is consistent. During fermentation, the juicy sweating of the pulp are drained away, the germ in the seed is killed by the increased heat and flavour development begins. The beans swell, becoming moist and their interior changes to a reddish-brown colour, accompanied by a strong, sharp aroma. During fermentation, the precursors of cocoa flavour are formed, including methylxanthines, which add bitterness and flavonoids, which provide both colour and astringency (Talbot, 2012).

2.2.3. Drying

After fermentation, drying process is essential for reducing bitterness and astringency (Jinap *et al.*, 1994). The beans are dried to a moisture content of 6 to 8% (wb) (Nair, 2010). Dried cocoa beans are less acidic due to the migration of volatile acids and the biochemical oxidation of acetic acid (Kongor *et al.*, 2016).

2.2.4. Alkalization

The alkalization method, introduced by the Dutchman van Houten in 1928, is commonly referred to as the Dutch process. Cocoa beans, cocoa nibs or cocoa liquor (product after grinding of cocoa nibs) treated in this way are described as alkalized or Dutched. The process involves treating the cocoa nibs with an alkali solution, such as potassium or sodium carbonate, to raise the pH from 5.2–5.6 to a more neutral range of 6.8–7.5, depending on the specific alkali and desired outcome. This treatment primarily aims to alter the colour and flavour of cocoa powder or liquor, as well as enhance the dispersion or suspension of cocoa solids in water. During the process, the alkali solution is sprayed into a drum containing the nibs, which are then gently dried at temperatures below 100°C (Awua, 2002).

Alkalization is applied to the cocoa beans, cocoa liquor or cocoa powder to obtain the desirable dark brown colour, reduce bitterness and astringency and prevent the sinking of cocoa powder in cocoa-based drinks (Miller *et al.*, 2008). To alkalize the dried fermented cocoa beans, one kilogram of beans was immersed in one litre of water mixed with ten grams of sodium bicarbonate ($NaHCO_3$) for three hours. The beans were stirred every 30 minutes during this time. The water was drained and the beans were allowed to dry. This alkalization method has been standardized by Kerala Agricultural University (Amma *et al.*, 2009). A high degree of alkalization was applied to 25 g of cocoa powder, using 20 ml of a 3% NaOH solution under a pressure of 0.1 MPa for 30 minutes. After the alkalization process, the cocoa powder was dried in a vacuum oven at 40°C for 12 hours, passed through a 60-mesh sieve (Li *et al.*, 2012).

Roasting the nibs, particularly after alkalization, enhances the quality of the cocoa powder. The level of alkalization, the mildness and darkness of the cocoa, is influenced by factors such as the concentration of the alkali solution, type of alkali used, duration of the reaction and the processing temperature. Alkalization also impacts the concentrations of polyphenols, theobromine, caffeine, amino acids and volatile compounds, which in turn affect the distinct flavour and colour of the final products (Li *et al.*, 2014).

2.2.5. Roasting

The evaporation of volatile acids further decreases the sourness and bitterness of the cocoa beans (Kongor *et al.*, 2016). During roasting, which typically lasts between 10 to 35 minutes at temperatures ranging from 120°C to 140°C, various compounds are formed as the precursors from previous phases react. This process reduces the levels of undesirable components and leads to the development of the distinctive aroma and flavour associated with chocolate (Barišić *et al.*, 2019).

2.2.6. Shelling and winnowing

The cocoa beans are normally broken, following roasting of the intact cocoa beans. The shelling process is typically performed using a shelling machine. The combination of cocoa nibs along with shells obtained as an output. To separate out shells from cocoa nibs, winnowing operation to be performed (Shahama *et al.*, 2023)

2.2.7. Cocoa butter extraction

Cocoa beans generally contain approximately 54% cocoa butter (Minifie, 1999). The typical process involves several stages, including cleaning, alkalizing, roasting, shelling and winnowing the beans, followed by grinding the nibs into a smooth paste known as cocoa liquor before pressing. Mechanical pressing is usually done using a hydraulic or screw press to defat cocoa beans. Cocoa butter constitutes about half of the weight of the cocoa nib. This fat is partially extracted from the cocoa liquor (product after grinding of cocoa nibs) using a hydraulic press, which applies pressures up to 520 kg/cm^2, with larger presses handling up to 113.4 kg per cycle. Depending on the pressing time and settings of the press, the resulting cake can have a fat content ranging from 10 to 24% (Afoakwa, 2016).

2.2.8. Refining

The process aims to reduce the size of cocoa mass particles. For dark chocolate, the target particle size after refining is usually under 35 μm, this can vary depending on the product and its composition (Awua, 2002). During the refining process, cocoa nibs, sugars and other ingredients are crushed and sheared, producing a smooth, fluid paste with particles typically smaller than 30 μm (Sonwai and Rousseau, 2008). Both refining and conching play a crucial role in determining the quality of the final chocolate product (Saltini *et al*., 2013).

