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Research Paper

IMPROVEMENT OF THE QUALITY OF THE COCOA DURING POST-HARVEST PROCESS IN CÔTE D'IVOIRE

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Abstract

This research was conducted to evaluate the evolution of some physicochemical parameters and the occurrence of ochratoxin A (OTA) in cocoa beans during the post-harvest process. Healthy, quilted, injured, rotten and peasant pods (all types combined) were fermented, dried and ground into powder and stored for 4 months. Ochratoxin A, moisture, protein, fat, titratable acidity and pH in pre-milled beans after cocoa harvest were analyzed according to standard procedures. The results obtained showed some lowest levels of moisture and titratable acidity for healthy pods. As for protein, fat and pH, these same types of pods showed lower levels overall than other types of pods. Otherwise, all defective pods recorded variable ochratoxin A levels. All injured pods have OTA levels greater than 2 µg / kg while others have shown OTA levels below 1 µg / kg. Partially rotten pods and all-round pods have levels below 0.5 µg / kg. Only the injured pods recorded levels of OTA higher than the standard set (2 µg / kg) by the European Commission on Agricultural Contaminants. It appears from the statistical analyzes that healthy pods throughout the post-harvest process differed from other types of pods for all analyzed parameters. All the results suggest that the peasants must be harvesting the cocoa pods with precaution.

Key words: *Cocoa, Pods, Fermentation, Breaking, Ochratoxin A, Chemical parameters.*

INTRODUCTION

Theobroma cacao L. is an important tropical rainforest tree. Native to the Gulf of Mexico and the northern part of America, cocoa farming was introduced in the sub-region of southeast of Côte d'Ivoire in the late 19 th century [1, 2].

Côte d'Ivoire is the world's largest producer of cocoa beans since 1980, and has a long history of successful production since the introduction of cocoa in 1892 [3]. Since its introduction to Côte d'Ivoire, cocoa has become both economically as well as culturally significant to the country. The launching of a new policy with the motto "land belongs to those who develop it" by the government, encouraged immigrant farmers to settle in the forest zone to cultivate cocoa [4]. This policy coupled with research recommendations of the use of high yielding Upper-Amazon hybrid cultivated under direct sunlight and government's subsidies contributed to increased production using forested areas [5, 6]. According to Statista [7], cocoa production in world's largest producer approaching 2 000 000 tons during 2017-2018 season, accounting for 60 % of Africa's production and more than 40 % of world production. Cocoa is also produced in Asia and Latin America [8] and occupies a prominent place in the economies of the producing countries. Côte d'Ivoire exports most of its cocoa production in the form of dried beans to industrialize and consumer countries. Cocoa contributes a greater proportion of foreign exchange earnings in Côte d'Ivoire [9]. As a result government policies in this country have always favored production increase, which has mostly depended on expansion of farmlands at the expense of forested areas.

However, in most producing countries, the absence or poor control of post-harvest practices inevitably leads to a degraded quality cocoa. This gives the final product a low market value in the international market. The cocoa sector, which is the subject of many issues in the West and Central African sub-region, is today disturbed by price instability. On the other hand, the prospects reveal threats to cocoa because of the presence of Ochratoxin A (OTA). Ochratoxin A (OTA and L - phenylalanylcarbonyl - 5 - chloro - 8 - hydroxyl - 3,4 - dihydro - 3 - R -methylisocoumarin) is a mycotoxin produced by molds and food contaminants [10, 11]. OTA is a mycotoxin formed mainly by some species of *Aspergillus* and *Penicillium* [12]. The main fungal sources of OTA in cocoa beans in African countries and in South America are black aspergilli (*A. carbonarius* and *A. niger* aggregate) [13, 14]. It is mainly known for its nephrotoxic and carcinogenic effects through a direct genotoxicity mechanism by covalent adduct formation [15, 16, 17, 18]. According to Sangare-Tigori et *al*. [19], this mycotoxin disrupts carbohydrates metabolism and blood coagulation. The long biological period and OTA make it a product that stays in the bloodstream and can contaminate breast milk [20]. Ochratoxin A levels in agricultural products are diverse, variable and range from 0 to 10 µg/kg [21].

All of these quality defects associated with marketable cocoa (moldy beans, high levels of free fatty acids, appearance of odors and undesirable taste, presence of OTA, etc.) are generally directly related to poor conduct of post-harvest operations [22].

The studies carried out in order to maximize the marketability of cocoa, focused on the conduct of fermentation and microbial succession [23], thus ignoring the health quality of the pods. Most Ivorian producers have a habit of harvesting all-round pods (healthy pods, injured pods, pricked pods and rotten pods) and storing them for about a week or more before opening. These practices constitute a risk of deterioration in the quality of cocoa. In the face of these problems, which constitute an economic threat for all cocoa-producing countries, the critical threshold of OTA-producing mold during primary processing, the transport, storage of cocoa and the influence of the health status of the pods on the quality of the beans must be determine.

