

Homogenization of Cocoa Beans Fermentation to Upgrade Quality Using an Original Improved Fermenter

Aka S. Koffi, N'Goran Yao, Philippe Bastide, Denis Bruneau, Diby Kadjo

Abstract—Cocoa beans (*Theobroma cocoa* L.) are the main components for chocolate manufacturing. The beans must be correctly fermented at first. Traditional process to perform the first fermentation (lactic fermentation) often consists in confining cacao beans using banana leaves or a fermentation basket, both of them leading to a poor product thermal insulation and to an inability to mix the product. Box fermenter reduces this loss by using a wood with large thickness ($e > 3\text{cm}$), but mixing to homogenize the product is still hard to perform. Automatic fermenters are not rentable for most of producers. Heat ($T > 45^\circ\text{C}$) and acidity produced during the fermentation by microbiology activity of yeasts and bacteria are enabling the emergence of potential flavor and taste of future chocolate. In this study, a cylindro-rotative fermenter (FCR-V1) has been built and coconut fibers were used in its structure to confine heat. An axis of rotation (360°) has been integrated to facilitate the turning and homogenization of beans in the fermenter. This axis permits to put fermenter in a vertical position during the anaerobic alcoholic phase of fermentation, and horizontally during acetic phase to take advantage of the mid height filling. For circulation of air flow during turning in acetic phase, two woven rattan with grid have been made, one for the top and second for the bottom of the fermenter. In order to reduce air flow during acetic phase, two airtight covers are put on each grid cover. The efficiency of the turning by this kind of rotation, coupled with homogenization of the temperature, caused by the horizontal position in the acetic phase of the fermenter, contribute to having a good proportion of well-fermented beans (83.23%). In addition, beans' pH values ranged between 4.5 and 5.5. These values are ideal for enzymatic activity in the production of the aromatic compounds inside beans. The regularity of mass loss during all fermentation makes it possible to predict the drying surface corresponding to the amount being fermented.

Keywords—Cocoa fermentation, fermenter, microbial activity, temperature, turning.

I. INTRODUCTION

THE basic product for chocolate manufacturing is cocoa beans. Each cocoa tree fruit contains about 40 beans (*Theobroma cacao* L.). This fruit, called cocoa pod, when ripening becomes orange or yellow. They are harvested and

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opened [1], [2] to extract the beans and their enveloping pulp inside for following alcoholic and acetic fermentations. The last step is the drying on the farm, in order to ensure their stability. The fermentation process involves many chemical reactions that lead to reveal the aromatic compounds and to develop chocolate taste precursors. Once the pods are opened, the beans are handled by the operator and thus get in contact with the operator hands and tools and surrounding air and insects. This fermentation environment thus brings them yeasts, bacteria and molds [3], [4]. The microbial activity generated by these germs is composed of two successive phases: an anaerobic alcoholic phase followed by an aerobic acetic phase.

The water contained in the pulp constitutes a barrier, which prevents the air to reach the beans inside the mass. This sugar-rich medium, acidity and temperature [5] makes it suitable for the development of yeasts [6]. Yeasts transform glucose into alcohol. This first fermentation can last up to 48 hours with a temperature up to 45°C . It leads to the degradation of the pulp and the flow of sugar water (pulp juice) through the cocoa beans mass, thereby reducing the mass of the product in fermentation. Thus, the acetic fermentation phase is favored by the improvement of oxygenation of heap of fermentation. The alcohol produced previously acts as a substrate for bacteria to produce acetic acid. During this fermentation phase, acetic acid is mainly produced by oxidization of alcohol by the acetic bacteria (AB); nevertheless, production of lactic acid by lactic bacteria is observed. Some of the acids evaporate, some are transformed into esters and some diffuse into the beans. These oxidation reactions are more exothermic than alcoholic reaction, and temperature in the cocoa beans mass can reach or overcome 50°C . This reaction produces water [7].

