A Short Review: Changes in the Physical-Chemical Properties of Cacao Beans During the Fermentation Process

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**Abstract.** Fermentation is one of the main processes influencing cacao beans' quality. Proper post-harvest cacao processing can affect the quality of cacao beans. Spontaneous fermentation of cacao beans is carried out carefully for 5 d to 7 d, characterized by a series of activities of certain microorganisms from three groups of microorganisms: yeasts, lactic acid, and acetic acid. Yeast aims to liquefy the pulp, while lactic acid and acetic acid bacteria play a role in raising and lowering the pH of cacao beans during fermentation. The activity of microorganisms affects the formation of aromatic compounds in fermented cacao beans. During the fermentation process, there is a change in pH and an increase in temperature in the seed heap; this creates conditions that cause changes in the seed's structure at the cellular level and the metabolites present in the seeds. Leucine, alanine, phenylalanine, and tyrosine are precursors contributing to cacao and chocolate aroma formation. The post-harvest processes affect the yield of cacao beans that will be used in the chocolate industry. Each process must be considered to produce high-quality fermented cacao beans.

**Keywords:** Activity of microorganisms, aroma formation, chocolate, precursors, yeast.

1 Introduction

Cacao is one of the commodities that is widely developed throughout the world. Cacao is used as an ingredient in drinks, food, medicine, and even cosmetics. Cacao is also considered a particular food because it is taken from Greece language, _i.e._ Theobroma, which means food of the God [1], which scientific name: _Theobroma cacao_ L. —several cacao varieties/cultivars developed around the world, namely the Criollo, Forastero, and Trinitario. The Trinitario cultivar is a cross of Criollo and Forastero. The Criollo variety is rarely cultivated because plant diseases easily attack it, so the ones still widely developed and planted are Forastero and Trinitario.

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Good-quality cacao beans have a high selling value. They are produced from processing methods during the planting, harvesting, and post-harvest processes [2]. The post-harvest process of cacao includes fermentation, drying, packaging, and storage [3]. The post-harvest process affects the quality of the cacao beans.

Dried cacao beans produced from post-harvest processing are the main ingredient in chocolate products. Unfermented cacao beans have an astringent and bitter taste, making them difficult for the senses to perceive. The purpose of fermenting cacao beans is so that the cacao beans do not have an astringent taste. Apart from that, it forms a flavor in the cacao beans. Fermentation is also carried out to produce biochemical changes in the seeds, which produce aroma, color, and taste precursors in the seeds. Cacao beans that have been fermented and dried will be roasted or roasted, which aims to reduce the water content still in the dried cacao beans. Please pay attention to the water content in cacao beans to avoid them becoming quickly moldy and damaged. Therefore, post-harvest processing of cacao beans has a significant role in producing quality cacao beans.

Cacao beans contain many chemical compounds that are good for the body. One of the chemical compounds in question is antioxidants. Antioxidants have a big role in fighting free radicals and preventing human cancer. The antioxidants in cacao beans are produced from polyphenolic compounds, namely the flavonoid group. Apart from that, the chemical components contained in cacao beans themselves can vary due to various processing processes to become products. The process of decreasing flavonoid levels in cacao beans is caused by oxidation, condensation, and other reactions during the fermentation and roasting of the beans [4, 2]. Cacao fermentation is carried out using various types of fermenters with varying times of 5 d to 7 d. Variations of fermenters that are commonly used are wooden boxes, wooden baskets or bamboo baskets, sacks, plastic, and styrofoam, and there are even those that ferment without using a fermenter, just putting them on the floor without any handling or control. The cacao beans' quality also varies depending on the fermenter used. This shows the importance of paying attention to the cacao post-harvest process so that the beans produced are good quality.

2 Methods

This article was written based on the results of a literature review related by searching on Google Scholar various journals from 2009 to 2023 regarding cacao fermentation and the post-harvest stages of cacao that affect the quality of the beans. The method used in the research is collecting secondary data from various literature obtained online and reviewing journals related to cacao fermentation and the post-harvest stages of cacao that affect the quality of cacao beans. The article also discusses changes in physico-chemical properties during the cacao fermentation process. The data were taken from various international journal literature.