2.2.9. Conching

Conching is a critical step in chocolate production, involving the mixing, shearing and aeration of the chocolate mass at high temperatures (above 40°C). After refining, the mixture undergoes conching, which helps to develop its viscosity, texture and flavour. To achieve the desired viscosity, additional cocoa butter and lecithin may be added towards the end of the process, making the chocolate easier to temper (Beckett, 2000). In the early stages moisture is reduced with removal of certain undesirable flavour-active volatiles and subsequently interactions between disperse and continuous phase are promoted. Conching times and temperatures vary: for milk crumb, it typically lasts 10 to 16 hours at 49–52ºC; for milk powder products, 16–24 hours at up to 60ºC; and for dark chocolate, temperatures range from 70 to 82ºC. If full-fat milk powder is replaced with skim milk powder and butter fat, conching temperatures can reach up to 70ºC (Awua, 2002).

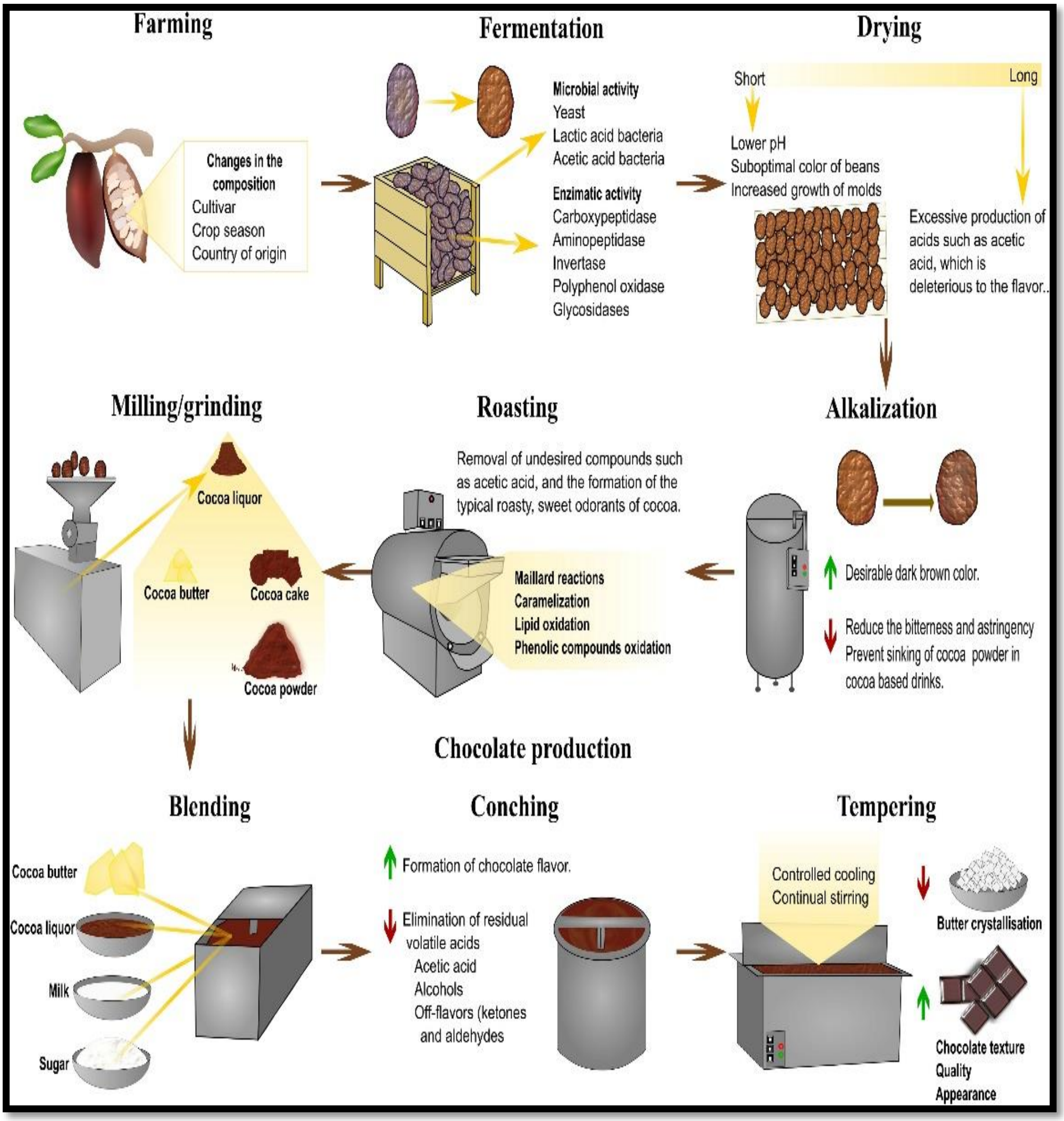


Fig. 2.1. Schematic diagram of chocolate making process

2.2.10. Tempering

Tempering is a process that involves pre-crystallization of small percentage of triglycerides, which form nuclei (1-3%) for the remaining lipids to solidify in the correct form. Tempering has four key steps as shown in Fig. 2.2: melting to completion at 50ºC, cooling to point of crystallization at 32ºC, crystallization at 27ºC and conversion of any unstable crystals at 29- 31ºC (Afoakwa *et al.*, 2007). Tempering is crucial for the crystallization behaviour of cocoa butter, which significantly impacts the final quality of the products, including characteristics like colour, hardness, texture and shelf life (Afoakwa *et al*., 2009).