This water will be evacuated by gravity or by evaporation because of the high temperature leading to a further reduction in the mass of the beans in fermentation, even if it is less important than the previous one. The combination of this high temperature and the acidity leads to the penetration of acetic acid into the nib. It causes a gradual browning of cotyledons, the death of the germ, the appearance of amino acids and other precursors of flavors [8]-[10]. These changes in the nib are carried out by enzymes whose activity are optimal at pH values about 5.0 [8]. Ideal fermentation process requires a regular mixing of the cocoa beans mass, by the operator. This action will consist in mixing the beans in heap during fermentation to homogenize the chemical reactions in

progress. The optimum frequency is to turn beans after the first 24 hours of fermentation, then every 48 hours [11]. Another approach consists of turning after 24 hours of fermentation and then 24 hours, with the aim of reaching 45°C in the fermented heap; According to Barel [7], a turning can occur after another 48 hours, in order to reach 50°C. An efficient mixing thus contributes to improving the quality of beans [12] by favoring the action of AB. Because of the fermentation process and the actions to accompany it, it appears that the fermenter has to realize three major functions to improve the quality of cacao beans: a) facilitate the activity of the fermenting germs, b) make the homogenization of the fermentation heap easy and efficient, c) contain the heat produced during fermentation for optimizing the chemical changes inside the nib.

The quality of fermented cocoa beans depends on the fermenter design [13], [14] then several authors recommend multilevel fermenter or compartments. Nevertheless, risks of heat losses are high for this fragmented architecture. Other works recommend using fermentation box made with solid plank of wood with at least 3cm of thickness to reduce these losses [3], but this way has an impact on the cost of realization and the mobility of the fermenter. In another study, the turning is automated and this fermenter may contain the harvest of a 10 hectare plantation [15]. Finally, another author refers to the use of old barrels of wine and turning will be realized by rolled it on the floor. But in this type of fermenter, the poor air circulation increases the risk of mold growth [13].

The aim of this study is to design and realize a fermenter integrating these three functions simultaneously. Then we will study its impact on the quality of the fermentation through the monitoring of the pH of the beans, evolution of temperature during the process, impact of the type of turning implemented, mass of beans at the end of fermentation, and impact of the fermenter on the quality of exported beans.

II. MATERIALS

The cocoa plant material came from the cocoa plantations of the Agricultural Society of Bandama (SAB) in Côte d'Ivoire in the village M'Brimbo. These pods are from different genotypes and the behavior of trees in the field is heterogeneous like the Ivorian orchard. Cultivars used are mainly "uncontrolled mixes"; it is a mix of mostly Trinitario and Foresterio (amelonado) with Criollo in very small proportion.

III. METHODOLOGY

A. Experimental Design

Pods have been harvested and stored during 5 days before pod breaking. On the 6th day from 7 a.m., pods are opened with a piece of wood, according to habits in rural areas. The impaired beans such as germinated, stung by insect, beans from unripe pods, flat beans and beans damage during pod breaking were discarded. Then, good beans are grouped in plastic containers for transport to the fermenter. The quantities loaded into fermenter varied between 50 kg and 170 kg. For

the whole experimentation, about 4 ton of fresh beans were used. The bottom and walls of the experimental fermenter was lined with about six large banana leaves. The loading of the fermenter was generally completed around 2:00 p.m. and the fermentation was stopped on the 6th day approximately around 10:00 a.m. (about 140 hours of fermentation). The mass of the beans at the inlet of the fermenter was weighed. The temperatures in the fermentation mass and in the immediate fermenter environment were measured during the fermentation. The pH of the beans was measured. Two turnings' timing were used, the first is a turning every 24 hours on average and the second is a turning after 48 hours and then every 24 hours. At the end of the fermentation, the beans were weighed again and separated into two equal lots. One lot was dried in a traditional dryer and the second in an experimental dryer. Drying was from 8:00 a.m. to 04:00 p.m. for 5 to 8 days. At the end of the drying, for the evaluation of the quality, a sample was taken for evaluation (Fig. 1).

