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DESIGN AND PERFORMANCE TEST OF OHMIC-ASSISTED COCOA FERMENTATION APPARATUS

S. Supratomo[1], A. Laga[2], M. Tahir[1], A. A. Mochtar[3] and S. Salengke[1]
[1]Department of Agricultural Engineering, Hasanuddin University, Makassar, Indonesia
[2]Department of Food Science and Technology, Hasanuddin University, Makassar, Indonesia
[3]Department of Mechanical Engineering, Hasanuddin University, Makassar, Indonesia
E-Mail: ssalengke@yahoo.co.id

ABSTRACT

Cocoa is one of the most important agricultural commodities in the world since it is traded globally at high volumes. Economic value of cocoa beans is based on its flavor quality which is mainly developed during fermentation. Therefore, it is of paramount important that cocoa fermentation is done correctly. The objectives of this study were to develop anohmically heated and temperatura controlled fermention system for cocoabean fermentation and to assess the degree of fermentation achieved. The experiment was conducted at three levels of temperatura (40, 45, and 50 ^{o}C) and 2 levels of fermentation duration (3 and 5 days). Results of this study indícate that Cocoa beans can be heated rapidly to the desired fermentation temperature using ohmic heating. Electrical conductivity of cocoa beans is moderate and it increased linearly with temperature. The conductivity also increased as fermentation progressed since more acids were produced. The degrees of fermentation achieved were high even at relatively short fermentation duration. Therefore, the overall results suggest that cocoa fermentation can be shorten to three days with good degree of fermentation by using ohmic heating.

Keywords: ohmic heating, cocoa fermentation, fermentation apparatus.

INTRODUCTION

Cocoa is an important agricultural commodity in the world with total production of more than 4 million tons per year (WCF, 2014; ICCO, 2018). Indonesia is an important cocoa producing country but its yearly production of more than 500 thousand metric tons in 2005/2006 (ICCO, 2007) has declined significantly. Data provided by ICCO (2018) indicated that Indonesia cocoa productions in 2014/2015 and 2015/2016 were down to only about 325 and 320 thousand metric tons. To reverse this trend, Indonesia government has launched a national program which was intended to revitalize Indonesia cocoa sector and to increase production to the level of about 800 thousand to one million tons per year. In addition to the efforts to increase production, Indonesia government also has put emphasis on increasing the economic value of the cocoa sector. The economic value of cocoabeans is highly dependent on the vean quality and one of the most important quality attributes of cocoabeans is flavor. The flavor of cocoabeans and its final products depends on the amount of flavor compounds contained in the beans (Magi *et al.*, 2012; Krähmer *et al.,* 2015). The chocolate flavor in the final products is mainly developed during fermentation (Ramli *et al.*, 2006; Afoakwa *et al.,* 2008).

Fresh cocoa beans are covered by mucilage or pulp which contains high moisture and sugars. In addition, the cotyledon of fresh beans contains about 60% moisture such that the bean must be processed through a series of postharvest processes such as fermentation and drying before it can be processed into valuable products. Before the cocoa pod is opened, the beans inside the pod are relatively sterile from microorganisms (Thompson *et al*., 2001; Jespersen *et al*., 2005). After the pod is opened, however, bacteria and yeasts from the surrounding contaminate the beans and when the beans are piled and allowed to stay for a few hours, spontaneous fermentation of the beans will commence and proceed to completion in about seven days (Schwan and Wheals, 2004).

Cocoa fermentation process is a succession process in which yeast and bacteria work successively through the fermentation process (Schwan and Wheals, 2004; Nielsen *et al*., 2006; Sandhya *et al*., 2016). Schwan and Wheals (2004) showed that yeasts ferment the sugars in the mucilage in the first two days of fermentation process while Lactic Acid Bacteria involve during the first three days and acetic acid bacteria involve at the second through the fourth days. These authors also indicated that after the fifth days, spore forming bacteria can grow in the bean pile and molds can be found after the sixth day. This fermentation process is an exothermic or heat producing process which causes the temperature of the beans to rise during fermentation.