This work aimed to know the impact of agricultural practices and post-harvest on the quality of merchantable cocoa by explored the impact of the health quality of pods on OTA contamination and evaluate some physicochemical parameters of cocoa at post-harvest stages.

MATERIALS AND METHODS

Biological material

The biological material studied is cocoa from the experimental plots of the CNRA (National Centre of Agronomic Research) in Divo. It consists of 5 types of pods classified as healthy pods, quilted pods, injured pods, rotten pods and peasant type pods (all classes combined). These pods all belong to the variety Forastero.

Sampling

The pods are grouped in jute bags, by category of defects from the production station (CNRA Divo). For the analyzes, five (5) lots of pods are constituted. A mixture of these different lots of pods is made to obtain five (5) piles of 500 pods consisting of:

-500 healthy pods (HP)

-250 healthy pods and 250 quilted pods (QP)

-250 healthy pods and 250 rotten pods (RP)

-250 healthy pods and 250 injured pods (IP)

-500 pods of all types combined (peasant heap) (all-round pods) (ARP).

Storage of the pods

The five (5) batches of pods were stored on the ground in the open air for seven (7) days prior to breaking.

The breaking of cocoa and removal of fresh beans

Cocoa was cut with a wooden club. The beans have not been separated from the spine to better simulate the conditions of post-harvest operations practiced in the peasant environment. Fresh beans were removed from each debreaked batch. They were stored in an Electrolux freezer, Medical refrigeration at - 81 °C. The OTA content and the various physicochemical parameters were then determined for each of the five (5) samples.

Fermentation

The beans were fermented with the spine according to the micro fermentation technique in 52 cm x 70 cm x 55 cm wooden perforated boxes for 4 days without mixing. At the end of the fermentation, the beans are removed.

Drying

The beans separated from the rachis were sun-dried for 9 days on a black plastic sheet bounded by a wooden frame of 2 m x 1m in area. Three (3) hand brews are performed daily at regular intervals of three hours.

Storage

The OTA content and the physicochemical parameters are determined during storage period which lasted four months.

Grinding of the samples

An overall sample of approximately 24 kg will be prepared and ground using a hammer mill equipped with a 10 mm grid for dried beans. The final sample is obtained by successive separation of the crushed global sample. The fresh samples are milled in the

wet phase using an electric 320 grinder. The ground material obtained is then dried in an oven at 45 °C for 48 hours. The various samples made are packaged and stored in a freezer at -81 °C for different analyzes.

Measurement of physicochemical parameters

Moisture was determined by drying in an oven at 105 ºC during 24 h to constant weight [24]. pH was determined using a pH meter (Model MP 220, Mettler-Toledo). Titratable acidity was measured by potentiometric titration with 0.1N NaOH [25]. Crude fat was determined by continuous extraction in a Soxhlet apparatus (Soxtec sostem HT 1043) for 6 h using hexane as solvent [24]. Crude protein was calculated from nitrogen (N x 6.25) obtained using the Kjeldahl method by AOAC [24].

Determination of ochratoxin in cocoa

- ***OTA extraction***

About 15 g of sample are weighed using a precision scale (Startorium BP 310 S) at ± 0.01 g is placed in the bowl of the waring blendor. 150 mL of aqueous methanol-bicarbonate 3 % (m/v; 50:50) were added. The mixture was homogenized by Ultra-Turax for 3 minutes and the homogenate was centrifuged at 5000 rpm for 5 minutes at 4 °C. The supernatant is removed and filtered through a Wathman Ref 066082.775 filter paper (185 mm) into tubes of 25 mL. A volume of 11 mL of filtrate were added 11 mL of saline phosphate buffered (PBS) at pH 7.3.

- ***Purification on an immunoaffinity column (IAC)***

Immunoaffinity columns brand Ochraprep and RBiopharm were conditioned with 10 mL of PBS. Purification of 20 mL of the mixture was made on immunoaffinity columns and OTA extraction was performed with two volumes of 1.5 mL of solvent (methanol/acetic acid; 98:2; v/v) at a flow rate of 5 mL/minute. The resulting sample was packed in a chromatographic tube and the analysis for OTA was made by HPLC using the European community regulation [26].