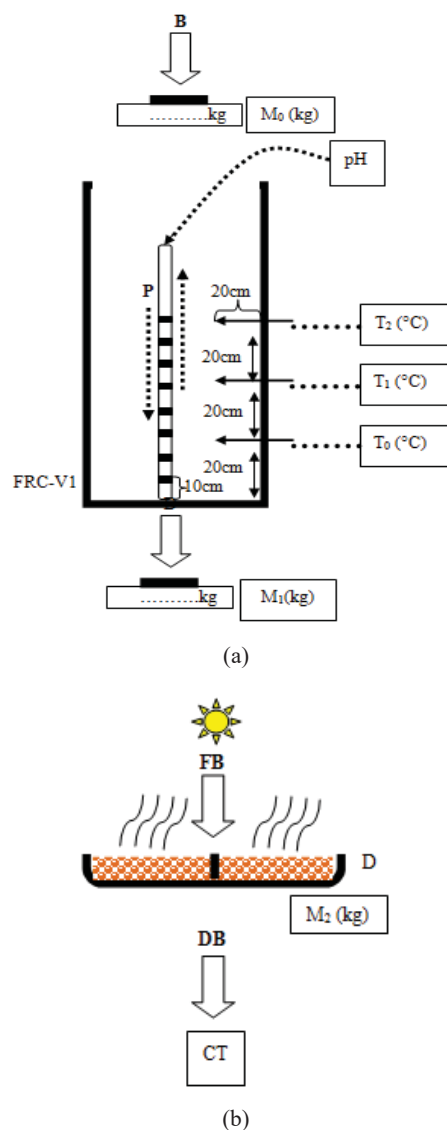


Fig. 1 Measure point during experimental design: (a) for fermentation, (b) for drying

TABLE I
CAPTION ASSOCIATED WITH THE MEASUREMENTS DESIGN

Annotations	Description of annotation	Annotations	Description of annotation
B	Healthy fresh beans	M ₀	Inlet fresh beans mass
P	Sampling probe (to retrieve the sample every 10 cm in height)	pH	Acidity of beans
FRC-V1	Experimental fermenter	M ₁	Fermented beans mass
FB	Fermented beans	T _i	Temperature each 20cm of the heap high
D	Drying	M ₂	Mass of dry beans

B. Methods of Measurement

Temperature during Fermentation: The temperature in the fermentation mass was measured by placing 3 waterproof probes (L=0.25m, pt100 3 wire) at different heights (0.20m, 0.40m, 0.60m) into the mass and at 0.20m from the edge. Then data were read and recorded each minute, on an acquisition unit (ALMEMO 8590-9, Wimesure France). The part of the probe outside the fermenter is protected from weather hazards.

pH during Fermentation: During the fermentation, 2 samples of beans are taken per day (at 0h, 18h, 28h, 42h, 52h, 66h, 76h, 91h, 101h, 114h, 124h and 140h) at different depths and in different areas in the fermenter, with coring of the sampling probe. A batch of 50g was crushed with a propeller mill and then 5g were weighed on a precision scale ($\pm 0,001g$). They were mixed with 50ml of distilled water according to the Association of Official Analytical Chemists' (AOAC)[16]. After stirring, a pH meter adapted to the pasty product (FY96PHEE, Wimesure France) and previously calibrated was immersed in the solution. After stabilization, the displayed value was recorded. The pH-meter and all the equipment used were abundantly rinsed with distilled water, for the next use.

Mass Weight before and after Fermentation: The total mass weight of the beans inside the fermenter was obtained by adding together the successive masses weight of the different batches introduced, with a precision balance (20g, PCE-PB 60N). The same principle was used at the end of the fermentation.

Final Quality of Exported Beans: Cut test has been done to evaluate the quality of beans after fermentation and drying. Beans are cut in half lengthwise and color of both halves were examined in full day light. The percentage of brown nib (well-fermented beans) is determined. It is established on 300 beans, taken from different parts of the bag, after collecting the beans from each dryer [16].