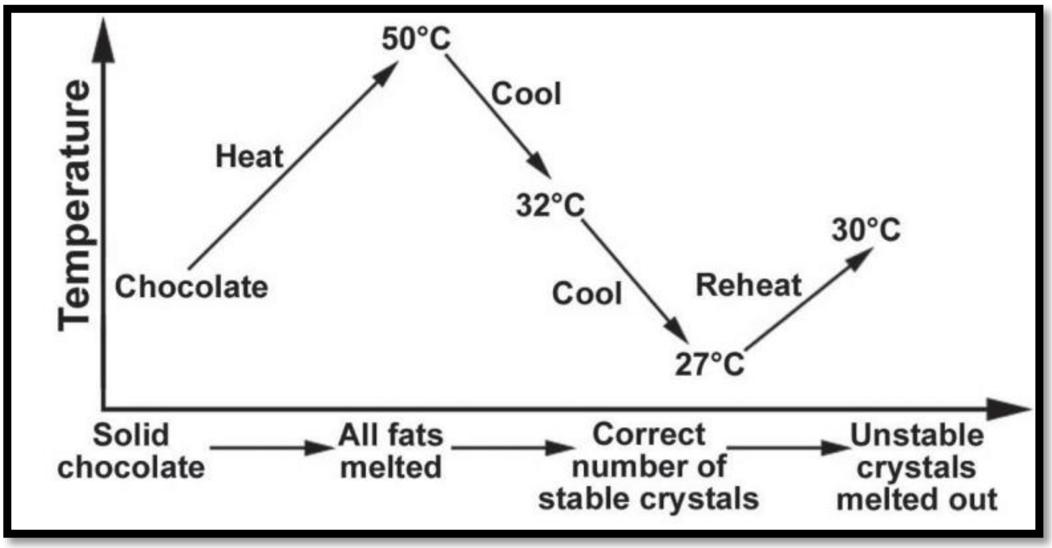


Fig. 2.2. Tempering sequence during lipid crystallization in chocolates

2.2.11. Moulding and Demoulding

The process typically involves pouring tempered chocolate into moulds, where it cools and solidifies before being demoulded. To remove trapped air and prevent unwanted bubbles, the moulds are tapped or shaken (Minifie, 1999). Depending on the design of moulds, the chocolate can take various forms such as bars, buttons, candies or blocks. Chocolate moulding is the process of shaping tempered chocolate in moulds to achieve its final shape (Gray, 2017). A widely used, cost-effective technique in small-scale and homemade chocolate production is gently tapping the mould or moulding plate on a table edge, which is simple and affordable (Thamrin *et al*., 2018).

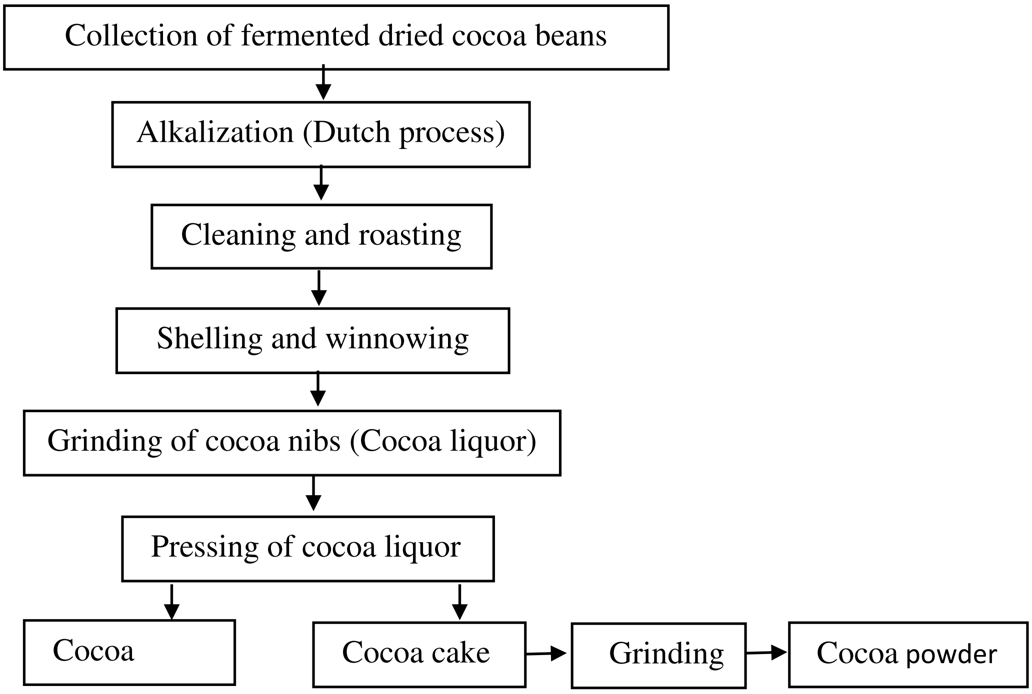


Fig. 2.3. Flow diagram for the production of cocoa butter, cocoa cake and cocoa powder

2.3. TYPES OF CHOCOLATE

2.3.1. Milk Chocolate

Milk chocolate is produced by substituting part of the cocoa liquor with whole milk solids. It typically comprises at least 10% cocoa liquor and 12% whole milk solids. Its composition includes sugar, milk powder, lecithin, cocoa butter and cocoa content of 20–25%. A quality milk chocolate needs to be glossy and having strong smell and persistent. The aroma of milk chocolate begins with a combination of milk and vanilla, transitioning into a rich, cocoa-dominant fragrance. High-quality milk chocolate is crisp when bitten but melts quickly into a soft, slightly mushy paste in the mouth. Its taste is predominantly sweet, with a mild bitterness from the chocolate (Verna, 2013).