The types of yeast that have been reported to play significant roles in cocoa fermentation are Candida, Pichia, Saccharomyces, Kloeckera, Trichosporon, and Schizosaccharomyces (Roelofsen, 1952), Torulopsis candida, T. castelli, and T. holmii (Gauthier *et al*., 1977), Saccharomyces chevalieri, Pichia membranaefaciens, Candida krusei, Torulopsisholmii, Torulopsis Candida(Ravelomanana *et al.,* 1985), Kloeckeraapis, Candida pelliculosa, Candida tropicalis, and Saccharomyces cerevisiae (Ardhana, 1990), Pichia membranaefaciens, Saccharomyces cerevisiae, Candida zeylanoides, Saccharomyces cerevisiae, Kloeckeraapiculate (Schwan *et al*., 1995).A more recent study reported by Galvez *et al.* (2007) indicated that the yeast isolated from Dominican cocoa beans during fermentation belong to the genera Hanseniaspora and Candida and the bacteria involve are from genus Lactobacillus and Acetobacter.

Fermentation of sugars in cocoa mucilage by yeasts ceases after a few days since ethanol produced and temperature increase during this process inactivate the yeasts. Therefore, the next phase of fermentation proceeds with the help of fermentative bacteria which consisted of Lactic Acid Bacteria (LAB) and Acetic Acid Bacteria (AAB). The growth of these bacteria is facilitated by an aerobic condition that started to form within the bean pile due to the degradation of the mucilage. Camu *et al*. (2007) reported that the dominant LAB found in cocoa fermentation were Lactobacillus plantarum, Lactobacillus fermentum, Leuconostocpseudomesenteroides, and Enterococcus casseliflavus. These group of lactic acid bacteria ferment the remaining sugars which causes reduction in the beans pH due to the acid produced by the bacteria. The availability of oxygen in the bean pile and the decrease of the bean pH at later stage of the fermentation process are vaporable conditions for the growth of acetic acid bacteria but tend to decrease the growth of lactic acid bacteria. Camu *et al*. (2007) also reported that there were four dominant AAB in cocoa fermentation, i.e. Acetobacterpasteurianus, Acetobactersyzygii-like bacteria, and two clusters of Acetobactertropicalis-like bacteria. The acetic acid bacteria oxidize the alcohol produced in the earlier stage of the fermentation process and produce acetic acid which further reduce the beans pH. This process is also an exothermic process which causes the temperature of the fermented beans to increase further to about 50^{o}Cor more. The combined effects of the acids, alcohol, and high temperature causes the bean embryo to die which lead to the disintegration of cocoa nib. This phenomenon might contribute to the formation of flavor precursors which improve the flavor of fermented cocoa beans.

Studies by various researchers indicate that fermentation of cocoa beans prior to drying is essential in developing good flavor and reduce bitterness and astringency (Robinson *et al*., 1961; Kim and Keeney, 1984; Biehl and Voigt, 1996). Lopes and Dimick (1995) indicated that the development of flavor precursor in cocoa beans occurs during fermentation and drying. This is due to a series of biochemical changes that take place inside the beans during fermentation and drying. Stark *et al*. (2005) reported that compounds such as epicatechin, catechin, procyanidin B2, procyanidin B5, and procyanidin C1 were the cause of bitterness in roasted cocoa beans. Oxidation of polyphenol into undissolved tannins during fermentation could lead to the formation of aroma precursors which further develop into chocolate aroma in subsequent processes (Jinap and Dimick, 1990; Haslam and Lilley, 1992; and Lee, 1992). Conversion of cyanidin into leucocyanidin is the main form of polyphenol degradation in bean cotyledon during fermentation which significantly affects the aroma of cocoa final products (Forsyth, 1952). Catechin degradation during fermentation is significantly affected by temperature and duration of fermentation (Wollgast and Anklam, 2000).

Cocoafermentation technology currently used in cocoaproducing countries can be categorized as conventional technology. With this technology, the cocoa beans are placed in containers made of wood, styrofoam, orbambo for five to seven days to allow for natural fermentation to take place. The fermentation condition is uncontrolled such that the vean temperatura increases slowly in the early stage of fermentation but may increase to above 50 ^{o}C as the fermentation process progressed. This conventional method has been reported to produce cocoabeans with good flavor. However, since fermentation progressed slowly with this method, the fermentation process generally take between five to seven days to complete. As a result, most of the polyphenol contained in the beans degrades during fermentation and the health benefits of cocoaproducts decreases. By controlling the fermentation condition, cocoafermentation might be accelerated and flavor quality of the beans might be improved while maintaining most of the beneficial compounds in the beans.

