Technology intervention to unleash the flavor potential of arabica coffee from Sulawesi highland

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Abstract. Coffee is arguably the most popular drink in the world after water and it is estimated that global coffee consumption exceeds 2 billion cups every day. Today, coffee is not only consumed for pleasure but it is also used as a catalyst for social gatherings and networking. This is due to the fact that coffee can provide pleasurable taste and aroma. In order to optimize these organoleptic properties, technology interventions during postharvest processing are needed to unleash the potential flavor in coffee beans. This study was done to address this issue, especially for improving flavor and aroma potential of arabica coffee beans from Enrekang and Tanah Toraja in the highland of Sulawesi. Technology interventions in the form of fermentation (wet process) and drying were carried out and flavor notes and aroma were assessed through cup test. The results indicated that cup test scores can be improved and different flavor notes can be generated through different processing conditions.

1. Introduction

Coffee is an important commodity because it is traded globally in high volume. This is because coffee is considered as one the most popular drink after water. Currently, it is estimated that daily coffee consumption has exceeded 2 billion cups [1]. This high consumption is due to the desirable flavor and aroma characteristics and its stimulating effects. In addition, many researchers have indicated that daily consumption of coffee at the right level can provide health benefits and can reduce the risks of type-2 diabetes [2], Parkinson’s disease [3], Alzheimer’s disease [4], coronary heart disease [5,6], and certain types of cancer [7,8].

The flavor and aroma of coffee are affected by many factors such topography, soil condition, growing temperature and humidity, coffee variety, and postharvest processing [9,10,11,12,13,14,15]. The importance of processing technology on flavor and aroma characteristics of coffee cannot be underestimated [15,16]. Many researchers have reported that flavor and aroma characteristics of coffee can be enhanced significantly through proper processing methods [17,18] but they can also be destroyed if an improper method is applied [19]. In addition to fermentation, two other important steps in coffee processing that can significantly affect quality are drying [20,21,22,23] and roasting [15,24,25].

Processing of coffee cherries are generally done in three different ways, namely natural process (dry method), wet process, and honey process [15]. These processing methods have been reported to produce coffee with different flavor characteristics [26,27]. In addition to these three methods, there is another processing method that is specifically used in Indonesia which is called wet hulling (also called...
giling basah in Indonesia). In the natural process, whole coffee cherries are dried directly under the sun for about three weeks to obtain dry coffee cherry at about 10 - 12% moisture content. After drying, the outer skin and the parchment are removed using a dehulling machine. The coffee beans obtained from this processing method is called natural processed beans with lower acidity, sweeter, smooth, and complex flavor [27]. For the wet process, the pericarp of the coffee cherries is immediately removed after harvest and the parchment coffee beans are soaked overnight in fermentation tanks to allow yeast and bacteria to ferment the sugar-containing mucilage surrounding the parchment. This process is believed can alter the flavor and aroma characteristics of coffee beans. Flavor notes generally associated with wet process are fruity, floral, and caramel [28]. In the honey process, the parchment coffee beans obtained after removal of the pericarp are sun dried directly without the fermentation step until the desired moisture content of about 10 - 12% is obtained.

The wet process is probably the most studied among the three methods of coffee processing. This is because this processing method can potentially produce coffee with excellent flavor and aroma characteristics but it can also destroy the flavor if it is not done correctly. Therefore, many studies have been done to identify processing conditions which can produce the desired flavor characteristics. The processing parameters studied include the length of fermentation time, the presence of oxygen, the absence of oxygen and the increased concentration of carbon dioxide, and the type of yeast and bacteria involved or used in the fermentation process.

It has been shown in many fermentation processes on other products that depending on the temperature used, the growth and activity of certain microbes are encouraged more than those of others. Therefore, one way to manipulate the types of microbes that are dominant in the fermentation process is by manipulating fermentation temperature. So far, coffee fermentation process is commonly done at ambient temperature or around 30 °C [29,30,31] and a few experiments at ambient temperatures below 28 °C have been reported [32]. Another approach that has been used to manipulate the types of microbes that are dominant in fermentation process and the rates of their activities is fermentation depulped coffee beans in the absence of oxygen (anaerobic fermentation) or fermentation of whole coffee fruits under anaerobic condition (carbonic maceration). These methods of fermentation have gained interests from many practitioners but they have not been studied extensively. However, a few have reported that these methods of fermentation can produce coffee with excellent flavor and aroma [33].