2.3.2. White Chocolate

White chocolate is made with ingredients like sugar, vanilla, milk powder and cocoa butter. It possesses a delightful and sweet taste and often used in desserts like mousse, creams and pastries. (Verna, 2013).

2.3.3. Dark Chocolate

Dark chocolate consists of up to 80% cocoa bean solids and cocoa butter by weight. It melts smoothly in the mouth, releasing a deep, lasting cocoa aroma and leaving behind a pleasant, bitter aftertaste. The quality of dark chocolate is primarily determined by its cocoa content. Most of the health benefits associated with chocolate consumption are specific to dark chocolate (Montagna *et al*., 2019).

Table 2.2. Nutritional values per 100 g of dark and milk chocolate (Source: Montagna *et al*., 2019)

Chemical Composition	Dark Chocolate	Milk Chocolate
Water (g)	0.5	0.8
Protein (g)	6.6	7.3
Lipid (g)	33.6	36.3
Cholesterol(mg)	0	10
Carbohydrate (g)	49.7	50.5
Sugar (g)	49.7	50.5
Total fiber (g)	8	3.2
Sodium (mg)	11	120
Potassium (mg)	300	420
Iron(mg)	5	3
Calcium(mg)	51	262
Phosphorus(mg)	186	207
Thiamin (mg)	0.07	0.09
Riboflavin(mg)	0.07	0.39
Niacin (mg)	0.6	0.6
Vitamin A (μg)	9	25
Phenolics (mg)	579	160
Flavonids (mg)	28	13
Theobromine (mg)	802	125
Energy(kcal)	515	545
Energy(kJ)	2155	2281

2.4. COMPOUND CHOCOLATE

Compound chocolates are chocolate-like products made from fat such as modified palm kernel oil and coconut oil, where the melting properties of these vegetable fats are adjusted to mimic cocoa butter. These compound coatings are primarily used for cost-effectiveness, as vegetable fats are cheaper than cocoa butter. However, there are cases where the unique properties of a particular vegetable oil are required for specific applications. Generally, the use of fat other than cocoa butter (CB) results in the product being labelled as compound coating (Lonchampt and Hartel, 2004). By modifying the triacylglycerol (TAG) composition of fats and oils, their physical properties, especially the melting behaviour are adjusted to resemble cocoa butter for use in confectionery (Biswas *et al.*, 2017).

Table 2.3. Compositions for chocolate and compound coating (Source : Hartel, 1998)

Ingredient	Chocolate	Compound Coating
Cocoa liquor	33%	-
Cocoa powder	-	14%
Sucrose	50%	48%
Cocoa butter	16%	-
Palm kernel oil	-	29.5%
Skim milk powder	-	8%
Lecithin	0.5%	0.5%

Cocoa liquor contains 50% cocoa butter

Cocoa powder contains 10 - 12% cocoa butter

2.5. COCOA BUTTER ALTERNATIVES (CBA)

Cocoa butter (CB) is obtained from the cocoa bean processing and comes from the mature beans of the *Theobroma cacao* plant. It plays a crucial role in the chocolate and confectionery industries due to its unique physicochemical properties, which are a result of its distinct fatty acid composition. The primary triacylglycerols (TAG) in CB are symmetrical and contain minimal amounts of highly unsaturated fatty acids. The main fatty acids in CB are palmitic acid, stearic acid, oleic acid and linoleic acid, with smaller amounts of lauric acid and myristic acid. The growing demand for CB, coupled with supply shortages, poor quality harvests, economic advantages and certain technological benefits, has led to the development of alternatives known as Cocoa Butter Alternatives (Naik and Kumar, 2014).

Cocoa butter alternatives (CBA) are fats that either fully or partially replace cocoa butter. Based on the functional differences of the vegetable fats used in chocolate, CBA are categorized as cocoa butter replacers (CBR), cocoa butter equivalents (CBE) or cocoa butter substitutes (CBS). These fats are derived from natural plants such as palm kernel oil (PKO), palm olein (PO), mango seed fat, soy oil, rapeseed oil, cotton oil, groundnut oil and coconut oil. Additionally, CBA derived from sources like shea butter and palm oil are used to replace cocoa butter (Hussain *et al*., 2018).

Fats used in coatings can be classified according to their compatibility with CB, under three major family names:

- Fats that are fully compatible with cocoa butter are known as cocoa butter equivalents (CBE).
- Fats that are partially compatible with cocoa butter are referred as cocoa butter replacers (CBR).
- Fats that are incompatible with cocoa butter are classified as cocoa butter substitutes (CBS).

2.5.1. Cocoa butter equivalent

Cocoa butter equivalent (CBE) fats must be fully compatible with cocoa butter. In this context, compatibility refers to the ability of the triacylglycerols (TAG) in two different fats to crystallize together without creating a eutectic. However, some CBE may not exhibit complete compatibility with cocoa butter (Naik and Kumar, 2014).