IV. RESULTS AND DISCUSSION

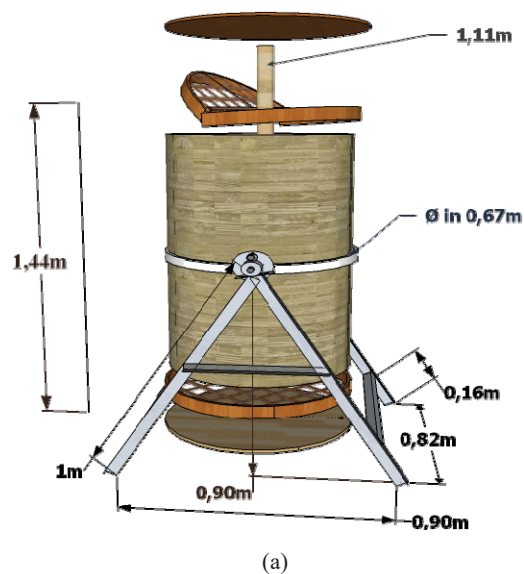
A. Specification and Implementation of the Experimental Fermenter

The analysis of the chemical process of fermentation taking into account the three essential functions in a cocoa fermenter, allowed us to have a new approach in the design of fermenter. This resulted in a realization of a cylindrical fermenter with

circular cross section. It is half loaded and in a vertical position, in addition it includes:

- A wooden frame with the partition walls lined with coconut fiber for thermal insulation;
- Two grid covers made in woven rattan, allowing air to circulate in the fermenter during the turning phases;
- Two airtight covers to be fixed on top of each grid cover, to reduce air flow circulation during rest of the time of fermentation. The bottom airtight cover will be pierced with a hole to facilitate the flow of the fermented sweating;
- A bean compression device has been used to press the fermenting mass, in order to eject the air pockets in between beans formed during the filling, and to remove a part of the pulp water;
- A cover on the surface of the fermenting mass, to separate it from the empty space left after the filling;
- A rake has been used to spread the beans during filling and also for removing them from the fermenter at the end of fermentation;
- A tilting mechanism and an axis of rotation. This axis of rotation must have three functions, the first allowing a rotation of the fermenter to realize the turning. The second is to keep the fermenter in a vertical position during the alcoholic phase. The third is to allow the fermenter to go and to maintain itself horizontally during the acetic phase, in order to increase the exchange surface of the beans with air and to manage the heat prevailing inside.

The axis of rotation should make it possible to ensure a drop of the beans which breaks aggregates. Each rotation corresponds to a turning to homogenize the distribution of the air and thus allows a homogenization of the chemical reactions in progress. Its size is related to its processing capacity. In our case, we processed 150kg of fresh beans with a fermentation volume of $V_{\text{ferm}} = 0,16m^3$ and a base radius $r_{\text{ferm b}} = 0,28m$ (cf. Fig.2).



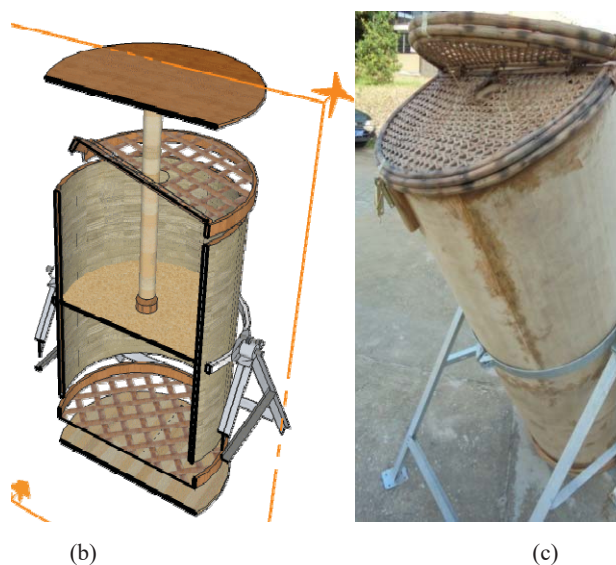


Fig. 2 Fermenter: (a) drawing with quotation, (b) Drawing interior view, (c) after implementation