This study was conducted in an effort to develop a technology which can be used to control temperature during fermentation of cocoa beans. The technology developed in this study employed ohmic heating during the early phase of fermentation to rapidly increase the temperature of the beans to the desired fermentation temperature. At the later stage when natural heat generation within the fermentation chamber increases, the beans temperature may increase beyond the desired temperature. Therefore, a mechanism is needed to reduce the beans temperature. The apparatus developed in this study was equipped with an aeration system which was triggered automatically to blow fresh air into the bottom of the fermentation chamber whenever the temperature inside the chamber increased beyond the desired temperature. The purpose of combining these two processes in the fermentation process was to shorten the lag phase in the early phase of fermentation by providing proper temperature for yeast to grow rapidly and to control the bean temperature at the later stage of fermentation. It is postulated that by doing this, the fermentation process can be shortened and the degradation of beneficial compounds in the beans such as polyphenol can be reduced.

Ohmic heating technology was originally developed for sterilization and pasteurization of milk in 1930's (Getchel, 1935; Moses, 1938) and its potential use for other purposes has been studied extensively since the 80's(Schreier *et al*., 1993; Zoltai and Swearingen, 1996; Wang and Sastry, 2002; Lima and Sastry, 1999; Kulshrestha and Sastry, 2003). Ohmic heating is accomplished by passing electric current through food materials and the electrical resistance of the material causes heat generation within the material (Sastry and Barach, 2000). This heating phenomenon that was first reported by James Prescott Joule in 1840 (Sastry *et al*., 2002) can be used effectively in food processing since solid and liquid food materials generally have the capability to conduct electricity (Salengke and Sastry, 2005; 2007a; 2007b). The amount of heat that can be generated inside the food material greatly depends on the applied electric field strength and the electrical conductivity the food material. This heating method can provide rapid, uniform, and efficient heating for liquid and solid foods (Bansal and Chen, 2006; Salengke and Sastry,

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2007b, 2007c). In addition, ohmic heating has been reported to cause electroporation in biomaterials (Schreier *et al*., 1993; Lima and Sastry, 1999; Wang and Sastry, 2002; Kulshretha and Sastry, 2003; and Lebovka *et al*., 2005) which can cause cotyledon disintegration and affect flavor formation and drying rate. Therefore, the objectives of this study were to develop anohmically heated and temperatura controlled fermention system for cocoabean fermentation and to assess the degree of fermentation achieved at several fermentation temperature and duration.

METHODOLOGY

Experimental setup

The cocoa fermentation system developed in this study consisted of three main parts, i.e. fermentation chamber, aeration system, and power supply and data accusation system (Figure-1). The fermentation chamber was made of a 12-inch diameter thick-walled PVC pipe with a volume of about 25 liters. The fermentation chamber was heated ohmically to the desired fermentation temperature. Electricity was supplied to the fermentation chamber through two plate electrodes made of stainless which were placed at the top and the bottom of the fermentation chamber. The electricity to the electrodes was supplied through a solid state relay which was controlled by a thermo-controller. The electricity to the blower was also supplied through a dedicated solid state relay which was controlled by a thermo-controller as well. The electric power supplied to the power supply was AC current with a voltage of about 220 Volts.