2.5.2. Cocoa butter replacers

Cocoa butter replacers (CBR), sometimes referred as cocoa butter extenders or hydrogenated domestic butter, do not fully replace cocoa butter. Their compatibility with cocoa butter is lower than that of CBE but higher than that of CBS. The primary sources of CBR are either hydrogenated or fractionated palm oil or hydrogenated domestic vegetable oils, such as soybean and cottonseed oil (Naik and Kumar, 2014).

2.5.3. Cocoa Butter Substitutes

CBS fats are typically derived from coconut or palm kernel oils. These oils are often hydrogenated or fractionated to enhance their hardness and improve their melting profile. CBS fully replaces cocoa butter in a coating, except for the cocoa butter present in cocoa powder. However, the compatibility of CBS with cocoa butter is very low (below 5%) due to significant differences in their triacylglycerol (TAG) compositions (Lonchampt and Hartel, 2004). Fats Commonly Used as a Source of CBA are shown in Fig. 2.4.

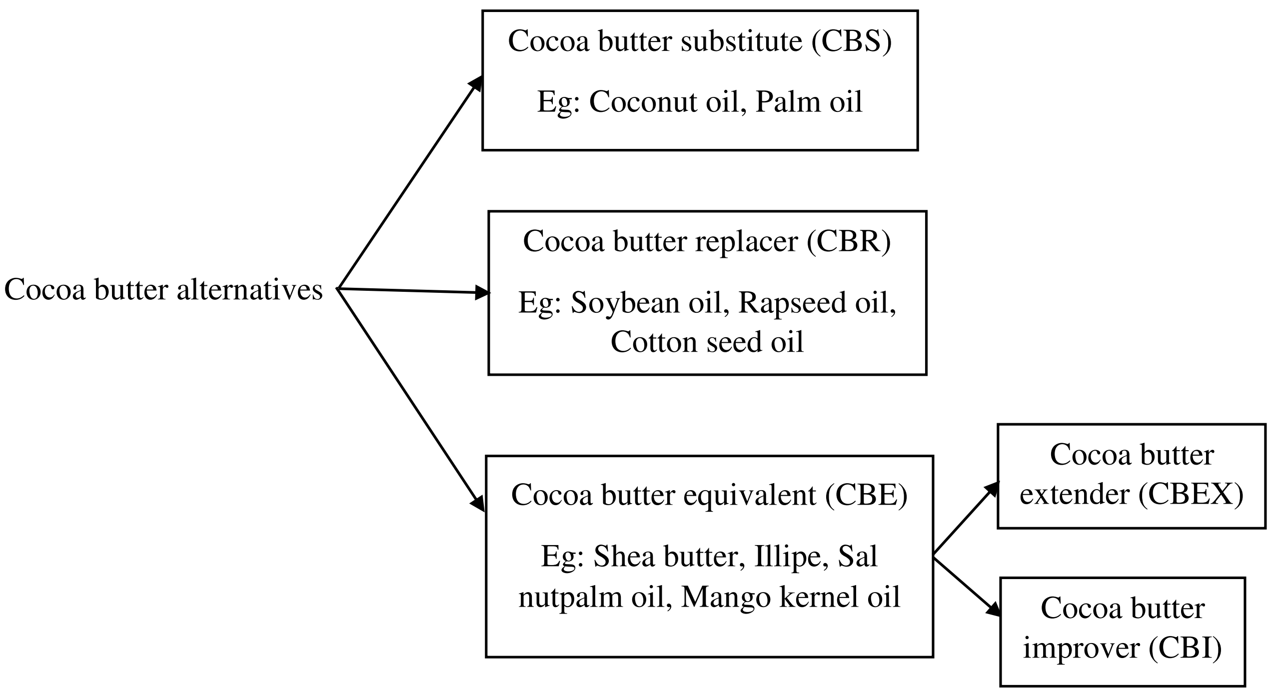


Fig. 2.4. Subgroups of cocoa butter alternatives (Source: Naik and Kumar, 2014)

Table 2.4. Properties of subgroups of cocoa butter alternatives (Source : Naik and Kumar, 2014)

Properties	Cocoa butter equivalent (CBE)	Cocoa butter replacer(CBR)	Cocoa butter substitute(CBS)
Types of fatty acids	non-lauric acid plant fats	non- lauric acid fats	Lauric acid containing fat
Physical and chemical properties	Similar in their physical and chemical properties like melting profile and polymorphisms to cocoa butter	The distribution of fatty acid is similar to cocoa butter, but the structure of triglycerides is completely different	Chemically different to cocoa butter, with some physical similarities
Mixing properties	Mixable with it in every amount without altering the properties of cocoa butter	Only in small ratios can mix to cocoa butter	Suitable only to substitute cocoa butter to 100%
Main fatty acid	Palmitic (P), stearic (S), oleic acid(O), linoleic (L), arachidic acid(A)	Elaidic acid (E), stearic acid(S), palmitic (P), linoleic(L)	Lauricacid (L), myristic acid (M)
Examples	Palm oil, illipe butter, shea butter, kokum butter, sal fat	Hydrogenated oil, soya oil, rape seed oil, cotton seed oil, ground nut oil, palm olein	Coconut oil, palm kernel oil, MCT