B. Evolution of Temperature during Fermentation

During the first 48 hours, the temperature of the beans in the fermenter increased from 29°C to 45°C. From 48 hours to 121 hours, its remains above 45°C and the highest value (48°C) occurred at 104 hours. The wave in temperature value and decreases are due to turning process. Before 120 hours of fermentation, the turning causes temperature increases. After, the changes in their progress are lower. The external environment in which the fermenter is located has no influence on the evolution of the temperature in beans heap during fermentation. Temperatures always reach 45 °C, although sometimes it can take about 3 days. These temperatures are much higher than those obtained in some research works where 500kg of beans were used [17]. Nevertheless, these temperatures are practically identical to those measured in a fermentation with 600kg [18]. After 120 hours (in 5th days), the proportion of oxidized alcohol has become very low [1], this may explain the non-significant increase in temperature accompanying the turnings (cf. Fig. 3).

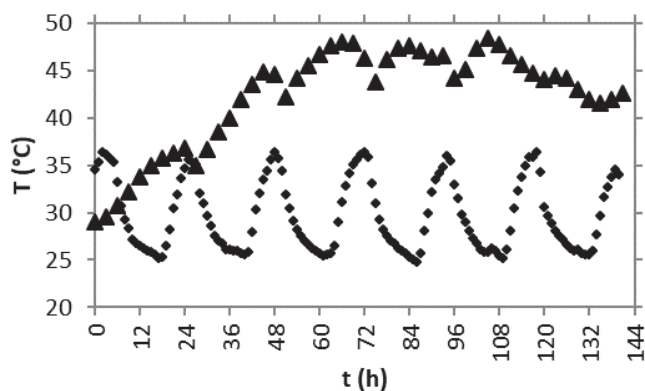


Fig. 3 Evolution of the temperature T in the fermenter FRC-V1 (Tmoy) with mixing every 24h and evolution of the ambient temperature (T_a). ▲: Tmoy; ◆: T_a

C. Modification of Bean's pH during the Fermentation

The initial pH of the bean is 5.72. During the first two days its value decreases to 4.5 and then oscillates very weakly between 4.78 and 4.53. Similar results have been found by Apriyanto et al.[19]. According to Afoakwa et al.[8], the number of pod storage days permits to increase the pH value at the end of the fermentation. Up to 48 hours, the decrease of pH value corresponds to an acid production in the fermenting mass. It is also observed by Ouattara et al [2] and it caused by acidification of the pulp, corresponding to an increase in the activity of lactic acid bacteria over this time range. The moderate increase of pH between 48 hours and 66 hours corresponds to a reduction of environment acidity. It is probably due to the consumption of part of acid. Indeed, during the acetic phase, a part of the acid will evaporate, another part will migrate inside the nib to melt the fat and the last part will be metabolized to esters [14], [15]. The very low oscillation recorded up to the end of the fermentation is probably due to the production of acid by the acetic bacteria and the consumption of this acid by evaporation, metabolization, and chemical interactions. The activity of acetic bacteria becomes more intense [1] (cf. Fig. 4).