Temperature within the fermentation chamber was controlled during fermentation by a control system which was integrated with a data acquisition system. At the start of fermentation, AC power was supplied to the electrode such that heat is generated internally within the beans pile due to the electrical resistance of the beans. Fermentation was maintained at the desired temperature by controlling the AC supply to the electrode and fermentation temperature was controlled using thermo-controllers. At the start of fermentation, bean temperature was about 25 ^{o}C (below the desired fermentation temperature) and a thermo-controller switch the SSR to the close position to send electric current to the electrode. After the desired temperature was reached, the electricity to the electrode was cut to stop the heating process. To maintain the temperature at the desired value, a dedicated thermos-controller was used to control the SSR which supply electricity the electrode. Whenever the temperature inside the fermentation chamber drop more than 1 ^{o}C below the desired fermentation temperature, the SSR was switched to close position to send electricity to the electrode and heating resumes. On the other hand, whenever the temperature within the chamber increased more than 1 ^{o}C above the desired temperature due to the heat produced from the fermentation process, the control system would send electricity to the blower so it blows fresh air into the fermentation chamber to cool down the beans to the desired fermentation temperature.

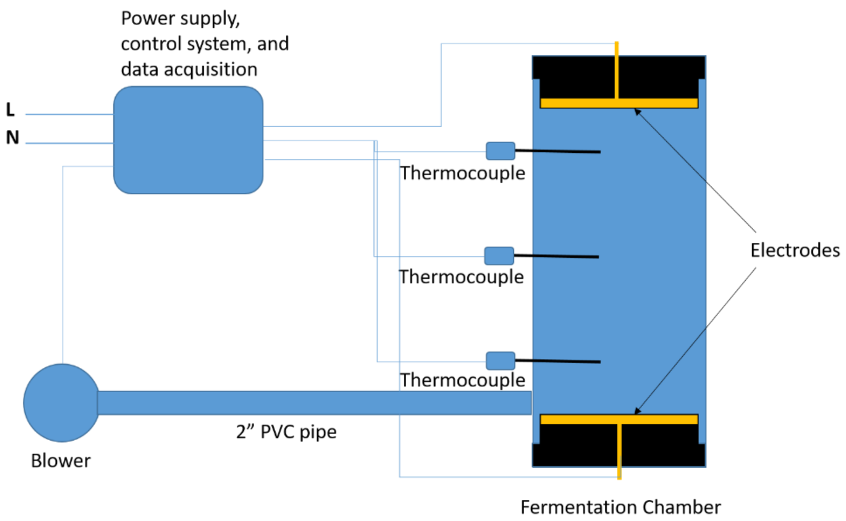

Figure-1. Experimental setup.

Experimental design

Fermentation of fresh cocoa beans was done at three levels of fermentation temperature (40, 45, and 50^{o}C) and two levels of fermentation duration (3 and 5 days). The experiment was conducted using full factorial design. In addition, conventional fermentation using a Styrofoam box (25 x 35 x 45 cm) was also done as comparison. It is important to note that the fermentation durations used in this experiment were shorter than the recommended 5 to 7 days of fermentation. This was done to examine the effectiveness of the ohmically heated fermentation system developed in this study. The level of fermentation achieved was assessed based on cut test results which has become a standard method in cocoa processing industries. In this case, the level of fermentation achieved was based on the internal color of the beans; fully brown color = complete fermentation, brown with purple spots = partial fermentation, and purple or gray color = unfermented

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(slaty beans).In addition, ohmic heating rate, AC current consumption, and electrical conductivity of cocoa beans pile were measured during the experiments. The electrical conductivity of cocoa beans pile was computed using equation 1.

$$\sigma = \frac{I}{V} \cdot \frac{L}{A} \quad (1)$$

In the above equation, I is the electric current that passed through the fermentation chamber, V is the applied voltage, L is the distance between the electrodes, and A is the cross section area of the fermentation chamber.

RESULTS AND DISCUSSIONS

Ohmic heating characteristics and electrical conductivity

The fermentation apparatus developed in this study can increase temperature inside the fermentation chamber rapidly. The heating time required for fermentation at 40, 45, and 50 ^{o}C was 9.3, 13, and 17 minutes respectively using relatively low electric field strength ((5,97 V/cm) as shown in Figure-2. It is shown in the figure that temperature in the beans pile increases linearly (R^2 = 0.998). This trend is similar to the relatively linear heating trend reported by Icier and Ilicali (2005) and Darvishi *et al.* (2013) at 30 V/cm electric field strength but slightly different from the trends reported by Palaniappan and Sastry (1991) which showed relatively concave temperature curve during ohmic heating of potato particles.