2.6. PREPARATION OF COMPOUND CHOCOLATE

The process of manufacturing compound coatings is similar to that of pure chocolate, with some variations due to the use of vegetable fats. Many vegetable fats do not require tempering to form stable crystals, so the tempering step may not be needed. However, tempering is essential for chocolate made with cocoa butter to ensure a high-quality, stable product. In coating made with modified palm kernel oils (fractionated or hydrogenated), it is recommended to add a nucleating agent, such as hardened palm oil, at around 2% to promote proper crystallization of lauric-based coatings. This saturated triglyceride crystallizes easily at lower temperatures, aiding the crystallization of the main fat phase. In contrast, coatings made with non-lauric fats (like hydrogenated cottonseed or soy) need tempering to achieve the most stable polymorphic structure (Hartel, 1998).

Tempering of compound chocolate is influenced by the characteristics of the lipid phase. Coatings made with lauric fats, such as palm kernel oil or coconut oil, do not require traditional tempering, as they naturally crystallize into the most stable polymorph (β′). Instead, these chocolates only need to be cooled appropriately to promote the formation of the correct number and size of fat crystals for the desired texture. This typically involves rapid cooling to a low temperature (10-12°C) to start the crystallization process, followed by maintaining low temperatures to dissipate the latent heat (Lonchampt and Hartel, 2004).

Table 2.5. Formulation of milk and dark compound chocolate (g/100 g) (Source : (Akdeniz *et al.*, 2021)

Raw materials	Milk compound chocolate	Dark compound chocolate
Cocoa	7	13
Powdered sugar	41.45	54.45
Palm oil	32	32
Whey powder	10	-
Milk powder	9	-
Lecithin	0.4	0.4
PGPR	0.1	0.1
Ethyl vanillin	0.02	0.02
Salt	0.03	0.03

2.7. VALUE ADDITION OF COCOA

Value addition plays a crucial role in the chocolate industry, driving differentiation, growth and sustainability. By incorporating unique flavours, utilizing innovative techniques such as enrobing, filling and using premium ingredients, chocolatiers transform their products beyond mere confectionary products. Creating new products by combining chocolate with cereal-based biscuits, wafers, fruits and nuts helps protect them from deterioration, such as preventing caramel from drying out and hardening by coating it with chocolate. The addition of a chocolate coating enhances the sensory qualities of the coated products, infusing them with a rich flavour. There are many methods of value addition of chocolate on the food products such as enrobing, panning, filling and moulding.

Chocolate is sold directly to the consumer as solid bars of eating chocolate, as packaged chocolate. It is also used by confectioners as coating for candy bars, cookies, cakes and by ice-cream companies as coating for frozen novelties. Cocoa powders, chocolate liquor and blends of the two are used in bulk to flavour various food products and to provide the flavours in such chocolate products as syrups, toppings, chocolate milk, prepared cake mixes and pharmaceuticals.

2.7.1. Enrobing

Enrobing is the process of applying a coating, typically of chocolate, to the exterior of a product. Common examples include coated biscuits, ice cream bars, cakes, fruits and nuts. Coating is typically applied using an enrober, a machine where the products move through a continuous curtain of the coating. As they pass through, the coating covers the top, sides and bottom of the products. Excess coating is removed and the remaining layer is crystallized by passing the coated products through a cooling tunnel (Talbot, 2009).

2.7.2. Panning

Dragees, also known as panned goods, are gaining significance in the confectionery and chocolate industry. The term "dragees" comes from the Greek word "tragemata," meaning sweets or dessert and refers to sugar-coated almonds in French. In these products, especially when a thin coating is required, the coating is often sprayed onto the surface of the product. This technique is commonly used to create thin barriers that helps to reduce moisture migration. Among various products, chocolate-panned confections, which feature a center containing nuts, fruits or dried fruit covered by multiple layers of coating like chocolate, are particularly popular due to their high consumer acceptance. Panning is a process which includes; pre-treatment of product, chocolate/compound panning, polishing and sealing. Precoating refers to applying a separate layer between the product surface and the panning layers, which prepares the product for the main panning process. The coating, typically a molten fat-based mixture, is applied either manually, automatically or through a spraying system. The molten mass solidifies under cold air and forming a smooth, uniform layer on the surface of the product. Hydrocolloids commonly used for precoating, include gum arabic, gelatin, modified starches and maltodextrin (Talbot, 2009).

2.7.3. Filling

Filled confectionery refers to a type of treat where the process begins with creating the coating, followed by placing the filling inside, unlike the traditional method where the filling is first made and then coated. In the production of filled confectionery, a chocolate shell is formed first and then the filling is placed inside it. This initial shell typically does not cover the entire product, so an additional step called backing off is used to apply more coating for full coverage. The final coating layer, known as the backing-off layer, which acts as the base of the end product, ensuring that the filling is enclosed within the coating for both aesthetic appeal and structural integrity. Chocolate shells are generally made in one of two ways: either by filling moulds with excess chocolate, inverting and rotating them to coat the inside and allow the excess to drain or by depositing a small amount of chocolate into the mould and plunging a cold former into it to create a shell with precise dimensions (Talbot, 2009).