In the present study, we tried to manipulate the rates of fermentative activities of naturally present microbes by performing fermentation process at constant and above ambient temperatures. In order to attain this condition, the fermentation process was performed in ohmically heated vessels. This approach has not been used before in coffee fermentation. The purpose of this study was to determine the effect of temperature and the length of fermentation on flavor characteristics and cupping score of arabica coffee from Enrekang and Tanah Toraja regions in the highland of Sulawesi.

2. Material and method

The coffee cherries used in this study were obtained from Enrekang and Tanah Toraja regencies in South Sulawesi, Indonesia at altitudes of around 1,350 – 1,450 meters above sea level. The cherries were handpicked and only mature cherries with fully red skin were chosen. After harvest, the cherries were immediately transported to Teaching Industry facility at Hasanuddin University Campus in Makassar for dehulling, fermentation, and drying.

Fermentation process was carried out using the experimental apparatus that we have reported previously [34]. This apparatus consisted of three ohmic vessels capable of fermenting 45 kg of freshly dehulled parchment coffee beans. The temperatures inside the vessels were independently controlled by temperature controller to maintain the fermentation temperature within 0.5 °C of the desired temperature. This is done by controlling power inputs to each of the ohmic vessels using either PID or fuzzy based temperature controllers. A schematic diagram of the ohmic heating apparatus used for coffee bean fermentation is shown in figure 1. Fermentation temperature was set at 30, 33, and 36 °C with fermentation duration ranged from 12 – 36 hours. Following each fermentation experiment, the
coffee beans were sun dried to reduce the moisture content to about 25 - 30% wet basis, then dehulled to remove the parchment, and sun dried again to the safe moisture content of about 12%.

Assessments of aroma and flavor of coffee drinks obtained from the fermentation process were performed by a certified coffee cupper at the Indonesian Centre for Cocoa and Coffee Research in Jember, East Java. Preparation of coffee samples for the cup test followed the procedures reported previously [34] and cupping protocol used was the standard tasting protocols established by Specialty Coffee Association of America [35].

![Figure 1. Experimental apparatus for fermentation of coffee cherries or parchment coffee beans in ohmic heating vessels. (1) ohmic heating vessels, (2) controlled power supply system, (3) control and data logging system, (4) computer.](image)

3. Results and discussion

3.1. Current consumption of ohmic assisted fermentation

In many studies that have been reported, coffee fermentations were generally done at ambient temperature and the experimental parameters used were mainly the length of fermentation, coffee origin, and the types of microbes used in fermentation. There has been no study reported on coffee fermentation at elevated temperatures. This study specifically dealt with this issue by performing coffee fermentation in ohmic heating chamber that can elevate and maintain temperature inside the fermentation chambers. In this case, we used ohmic heating to generate heat internally inside the fermentation vessels. Therefore, the first aspect that need to be investigated is the amount of energy needed throughout the fermentation process.

The results reported in this study were obtained from fermentation process at elevated constant temperatures. Depulped coffee beans at temperature of about 25 - 27 °C were first heated to the desired fermentation temperature by passing electric current through the fermentation vessels. The passage of the electric current was controlled using thermo controller. When the temperature inside the fermentation vessels were below the desired fermentation temperature (set point temperature), the controller will activate a solid-state relay (SSR) on the power supply system so it will allow the flow of electric current through the fermentation chamber. On the other hand, once the temperature inside the vessels has reached the desired fermentation temperature, the thermo controller will deactivate the SSR.
and the flow of electric current to the fermentation vessels will stop. Due to energy loss from the vessel wall to the environment, the temperature inside the vessels will eventually drop below the fermentation temperature. In this case, the thermo controller energizes the SSR and the flow of electric current to the fermentation vessels resumes such that internal heating will occur. The SSR will be deenergized when the temperature inside the fermentation vessels reaches the set point temperature. This is the mechanism used to control fermentation temperature at a desired level. The flow of electric current inside the fermentation chamber is due to electrical conductivity of materials (coffee beans and of the water used as fermentation medium) inside the fermentation vessel. During its flow, electric current has to overcome electrical resistance of the materials which causes internal energy generation within the material. The rate of energy generation due to the passage of electric current through a material depends on the electric field applied and electrical conductivity of the conducting material [36]. In this case, the rate of heat generation inside the fermentation chamber depends on the electrical conductivity of coffee beans and the water inside the fermentation vessel.