The above results show that application of ohmic heating to cocoa beans pile increased the bean temperature to the desired fermentation temperature in just a few minutes. The time required to reach the desired fermentation temperature was only a fraction of the time required to reach about 40 ^{o}C by conventional fermentation which can take about 8 to 12 hours. This can reduce the lag phase of yeast growth if fermentation temperature was set close to the ideal temperature for yeast growth such that the fermentation process can be accelerated. In addition, the combination of ohmic heating and aeration was able to keep the temperature inside the fermentation chamber at the desired fermentation temperature.

Electrical consumption during heating at the beginning of fermentation ranged from about 3.3 Amps at 31 ^{o}C to about 3.45 Amps at 50 ^{o}C (Figure-3). The increase of the electric current that passed through the fermentation apparatus was due to the increase in the electrical conductivity of the bean pile as temperature increased as shown in Figure-4. It can be seen from Figure-4 that the electrical conductivity of cocoa bean pile increased linearly with temperature and a linear equation (R^2=0.989) can be used to approximate the conductivity of the pile as shown in Equation 2. This trend is similar to the trend reported by Palaniappan and Sastry (1991) for potato, Castro *et al.* (2004) for strawberry pulp, Icier and Ilicali (2005) for peach and apricot purees, Sarang *et al.* (2008) for several types of fruits, Darvishi *et al*. (2011) for lemon juice, and Darvishi *et al*. (2013) for pomegranate juice.

$$\sigma = 0.1072 + 0.000276T \quad (2)$$

The data on temperature increase and electrical conductivity of cocoa bean pile clearly indicate that ohmic heating can be used to accelerate heating during the initial stage of cocoa fermentation. Furthermore, temperature setting can be tailored to the ideal temperature for yeast or bacterial growth such that cocoa fermentation process can be accelerated. By accelerating the fermentation process, it is hoped that the destruction of polyphenol compounds during fermentation can be reduced. However, this aspect is beyond the scope of this study and it will be addressed in future studies.

During fermentation of cocoa beans, the sugars in the pulp surrounding the beans are fermented by yeasts and converted into alcohol. This process generally takes place in the first two days of fermentation. The presence of lactic acid bacteria in the pile will cause the alcohol to be converted into lactic acid and the presence of acetic acid bacteria will convert the remaining sugars into acetic acid. The formation of these acids causes the electrical conductivity of the beans to increase as indicated by the increase in current consumption as fermentation process progressed (Figure-5) and the corresponding electrical conductivities are shown in Figure-6.

The data shown in Figure-4 indicate that the amount of electric current that flowed through the fermentation chamber increased continuously from day one to day five of fermentation except for the fermentation at 50 ^{o}C. The trend observed at 40 and 45 ^{o}C fermentation was plausible since acid formation was expected to increase as fermentation duration increased and consequently electrical conductivity of the bean pile increased. On the other hand, the trend observed at 50 ^{o}C fermentation was probably due to a drying effect at this temperature which caused the decrease in electrical conductivity of the cocoa bean pile beginning at day three of fermentation (Figure-6). It is important to note that the surface of the bean skin was noticeably drier at the end of fermentation when fermentation was held at 50 ^{o}C.

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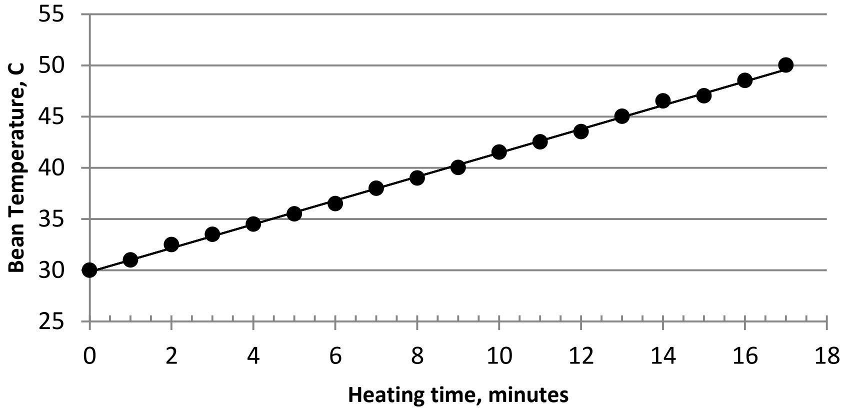

Figure-2. Temperature increase in the bean pile inside the fermentation chamber.