2.7.4. Moulding

Moulding of chocolate involves shaping chocolate into a wide range of shapes, sizes and designs. Specialized moulds are used to form molten chocolate into detailed patterns, motifs or three-dimensional figures. Moulded chocolates can be either filled with various ingredients or kept solid, allowing for limitless creative and customization options. Tempered chocolate is poured into the mould to create the desired final shape (Talbot, 2009).

2.8. CHOCOLATE ENROBING PROCESS

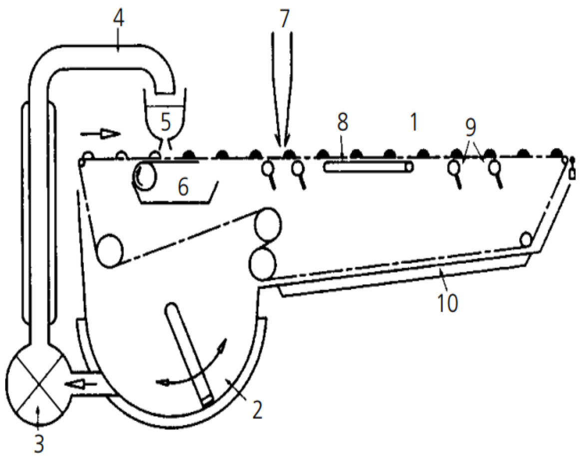
2.8.1. Enrobing

Enrobing technology is commonly used in the chocolate manufacturing industry. In the enrobing process, a pre-formed centre is coated with chocolate by pouring molten chocolate or coating over it. The chocolate flows in a vertical sheet onto a moving belt, coating the product as it passes through (Beckett, 2000). The thickness and consistency of the coating are regulated by using chocolate with the appropriate viscosity and by removing excess chocolate with air and vibration (Bean, 2009).

Coating biscuits or cakes with chocolate creates a moisture barrier that protects the product from the surrounding environment. Cakes typically lose moisture to the air, leading to dryness and staleness, while biscuits absorb moisture, becoming soft and stale. Since chocolate is a fat-based product, it helps prevent this moisture transfer, thereby extending the shelf life of the product (Brown, 2009).

2.8.2. Enrober

The role of an enrober is to coat all surfaces of the centre with chocolate, ensuring the final product is visually appealing, glossy, free of voids or holes, without tails or defects and has a uniform, controlled thickness. The sweets entering the enrober are transferred from a plastic feed belt to a wire mesh belt, passing beneath one or more chocolate curtains. A plate or trough with a roller underneath the belt ensures the underside is coated. Excess chocolate from the curtain falls through the mesh into a sump and is recirculated. After passing through the curtain, excess chocolate is removed using an air blower and a licking roller controls the amount of chocolate on the underside. A vibrator follows to remove further excess chocolate and enhances the appearance of the product. Finally, a detailing roller between the wire belt and the cooler belt ensures the product exits the enrober without a tail, hence the name de-tailer (Gray, 2017). The components of an enrober is illustrated in Fig. 2.5.



1. Wire grid conveyor belt
2. Reservoir tank
3. Chocolate pump
4. Riser tank
5. Top flow pan
6. Bottoming trough
7. Air nozzle
8. Grid shaker frame
9. Licking rolls
10. Heated extension trough

Fig. 2.5. Components of chocolate enrobing machine (Source : Gray, 2017)

2.9. PRINCIPLE OPERATIONS IN ENROBING

In enrobing machines, the centres are moved along a wire belt, enabling chocolate to be applied to both the top and bottom of the centre, while allowing excess chocolate to drain off. Initially, the enrober applies chocolate to ensure complete coverage. Any excess chocolate must be removed to achieve the desired chocolate pick-up weight, while avoiding pinholes or leakage paths that could cause the centre to leak or allow air to enter after solidification. Finally, the enrober must transfer the product to the in-feed of the chocolate cooler without creating a chocolate tail or damaging the bottom layer of coverage. The operations to be performed are as follows:

2.9.1. Formation of Chocolate Curtain

There are two primary methods for controlling the feed rate of chocolate to create a continuous curtain: using a trough with an adjustable slot at the bottom or trough with rotating rollers to control feed rate. The trough with an adjustable slot allows precise control over the flow of tempered chocolate, enabling the regulation of the curtain thickness and consistency. The second method involves a trough with rotating rollers, which helps maintain a steady chocolate flow onto the product, ensuring an even coating. By adjusting the speed and direction of the rotating rollers, the desired thickness and coverage of the chocolate curtain can be achieved (Talbot, 2009).

2.9.2. Chocolate coating

Chocolate is applied to the top and sides of the centre using one or more chocolate curtains as the centres move along the wire belt. The amount of chocolate that adheres to the centre depends on the surface consistency of the centre and the rheological properties of the chocolate in the curtain. It is crucial to maintain continuous curtains across the machine during this process to ensure uniform coating (Talbot, 2009).