3 Results and discussion

3.1 Fermentation preparation process

3.1.1 Harvesting

Harvesting of cacao pods is carried out when the pods are ripe by looking at the physical characteristics of the pods. The skin color of the cacao pod is the primary indicator in determining fruit ripeness [5]. Cacao pods that are ripe will have different physical properties
from cacao pods that have not yet entered the ripe phase. Ripe cacao fruit has physical characteristics; namely, for fruit that has green skin, the grooves or gaps in the fruit will be yellow, while cacao fruit that has dark red, pink, and orange skin will change color to yellow and when shaken, the fruit will make a sound. It sounds like a space inside because the fruit is separated from the inner skin [6, 5]. Cacao farmers harvest the fruit using sharp machetes and cut the fruit stalk without injuring the cacao tree trunk [7]. Cacao pods that have been harvested will then go through an initial sorting process to differentiate between still-intact fruit and fruit with holes or disease. The sorted cacao pods will be stored or matured for several days.

3.1.2 Pod storage

Pod storage is carried out for 2 d to 8 d, starting when the pod is harvested [8]. The purpose of storing cacao pods is because this post-harvest process affects the quality of the cacao beans, which will later be fermented. Pod storage affects the organoleptic properties of cacao beans, so it needs to be done in the same way as the fermentation process [9]. Pod storage is recommended for cacao beans, characterized by a robust sour taste. Pod storage itself can reduce the content of sucrose, glucose, fructose, ethanol, and acetic acid and can increase the pH of fermented cacao beans so that it can enrich the taste of the final cacao bean product [10, 11, 3]. However, pod storage also has its challenges, namely that it can increase moldy or damaged seeds due to storing pods for a long time and uncontrolled storage conditions.

3.2 Fermentation

Cacao fermentation is the most crucial process in determining the quality of the cacao beans produced; it stands to reason that the fermentation process affects the taste and flavor of the cacao beans produced. If the fermentation of cacao beans fails, they will produce low-quality cacao beans with low selling value. Fermentation of cacao beans is done spontaneously, and some people add yeast or bacteria to speed up the fermentation process. The length of fermentation time also depends on the type and region of cacao harvested; each variety has a different fermentation time. The Criollo variety has a shorter time compared to the other two varieties,/ cultivars, namely Forastero and Trinitario, which are carried out for 5 d to 8 d [12].

In general, cacao fermentation is carried out for 5 d to 7 d [13–17] and there is even some a place that ferments for less than 5 d. During the fermentation process, the beans will be turned over twice in the fermenter by stirring after the first 48 h after the fermenter is closed and 48 h after the first turning, which will then be continued with drying [16]. Fermentation of cacao beans is often carried out using fermenter boxes [18, 14, 15] which are made from wood. However, not only wooden boxes but many types of fermenters are used to ferment cacao.

Fermenters used in addition to wooden boxes include sacks, bamboo baskets [19, 18], plastic baskets [18], styrofoam [20], and others, which are simply placed on a perforated banana leaf [21, 14] and left for several days without control. When fermenting cacao, wooden boxes or other fermenters are lined with banana leaves and then covered with banana leaves [7, 14] and covered with jute sacks and then given a little weight to put pressure on the cacao beans, which will be fermented. This spontaneous process of cacao fermentation is caused by bacteria in the inoculating pulp and various other microorganisms. Apart from that, cacao pulp also contains high levels of sugar as food for microorganisms during the fermentation process [22].

All processes, starting from planting the beans and post-harvest handling to drying the fermented cacao beans, greatly influence the quality of the beans produced. Processes such as storing cacao pods, sorting between healthy and diseased pods before opening, removing
the placenta after opening the cacao pods, the amount of wet beans and pulp, cleanliness of equipment used to open the cacao pods, temporary storage of cacao bean pulp during the process drying, controlling the temperature of fermented cacao beans, as well as the length of the fermentation process, seasonal variations and weather conditions greatly influence the final yield of cacao beans [9]. Judging from this, chocolate producers need to use fermented dry cacao beans for the chocolate recipes they produce so that the quality of the chocolate produced is more consistent and has a standardized taste profile for consumers [23].

3.3 Microbial activity during fermentation

Cacao fermentation occurs due to the activity of certain microbes, such as yeast, Lactic Acid Bacteria (LAB), and Acetic Acid Bacteria (AAB) [24, 25]. This fermentation process depends on the fermented cacao beans' microbiological quality and physicochemical parameters, namely temperature, pH, and oxygen pressure [26, 9]. The process of microbial development during the fermentation process will only be maximum in the first 4 days; if fermentation is carried out longer, it will cause fungal growth, thereby damaging the quality of the cacao beans [27, 28].