- ***OTA assay***

A liquid chromatograph HPLC brand Shimadzu coupled to a fluorescence detector was used to determined OTA concentration in samples. OTA content was determined according method used by Coulibaly *et al.* [27]. This HPLC equipment is energized; 30

minutes later, the end of the suction tube is immersed in degassed distilled water. The "DRAIN" valve is turned 180 ° counterclockwise before purging with distilled water. At the end of the purge, the valve is turned "DRAIN" clockwise again until the DRAIN is completely closed. After switching on the pump, the distilled water is passed through the column for 20 minutes during normal operation ("LOAD"). The pump is stopped and the tip of the suction tube is immersed in acetonitrile. The latter is passed through the column for 20 minutes the tip of the suction tube is immersed in the mobile phase consisting of acetonitrile / water / acetic acid (99/99/2: v / v / v). Then drive for 10 min. Using a syringe (Hamilton Microliter), taken 100 µL of the sample is loaded in the LOAD position and injected into the "INJECT" position. At the same time, START is pressed on the chromatopac before removing the syringe. Three injections are performed for each sample. After the analyzes, the column is washed by circulating the distilled water and then acetonitrile for 20 min each.

The detector sends the data to the chromatopac as a chromatographic signal.

Statistical analysis of the data

Two types of statistical analysis were used for data processing. These are ANOVA variance analysis and Duncan's test for averaging. Both of these analyzes are done by the SPSS software. The meaning is accepted at a level of 5 % ($P \leq 0.05$).

RESULTS

Ochratoxin A (OTA) content (µg / kg)

Table I presents the evolution of the OTA content according to the type of cocoa pods. A significant difference is observed for this parameter ($P < 0.05$). OTA content differs from one type of pod to another except for partially rotten pods (PRP) and all-round pods (ARP). There is no distinction between these types of pods at the breaking stage (0.30a ± 0.05, 0.22a ± 0.03), fermentation (0.27a ± 0.04, 0.18a ± 0.00), drying (0.35a ± 0.06, 0.28a ± 0.07). Duncan's test also found that the highest OTA content is found in injured pods (IP) and quilted pods (QP), respectively. The post-harvest analysis (Appendix) indicates that breaking (Break) has the highest OTA content for injured pods (2.49b ± 0.10) and quilted pods (0.72d ± 0.05). For partially rotten pods (PRP) and all –round pods (ARP), it is at the fermentation stage that we have the lowest OTA content, ie PRP (0.27a ± 0.04) and ARP (0.18a ± 0.01).

Moisture (%)

Evolution of the moisture content (%) according to the type of pods was presented in Table II. Analysis of variance showed no significant difference between pod types at the breaking (P> 0.05). The moisture content doesn't differ from one type of pod at this stage. For the other stages, a very significant difference is observed (P <0.05). Humidity varied from one type of pod to another. At these stages, however, similar humidity levels are observed for PRP and ARP at storage 1 ($7.74^{d} \pm 0.06$; $7.8^{d} \pm 0.07$) and storage 2 ($7.78^{d} \pm 0.01$; $7.78^{d} \pm 0.0$). Outside the breaking stage, beans of healthy pods have the lowest moisture content regardless of the postharvest stage considered. Comparison test shows moisture levels for beans of healthy pods lower in the Drying stage ($7.09^{a} \pm 0.00$), storage 1 ($7.09^{a} \pm 0.01$) and storage 2 ($7.1^{a} \pm 0.01$). For other types of pods, it appears that the values are statistically different from one stage to another. The moisture content is not significantly different at storage 1 and storage 2, their moisture levels is substantially the same for the two types of pods.

Quantity of fatty matter (g/100 g)

The values of the fat content are summarized in Table III. The fat content doesn't change from one type of pod to another for storage 1 and storage 2 since their averages are statistically identical (P> 0.05). At the breaking and drying stage, this rate is statistically identical for injured, quilted, partially rotten and all-round pods. In the fermentation stage, similar fat levels are observed for injured pods, quilted pods, partially rotten pods. At storage 3, significant differences are observed (p <0.05). Fat contents differ from one type of pods to another except QP ($0.28^{ab} \pm 0.07$) and PRP ($0.3^{ab} \pm 0.00$). As for storage 4, mean values were significantly different for HP (0.44b ± 0.06), IP (0.22a ± 0.05) and PRP ($0.26^{ab} \pm 0.06$) while PRP and ARP have identical rates ($0.26^{ab} \pm 0.06$; $0.34^{ab} \pm 0.12$). Variance analysis and post-harvest stage analysis revealed statistically identical averages for healthy pods, partially rotten pods, all-round pods (p> 0.05).