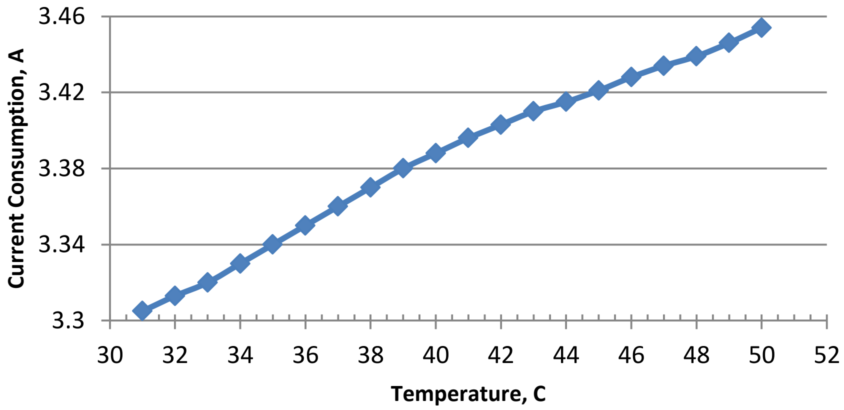

Figure-3. Current Consumption during heating at the start of fermentation.

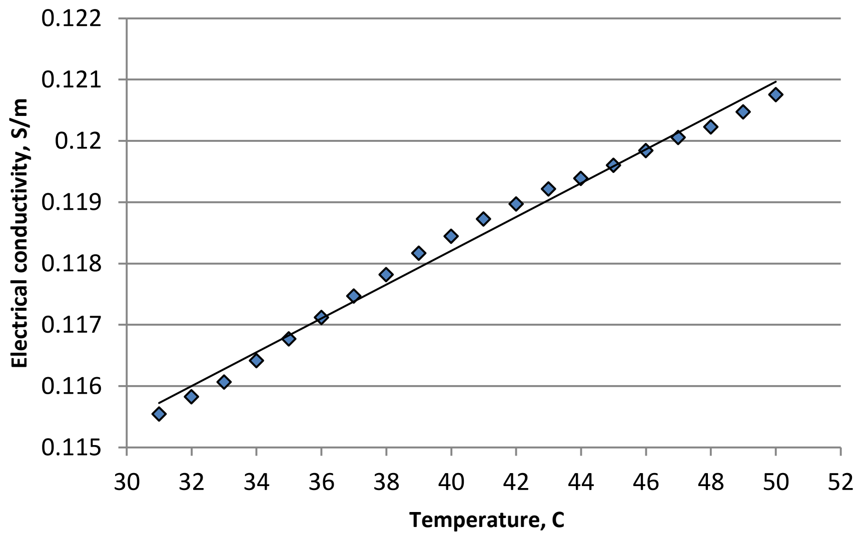

Figure-4. Electrical conductivity of cocoa bean pile during ohmic heating.

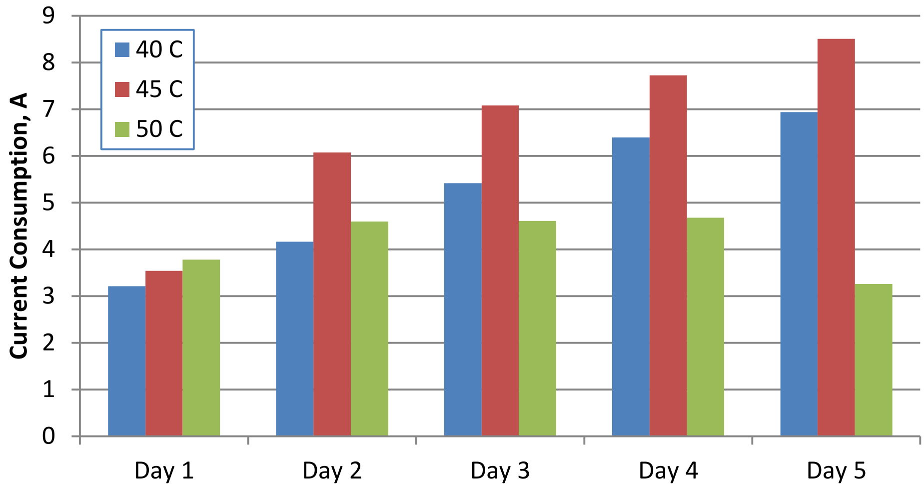

Figure-5. Current consumption at various fermentation temperature.