The power supply system developed for the ohmic heating assisted fermentation system for coffee beans fermentation used 220 V of electric source and with the distance between electrodes inside the fermentation vessels of about 125 cm, then the electric field used during fermentation was only about 1.76 V/cm. The extremely low electric field resulted in slow heating rate inside the fermentation vessels so it took relatively long time to reach the desired fermentations temperatures. This is desirable since it will provide enough time for the fermenting microbes to adjust to the fermentation temperature. For fermentation at 30 °C, the time required to reach the fermentation temperature from an initial temperature of 25 °C was about 4 hours, and the times required for fermentation at 33 and 36 °C were about 5.5 and 6.5 hours. If higher heating rate is desired, we can use 380 V of electric source which can provide almost three time of heating rate compared to that provided by the 1.76 V/cm electric field.

The electric field applied and the electrical conductivity of coffee beans and the water medium significantly affect the amount of electric current which pass through the fermenter. The electrical conductivity itself is temperature dependent [36,37,38]. Therefore, during heating phase when temperature inside the fermenter was increasing from initial temperature to fermentation temperature, the electrical conductivity tended to increase. In addition, acid compounds from the mucilage might also diffuse into the water medium which can also contribute to the increase in the electrical conductivity. As a consequence, the amount of electric current which flows through the fermentation chamber also increased which in turn increased the heating rates as demonstrated previously through experimental and modelling studies [37-39]. The amount of electric current which flowed through the fermentation chamber during fermentation is shown in figure 2.

![Figure 2. Current consumption during ohmic assisted fermentation of parchment coffee beans.](image-url)
That data shown in figure 1 indicate that electric current consumption in the beginning of the fermentation process (0 - 6 hours) increased at higher rates compared to the increase thereafter. The increase in current consumption during this stage was more due to the increase in temperature which causes the increase in the electrical conductivity of fermentation medium and the fermented coffee beans. Much of the heat generated during this stage was used to increase temperature to the desired fermentation temperature. It can also be seen that temperature increase during this stage can be adequately approximated using linear correlations. This is usually the case when the increase in current consumption, and thus the internal energy generation, is solely due to the increase in electrical conductivity of the material. This is in accordance with findings reported by many researchers which showed that the rate of heating due to the passage of electric current through a material is dependent on electrical conductivities, while electrical conductivities are linearly dependent on temperature [36-38].

In parchment coffee beans fermentation, mucilage surrounding the parchment is degraded by fermentative yeasts and bacteria due to its sugar content. During fermentation, the sugars in the mucilage are converted into alcohol and subsequently into acids. Therefore, as fermentation progressed, the acids formed also increases which increase concentration of ions in the fermenting media. As a result, electrical conductivity of the media increases and the amount of electric current which can flow through the media also increases. The increase in current consumption during fermentation after constant temperature in the fermentation chamber was reached was a clear indication of this process.

The rate of increase in electric current consumption after six hours of fermentation at 30 °C and 33 °C tended to decrease a little bit since during this stage, temperature inside the fermentation chamber was relatively constant. At constant temperature and constant ionic concentration within a conducting media, the electrical conductivity of the media is must be constant and as a consequence current flow should also be constant. Therefore, the increase in current consumption during the constant temperature period indicates that ionic concentration within the fermentation media is increasing. This increase in ionic concentration might result from acid compounds produced by fermenting microbes during fermentation. The increase in current consumption continued up to about 24 hours of fermentation, after which current consumptions were relatively constant. This might indicate that conversion of sugar in the mucilage had subsided and fermentation can be ended at this time.

The is an interesting phenomenon observed during fermentation at 36 °C as indicated by the data in figure 1. Current consumption jumped significantly after six hours of fermentation and started to plateau after ten hours of fermentation. It is important to note that after six hours of fermentation, the temperature inside the fermentation chamber was relatively constant. Therefore, the significant increase the current consumption might indicate that the rate of fermentation and thus acids formation were high during the period which significantly increased electrical conductivity of the material inside the fermentation chamber. After ten hours of fermentation, current consumption only increased slightly and relatively constant after 18 hours of fermentation. This trend might indicate that the mucilage had degraded completely and there were no fermentable sugars left after 18 hours of fermentation. Therefore, the constant electric current can be used as an indicator that fermentation process has been completed. In the aforementioned cases, the fermentation process can be ended after about 24 hours for fermentation at 30 °C and 33 °C and 18 hours for fermentation at 36 °C.