Yeast is the microorganism that dominates during the fermentation process's first 24 h to 48 h (Figure 1). The yeast has a role in liquefying the cacao pulp so that the pulp produces sweat during the fermentation process [27]. This triggers air entry into the seeds, which will later form a cavity inside the seeds. The production of ethanol from carbohydrates due to yeast activity is essential during fermentation.

Cacao pulp has a high sugar and low pH because it contains citric acid [22]. During the fermentation process of cacao beans, there is a change in pH caused by organic acids produced by microbial activity, such as lactic acid [29] and acetic acid, which enter the beans, thereby lowering the pH in the beans and making them acidic [30]. Yeast and lactic acid bacteria utilize citric acid for the growth process during fermentation; this causes a reduction in the citric acid content contained in the pulp [31]. As a result of decreasing citric acid in the pulp, the acidity will decrease so that the pH of the pulp will continue to increase until the end of fermentation [30] (Figure 1).

Several studies report using starter cultures to increase the production of by-products from cacao pulp using pectinolytic yeast. The use of yeast does not affect the cacao beans' quality. However, some starter cultures produce fermented cacao beans with a higher pH and acetic acid content, and the resulting chocolate tastes less good compared to fermented beans without a starter. The choice of starter culture used in cacao fermentation can influence the taste of chocolate from fermented dry cacao beans. The function of fermenting cacao beans by adding a starter culture not only guarantees a short and optimal cacao fermentation process but also avoids variability in the degree of fermentation and flavor profile that is usually seen in the case of spontaneous fermentation of cacao beans.

3.4 Flavor and aroma compound in cacao beans

Fermentation is a stage that significantly influences the taste and aroma of chocolate [32, 9]. The Maillard reaction develops aromatic compounds in cacao beans from aroma precursors [33]. Fermentation itself plays a vital role in forming aroma precursors, and this process is carried out by microorganisms such as yeast, lactic acid bacteria, and acetic acid bacteria [34]. Fermentation cannot improve wet cacao beans with low precursor content. Therefore, the right ratio of aroma precursors is critical to producing cacao beans with optimal aromatic compounds [35]. Activity of yeast, lactic acid bacteria, and acetic acid bacteria during the spontaneous fermentation process in which substrate degradation occurs and the kinetics of metabolite production can be seen in Figure 1.
The genetic makeup of cacao varieties is also a factor in chocolate's unique taste and aroma [9]. Flavor compounds formed during the fermentation process are caused by biochemical and enzymatic reactions [37]. The sugar in the pulp provides a substrate for use during the fermentation process, where the pulp sugar is later converted into ethanol and lactic acid by lactic acid bacteria, then the ethanol is oxidized into acetic acid by acetic acid bacteria [38, 39, 28, 30].

Research shows that peptides and free hydrophobic amino acids such as leucine, alanine, phenylalanine, and tyrosine are precursors that contribute to the formation of cacao and chocolate aromas [40, 41]. Hydrophilic peptides and hydrophobic free amino acids contribute to aroma through their reaction with fructose and glucose during the roasting process [42]. Sucrose in the pulp is hydrolyzed into glucose and fructose by yeast activity and in seeds through the diffusion of acetic acid, lactic acid, and ethanol along with heat production [43]. Leucine and glucose produce an aromatic aroma that is described as sweet chocolate [42].

Cacao beans themselves contain around 32 % to 39 % water, 30 % to 32 % fat, 8 % to 10 % protein (albumin and vicilin class globulin (7S), 2 % to 3 % cellulose, 4 % to 6 % starch, 4 % to 6 % pentosan, 2 % to 3 % sucrose, 1 % acids (mainly citric, oxalic, and malic acids), 1 % to 3 % theobromine, and 0.2 % to 1 % caffeine [44]. During the fermentation
process, there is a change in pH and an increase in temperature in the seed pile; this creates conditions that cause changes in both the structure of the seed at the subcellular level and the metabolites present in the seed [12, 28, 37]. Apart from that, there are also bacteria that play a role in cacao fermentation. The role of bacteria during the fermentation process is that lactic acid bacteria play a role in the production of citric acid, which can reduce pH [45].

Acetic acid bacteria have a role in producing acetic acid, which is responsible for the oxidation of ethanol, which later becomes acetic acid and then oxidizes again to carbon dioxide and water [28]. These microorganisms also influence the acidity of cacao beans, increasing the temperature during fermentation and hydrolysis of proteins in the cotyledons [46]. In the fermentation process, there are also spore-forming bacteria that can affect the taste of cacao beans [47, 48, 12]. These bacteria are influenced by oxygen pressure, which can accelerate their growth during the fermentation process [47, 48, 12].