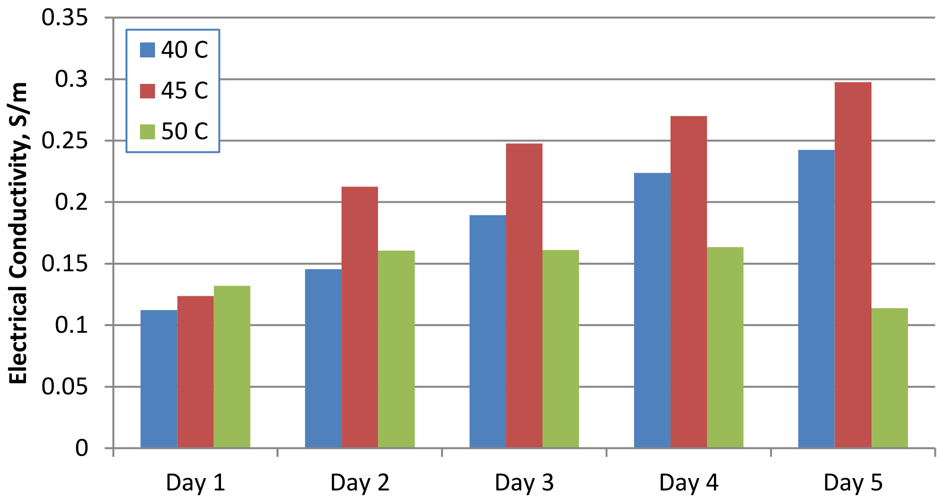

Figure-6. Electrical conductivity of cocoa bean pile at various fermentation temperature.

Degree of fermentation

The degree of fermentation achieved after fermentation is commonly assessed based on the internal color of bean cotyledon and this is usually done through cut test. The cut test is commonly done using cut test knife which can slice the beans longitudinally into two equal parts. The cut test knife used in this study can slice 50 beans at a time. The internal color observed from cut test results are given in Table-1.

The data shown in Table-1 indicate that ohmic heating assisted fermentation of cocoa beans can produce fully fermented cocoa beans at shorter duration. Conventional fermentation resulted in about 33% unfermented beans after 3 days of fermentation while ohmically assisted fermentation only resulted in less than 2.5% unfermented beans at the same fermentation duration. The cut test results also indicated that fermentation at relatively low temperature (40^{o}C) was able to produce high degree of fermentation after 3 days of fermentation. At this condition, the total amount of unfermented and half fermented cocoa beans was only about 5%. Fermentation at higher temperatures (45 and 50 ^{o}C) also provided approximately the same results. These results clearly indicate that ohmically assisted cocoa fermentation at controlled temperature can provide high degree of fermentation with shorter fermentation duration.

Unfermented cocoa beans or beans with low degree of fermentation showed purple color in the inside of the nib and their texture were rubbery. For well fermented beans, the inside color of the nib was brown and there appeared disintegration of the nib as shown by cracks which were formed during fermentation. Conventional fermentation for three days produced nibs with mostly brown internal color but with some purple spots. Some of the nibs also showed rubbery texture indicating that the fermentation was incomplete. Conventional fermentation for five days yielded well fermented beans as shown by fully brown of the internal color of the nibs and the nibs were easily cracked with fingers.