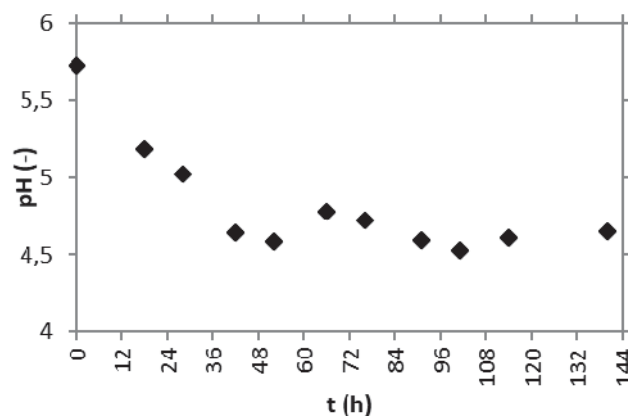


Fig. 4 Evolution of beans pH during the fermentation

D. Thermal Behavior in the Heap during Turning

Before the first turning after 27 hours of fermentation, the temperature evolves more rapidly to 0.6m of height in the heap. This evolution is less important at 0.4m and still less at 0.2m. After turning by rotation, a decrease of temperature is shown at 0.6m and at 0.2m. Moreover, at 0.4m, this evolution is moderate. After the first turning of 27-hour, the temperature increases rapidly at 0.6m. At 0.4 and 0.2, the increase is lower and less rapid. After the second turning of 48 hours, the temperature differences recorded at the three locations in the fermenter are practically negligible. The ambient temperature has no effect on the temperature in the fermenter (Fig. 5). According to Hatmi et al. [20], the temperature pattern is stratified in the fermenter. With this observation made before the first turning, it can be supposed that the fermenter sweats by gravity, cooling the beans in the bottom of the fermenter causing this decrease. The two sudden changes in temperature

recorded after the first turning, are probably due to the movement of the beans following the rotation of the fermenter. Thus, the beans at 0.2m were moving to 0.6m and vice versa. For the beans at 0.4m, it can be assumed that the temperature on either side of the probe was very close. This type of turning by dropping makes it possible to mix the beans

well by bringing up those at the bottom of fermenter. With the degradation of the pulp, the end of the flow of the fermented sweating and the movement of the fermenter to the horizontal position, the temperature differences are reduced. They are probably due to the reduction of the thickness of the mass in fermentation.

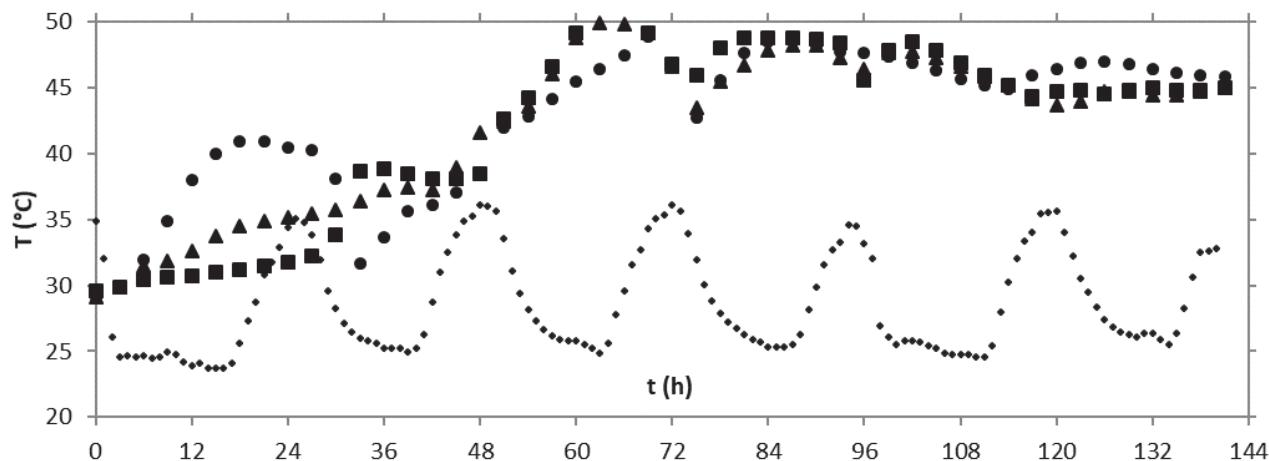


Fig. 5 Effect of rotational turning on the temperature T at different heights h in the fermented mass during the fermentation. ■: h=0.2m; ▲: h=0.4m; ●: h=0.6m. Turning at t = 27h, 48h, 70h, 92h, 112h, 140h. Fermenter in horizontal position between 0h to 48h. Fermenter in vertical position between 48h to 140h. Evolution of the ambient temperature (Ta) during fermentation ♦ :Ta