The phenomenon observed on current consumption during ohmic assisted coffee fermentation has an important implication since it can be used to control the length of fermentation process to obtain optimal flavor and aroma. Currently, coffee beans fermentation is customarily done in a predetermined length of time without using any indicator on the end point of the fermentation process. This practice may lead to under fermentation or over fermentation which in turn can lead to suboptimal or inconsistent quality. It is important to note that the rate of fermentation is affected by many factors such as variety
and fruit maturity at harvest which affect the amount of fermentable sugars in the mucilage, temperature, and the types and population of fermenting microbes present at the surface of the beans after depulping.

The ohmic based coffee bean fermentation technology developed in this study was intended for farmers groups. Therefore, the amount of electric power needed to operate this technology must be considered. Based on the current consumption data collected during fermentation experiments, we found that the amount of electric power needed was about 230 Watts for each fermentation vessel or about 700 watts for three fermentation vessels working in parallel, each using one phase from a 3-phase electricity. Power needs of this amount can be easily obtained in villages in coffee producing regions in Indonesia. It is also important to note that after fermentation temperature is reached, any additional energy supplied to the fermentation vessels is only used to compensate for energy loss through the vessels walls in order to maintain the temperature inside the fermentation chamber. Observations done during the constant temperature period revealed that power supply only switched to the “on” status for about 2 seconds for every 5 minutes interval which indicate that power consumption is very low.

3.2. Changes in pH during fermentation

As has been alluded to previously, fermentation of freshly depulped coffee beans is done to developed desirable flavor characteristics in coffee beans by degrading the mucilage surrounding the beans through microbial actions. The development of flavor and aroma characteristics during this process might be due to the secondary metabolites produced by the microbes which penetrate into the beans [40-42]. In addition, fermentation of sugars in the mucilage produces organic acids [15] such as lactic acid, acetic acid, citric acid, malic acid, and succinic acid [32,43]. The production of these organic acids causes the pH to decrease as fermentation progressed.

The pH of mucilage in freshly harvested coffee beans is generally around 5.5 – 5.7 [44]. The coffee fruits used in this study was harvested at farms about 350 km from the campus where the fermentation study was done and the fruits were depulped at about 18–20 hours after harvest. Therefore, anaerobic fermentation may have taken place during transportation which caused the pH to decrease to about 4.2 - 4.5 as measured right after depulping which might indicate that it had degraded during transportation. The pH tended to decrease during fermentation from start to finish, as shown in figure 3. The same trend was reported by Avallone et al [44] but different from the trend observed by Jackels and Jackels [45] which showed relatively constant pH during the first fifteen hours of fermentation. The reduction in pH is due to the acids produced by the microbes involved in fermentation process.

![Figure 3. Changes in pH of fermentation media during parchment coffee beans fermentation.](image-url)
The data shown in figure 2 indicate that the pH of fermentation media decreased linearly up to 24 hours of fermentation and tended to plateau thereafter. It is also important to note that the effect of the fermentation time on pH was much more pronounced compared to the effect of fermentation temperature.

3.3. Effects of fermentation on quality
Flavor quality of coffee drinks from beans produced through the ohmic assisted fermentation process was assessed through cup-test using the standard cupping protocol established by Specialty Coffee Association of America (SCAA). Cupping was conducted by an internationally certified coffee cupper at Indonesia Research Center for Coffee and Cacao in Jember. A total of 24 samples from a full factorial fermentation experiment at three levels of temperature (30, 33, dan 36°C) and four levels of fermentation duration (12, 18, 24, dan 30 hours) with two replications. Cupping results indicated that all the samples can be classified as specialty coffee with final scores higher than 83. In fact, based on the standard used by SCAA, 15 of the samples can be classified as “Excellent” with final score of 85 or higher and the rest can be classified as “Very Good” with final scores of 83 or higher. It is also important to note that all the samples tested received perfect score in sweetness, clean cup, and uniformity attributes. Based on the cupping scores of all the samples, we are confident that ohmic assisted fermentation technology for coffee fermentation can consistently produce coffee beans with high quality. However, optimization of process parameters is still needed to optimized all the attributes in the SCAA standard. Examples of cupping scores for samples with the highest and the lowest final scores are given in figure 4.

Figure 4. Cupping scores of attributes used in SCAA standard.

4. Conclusions
Technology intervention in the form of ohmic assisted fermentation of depulped coffee beans can increase cupping scores of coffee beans from Enrekang and Toraja in the highland of Sulawesi. This fermentation technology can consistently produce coffee beans with high quality as indicated by the final cupping scores and it can be used at farmers group level. This technology can be easily scaled up simply by inserting fermentation vessels into an existing system. Energy input required is relatively small so it can be powered through electric lines which are available in villages.

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