The cocoa beans fermented using the ohmic heating chamber showed good fermentation results even at low temperature (40^{o}C) and short duration (3 days) as can be seen from the internal color of the nibs and the nib texture. At this condition, only very small fractions of the

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beans were half fermented. By extending the fermentation duration to five days, all of the beans were fully fermented. However, the quality of final product from the three-day fermentation will not differ significantly from that from the five-day fermentation since the fraction of the half fermented beans was very small. Therefore, fermentation process can be reduced to three days by using the ohmic assisted fermentation apparatus. Fermentation at 45 and 50^{o}C also showed that the degree of fermentation achieved after three days of fermentation was high.

Various studies have indicated that the length of fermentation and fermentation temperature can significantly affect the degradation of polyphenol compounds in cocoa beans. Therefore, shorter duration of fermentation at lower temperature can potentially reduce the degradation of polyphenol in fermented cocoa beans. This aspect is beyond the scope of this study but it will be meaningful to address in future studies.

CONCLUSIONS

An apparatus for ohmically assisted cocoa bean fermentation has been successfully developed and it can be used for fermentation of cocoa beans at controlled temperature. Cocoa beans can be heated rapidly to the desired fermentation temperature using ohmic heating. Electrical conductivity of cocoa beans is moderate and it increased linearly with temperature. The conductivity also increased as fermentation progressed since more acids were produced. The degrees of fermentation achieved were high even at relatively short fermentation duration.

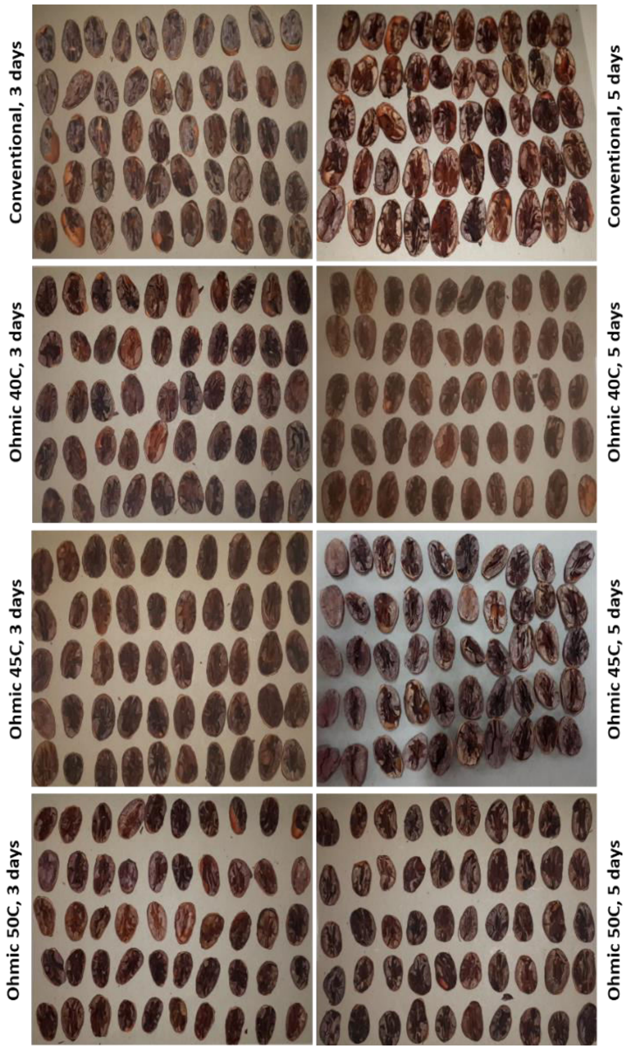

Figure-7. Internal color of cocoa bean after fermentation.

Table-1. Cut test results of fermented cocoa beans.

Fermentation Treatment	Complete fermentation (brown), %	Incomplete fermentation (brown + purple), %	Unfermented (purpleor gray), %
Conventional (3 days)	63.33	3.33	33.33
Conventional (5 days)	95.33	1.33	3.33
Fermentation at 40^{o}C (3 days)	95	3.33	1.67
Fermentation at 40^{o}C (5 days)	98.67	1.33	0
Fermentation at 45^{o}C (3 days)	95.67	2.0	2.33
Fermentation at 45^{o}C (5 days)	96.33	2.67	1.00
Fermentation at 50^{o}C (3 days)	94	3.67	2.33
Fermentation at 50^{o}C (5 days)	98.33	1	0.67

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