E. Effect of the Fermenter on the Mass of the Beans at the End Fermentation

After several fermentations, the losses of mass between the beginning and the end of the fermentation evolve in the same proportions independently of the quantity used, from input values between 170 kg and 47 kg (Fig. 6). These losses of mass during the fermentations are mainly due to the evacuation of the fermented sweating. They are due to water and sugar leaching and mainly resulting from the degradation of the pulp during the alcoholic phase [21]. During the acetic phase, the oxidation reactions of the alcohol to acetic acid produce also water but in small proportion [14], [15]. This water will be evacuated as water vapor or by flow. The fermentation process is responsible for the loss of mass and related products from alcoholic fermentation. Indeed, some works on the fermentation of the dates (dates palm fruit) showed that the loss of mass is caused by the consumption of the sugars by the yeasts during the alcoholic fermentation [22]. In other studies, in particular on the fermentation of wine, the quantity of carbon dioxide produced during alcoholic fermentation is sometimes determined by a regular measurement of the mass loss of the grape must [23]. At the end of fermentation, the mass is therefore the memory of the fermentation process. In a future study, it will be interesting to see if this evolution of the loss of mass is the same in the other fermenters. In our works, its reduction remained linear. This evolution could be used as a criterion to evaluate the efficiency of the fermenter. This possibility of predicting the mass weight at the end of fermentation in our fermenter will already make it possible to predict the necessary drying surface corresponding to the quantity in fermentation.

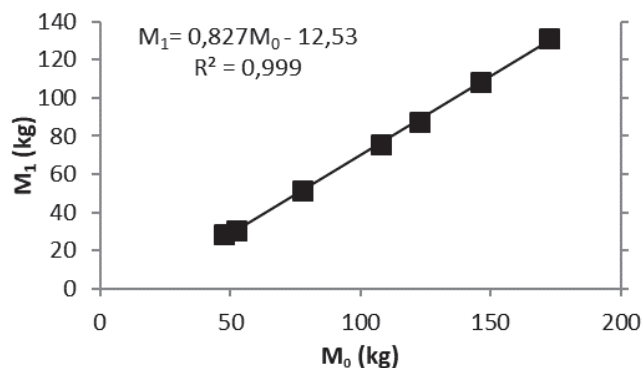


Fig. 6 Loss of mass recorded after several fermentations M_0 (before fermentation), M_1 (after fermentation)

F. Quality of the Beans at the End of the Process (Fermentation and Drying)

The proportion of well fermented beans (brown beans) is about 83.23%. The proportion of beans insufficiently fermented is of the order of 16.77%. No defective bean was found. The same ratio of brown beans was found in other research with 500 kg are fermented in a wooden box [17]. The absence of defective beans in our results is probably due to the fermentation of only healthy beans. The good proportion of well fermented beans is explained by a good hydrolysis of the anthocyanin pigments to anthocyanidins [24]. These changes in the bean are favored by the combination of temperature and acid which penetrates inside. The insufficiently fermented beans (purple) are probably due to insufficient hydrolysis of the pigments.

V. CONCLUSION

These results show that during the fermentations in our equipment, the temperature of 45 ° C in the fermentation mass, allows to activate the change inside the nib since the 3rd day. The movements of the mass by this type of rotation, combined with the homogenization of the temperature and by the horizontal position in the acetic phase of the fermenter, contribute efficiently to have a high proportion of well fermented beans (83.23%). It is also observed that the turning before 120 hours contributes to increase the temperature in the fermentation heap. Moreover, the pH values of the bean are in the range leading to the better activity of enzymes for production of the aromatic compounds. Finally, the possible anticipation of the mass weight at the end of the fermentation makes it possible to predict the necessary logistics, for the following treatments. This improved fermenter made of local materials integrating the main functions of the fermenter gives good results. Its originality is in its realization and in its way to manage it with an easy functioning. Their actions on the development of microorganisms and on chemical modifications have to be studied and compared with other types of fermenter.

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