Microbial succession is changed and formed from the growth of sugar and oxygen, and this is a key parameter for the success of the fermentation process, which influences the quality of the fermented beans produced [36]. Apart from that, the color and taste characteristics of cacao beans are also influenced by the roasting process [23] and the subsequent conching used in making chocolate [9, 10].

### 3.5 Traditional fermentation process versus industrial production

Fermentation has become one of the oldest preservation processes still carried out by people today. Today's modern food fermentation processes use starter cultures that have been modified and scientifically formulated to inoculate and control fermentation [12]. Fermented products are greatly influenced by the diversity of microorganisms and microbial activity, and this needs to be developed for industrial-scale production [49, 12]. As time goes by, advances in microbiology are now greatly influencing large-scale production processes such as bread, milk, and beer products.

Carrying out fermentation using culture to improve the quality of the product produced can replace the traditional cacao bean fermentation process. Using starter cultures is a promising effort to achieve this goal [50, 49]. The inoculated starter culture species can overcome the natural contamination of the cacao bean pulp mass during the fermentation process. Sensory analysis showed that the application of both additional starter cultures produced fermented dry cacao beans that provided reliable flavors, regardless of the cacao-producing region or fermentation method [49].

Simplifying the fermentation process and switching to using starter cultures in modern fermentation has its advantages and disadvantages. The advantages are that the quality produced is consistent [51], produces more products [52, 12], and generates many profits for farmers. Meanwhile, this disadvantage is that it risks losing microbiotic diversity and the variety of flavors produced [51, 52].

### 3.6 Chocolate quality

Post-harvest handling is critical in producing high-quality cacao beans. Post-harvest handling is one of the most essential stages in determining the quality of cacao beans, namely fermentation. The fermentation that is carried out spontaneously, if carried out without reasonable control and without using appropriate methods, will not be able to produce good-quality cacao beans [53, 49, 36]. Chocolate quality is still not a priority because there is no financial incentive to produce high-quality fermented cacao beans [54].

The quality of chocolate is gradually improving, and there is a market for selling good quality fermented cacao beans [54, 12]. The characteristics of fermented seeds that have good
quality are that they do not have an astringent taste, are not slaty, are not moldy, do not contain insects, do not flatten, do not shrink, and do not germinate [55, 26].

Before the chocolate-making process is carried out, it is necessary to evaluate the quality of the beans by carrying out a bean count by calculating the beans per 100 g or calculating the weight of 100 cacao beans [56, 9] because of the size of the dry fermented cacao beans. The world cacao market is very influential.

Price apart from that, there are other techniques, namely by looking at several indicators such as length of fermentation time, the maximum water content of 6%, number of defects, number of crushed beans, bean count, moldiness, taste profile, color, the fat content of at least 52%, and insect infection. The main thing that needs to be considered in chocolate products is the quality of taste consumers obtain [42].

Chocolate with good taste is produced from good quality beans. However, it is essential to note that even though the seeds are taken from the same place, the taste quality will still vary yearly due to treatment during the planting and post-harvest processes. Therefore, before making chocolate formulations, chocolate producers need a continuous assessment before using cacao beans in recipe formulations [57]. This aims to ensure that the chocolate produced still has a distinctive taste like before.

4 Conclusion

Based on the literature review results, quality cacao beans are produced from proper post-harvest processes and correct fermentation processes. Fermentation is a critical stage in producing quality cacao beans. Cacao fermentation can be done spontaneously, and yeast or bacterial culture can be added to speed up the process. Factors that influence the final results of fermented cacao beans include the method of storing the cacao pods, initial sorting, cleanliness of the equipment used in the fruit pulp disposal process, temperature control during the drying process and length of fermentation time, as well as weather conditions during the fermentation process. During fermentation, microbial activity occurs caused by yeast, lactic acid, and acetic acid bacteria. Several factors, including microbiological quality, temperature, pH, and aeration process, influence fermentation. Quality cacao beans will produce chocolate that has a taste that consumers like. Some indicators of good quality cacao beans include that the beans do not have an astringent taste, are not slaty, are not moldy, do not contain insects, are not flat, shrink, or do not germinate.

The authors would like to thank the Faculty of Agriculture and Animal Science, University of Muhammadiyah Malang for the funding given to the Research Blockgrant Program with No SK: E.2.a /131/FPP-UMM/II/2023.

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