2.9.3. Excess chocolate removal

After coating, the next step is the removal of excess chocolate to achieve the desired pick-up weight without exposing the centre. This is done through a process called blowing, where the product moves under an air curtain created by a specially designed blower. The blower is fed with temperature-controlled air from a centrifugal fan located above the product zone. The velocity of the air curtain, height of the blower and blower angle are all adjusted to ensure the optimal chocolate thickness on the top surface of the centre. The excess chocolate then flows down the sides of the centre (Talbot, 2009).

2.9.4. Shaking

After the blower has removed the excess chocolate from the top of the centre, the excess chocolate from the sides is removed by vibrating or shaking the product on the wire belt. This is achieved using a vertically vibrating frame or shaker that makes contact with the underside of the belt. The shaker frame can be pivoted at one end and oscillated at the other by a mechanical cam or ratchet mechanism. The speed of the cam drive motor can be adjusted to change the shaking frequency, while the amplitude of the shake can be controlled through a simple mechanical stroke adjustment. The duration of shaking, as the centres pass over the shaker frame, is crucial for effective chocolate removal (Talbot, 2009).

2.9.5. Cooling

The coated centres are transferred to the band of the chocolate cooler. Cooling chocolate-coated products involves the use of cooling tunnels with optimal settings according to the product and chocolate properties, ensuring the desired surface gloss and coating hardness. These cooling tunnels are divided into different zones, each offering separate control over air temperature, bottom and radiant surfaces and air velocity. This allows for precise regulation of cooling conditions to meet the specific needs and characteristics of the product. A slow or gentle cooling process results in better gloss compared to more intense cooling. The crystallization rate of the chocolate coating should be slow and longer cooling times are required to achieve the necessary solidification for packaging. If the coating is insufficiently solidified, the surface may remain soft, making it prone to scratches during packaging and leading to potential quality issues. For enrobed products, both latent heat and heat of crystallization must be effectively removed. A higher cooling temperature combined with a longer cooling duration is generally more favourable than using lower temperatures with shorter cooling times. Milk and white chocolates require longer cooling periods compared to dark chocolate due to their higher milk fat content, which results in lower solidification temperatures. The air temperature settings depend on the recipe, cooler length and zone configurations. For milk chocolate, the ideal conditions are 14–18°C at the inlet, 10–12°C in the central section and 12–16°C at the outlet. Lauric compounds, require a more aggressive initial cooling phase at 6–8°C, followed by a gentler second stage to avoid issues related to the dew point. For non-lauric coatings, the recommended cooling temperatures fall between those for chocolate and lauric coatings, typically in the range of 8–12°C (Talbot, 2009). After cooling, the products are packed using methods such as flow-wrapping, foil wrapping or placing them into boxes (Talbot, 2012).

2.9.5.1. Cooling time

The minimum total cooling time required depends on the coating composition and thickness. Cooling time for the different type of chocolate are shown in Table 2.6.

Table 2.6. Cooling time for different coatings (Source : Talbot, 2009)

Coating Type	Cooling Time
Dark chocolate	4–6 min
Milk chocolate	6–9 min
Milk chocolate with high milk fat, nut oil or softer CBE	9–12 min
Lauric coating	2–3 min
Non Lauric coating	4–6 min

2.9.6. Storage of chocolate products

The best storage conditions for preserving optimal product quality of the chocolate products were found to be 6°C and 12°C, where most attributes maintained their ideal qualities. At 20°C, minor changes occurred, mainly due to fat bloom, but colour and hardness were unaffected. However, 30°C proved to be highly damaging, leading to significant bloom defects and a decline in quality. Therefore, storing chocolate products between 6°C and 12°C is crucial for preserving their sensory and physical properties, while 30°C should be avoided to prevent bloom-related issues (Machálková *et al.*, 2015).

2.10. COST ANALYSIS

Generally, there are two types of costs: fixed costs and variable costs, which are used in conjunction with the number of units to determine the selling price of the product. Fixed costs are expenses associated with the acquisition of long-term assets, such as plant and machinery. These assets depreciate over time due to their use in operations. Fixed costs typically include equipment depreciation, interest on investment, taxes, storage and insurance. Operating costs fluctuate directly with the level of production. The variable cost per unit is calculated by considering electricity charges, repairs and maintenance, raw materials and labour costs. Labour costs encompass direct wages, food allowances, transport and other employment-related expenses. The machine rate is the total of fixed costs, operating costs and labour costs. To calculate the product cost per kilogram (cost/kg), the total manufacturing cost is divided by the annual production rate (kg/year). The payback period, commonly measured in years, is the duration it takes for the cumulative cash flow to recover the initial investment. (Saravacos and Kostaropoulos, 2002).

Depreciation is the reduction in the value of assets over time caused by usage and wear. The depreciation cost typically begins once the assets are put into operation. It is commonly calculated at 8% of the fixed investment. Salvage value refers to the amount for which equipment can be sold when it is disposed of. This value is often estimated as 10 to 20% of the original purchase price (Sahu *et al.*, 2016).

The energy consumption was determined based on the amount of electricity used per hour. (Srikanth *et al.*, 2020) developed a cocoa bean extractor, with an operational cost of Rs. 74.42 per hour, total machine cost of Rs. 27,600, payback period of 2.01 years and benefit-cost ratio of 1.67:1. The machine had a maximum capacity of 626.8 kg per hour, efficiency of 96.78% and energy consumption of 10.54 kJ.