Protein content (%)

Table IV shows the evolution of the protein content according to the type of cocoa pods. The analysis of variance ANOVA shows a significant difference (p <0.05) except in the storage 2 stage. The protein level doesn't vary at this stage for the type of pods considered. In other stages, the protein levels are variable and are highest for healthy pods and then follow the all-round pods. Taking into account post-harvest stages, there

is a highly significant difference for healthy pods at all stages. It is at storage 1 stage ($12.23^{a} \pm 0.13$) that we have the lowest amount of fat while this parameter is the highest at the breaking stage ($15.87^{e} \pm 0.09$). In the Drying stage, the fat content is $13.86^{b} \pm 0.13$ for the same healthy pods.

Titrable acidity (meq / 100g)

The values of the titratable acidity have been grouped in Table V together with the result of the statistical tests. Titratable acidity changes for all pod types at all post-harvest stages since the values are statistically different ($p < 0.05$). This difference is highly significant at the drying stage. The comparison test shows that the titratable acidity is low when the pods are healthy at the breaking stage ($24.73^{a} \pm 0.64$); fermentation ($22.53^{a} \pm 0.68$); drying ($22.63^{a} \pm 1.07$); storage 1 ($22.27^{a} \pm 1.06$); storage 3 ($31.88a \pm 1.23$); storage 4 ($22.27^{a} \pm 3.32$). On the other hand, the highest amount of acid is observed for injured pods at all stages.

PH

Table VI presents the evolution of the pH according to the type of cocoa pods and the results of the comparison tests. A highly significant difference is observed ($p < 0.05$). The pH differs from one type of pods to another depending on the stage. There are still pods that behave similarly. These are partially rotten pods ($2.94^{e} \pm 0.04$) and all-round pods ($2.96^{c} \pm 0.03$) at the breaking stage ; ($2.68^{b} \pm 0.04$) quilted pods and partially rotten pods in the fermentation stage; quilted pods ($3.94^{b} \pm 0.06$), partially rotten pods ($4.06^{b} \pm 0.43$) and all-round pods ($4.03^{b} \pm 0.01$) at the drying stage; quilted pods ($3.81^{b} \pm 0.22$) and partially rotten pods ($4.03^{b} \pm 0.01$) at storage 1 stage ; Partially rotten pods ($4.14^{c} \pm 0.12$) and all-round pods ($4.31^{c} \pm 0.04$) at storage 3 stage ; healthy pods ($4.7^{d} \pm 0.07$) and all-round pods ($4.61^{d} \pm 0.06$) at storage 4 stage. The Duncan comparison test shows the highest healthy pods values of all the different types of pods. These values are the lowest for injured pods and follow quilted pods.

DISCUSSION

This study made it possible to observe the incidence of OTA in cocoa. This quality parameter is strongly influenced by the health status of the pods. At all post-harvest treatment stages, the presence of OTA varies according to the type of pod. OTA rates of injured pods range from 2.26 µg/kg ± 0.12 to 2.55 µg/kg ± 0.014. Those of other

types of pods range from 0.22 µg/kg ± 0.03 to 0.72 µg/kg ± 0.05. This presence is confirmed by the work of Cocoqual [28]. Indeed, cocoa is a fermented dry fruit product. Fungi and OTA can be present in all stages of the production chain: harvesting, fermentation, drying, storage, processing, and transportation. The highly significant difference observed for pods types is consistent with that found by the Codex Alimentarius Commission in its first session on April 20, 2007. Walker [21] also explains that OTA levels in agricultural products are variable and may vary from 0 to 10µg/kg. The work of Amezqueta *et al*. [29] shows values consistent with those at the stage of the breaking for partially rotten pods (0.30 ± 0.05) and all-round pods (0.22 ± 0.03).

In the fermentation, drying and storage during three month, the OTA contents of partially rotten pods and all-round pods are below those of Bastide *et al*. [30]. Indeed, the incidence of OTA during the primary processing of cocoa varied with the phytosanitary conditions of the harvest.

The highest OTA levels are observed in injured and quilted pods at all stages. This strong presence could be due to a high concentration of OTA-producing molds in these types of pods as confirmed by Copetti *et al*. [31]. Beans with major defects such as breaking wounds are invaded by mycotoxins that would be responsible for the production of OTA. These OTA levels of injured pods at all stages are higher while the other pods have OTA levels lower than the standards set by the European Commission [32] on agricultural contaminants which are 2 µg / kg.

For the moisture content, at the breaking stage, high water content statistically identical for all types of pods is obtained. The seeds are covered with pulp at this stage. However, the pulp contains mainly 80 % water. This would explain these high water contents. In the fermentation stage, the water content varied from one type of pod to another. The purpose of drying is to reduce the water content of cocoa beans to around 8 % according to Mossu [33]. At this stage, we can distinguish grades ranging from 7.09 ± 0.00 to 7.73 ± 0.06. These results are consistent with those given by Deus et *al*. [34]. Fermented and well-dried beans are stored. At different stages of storage, the humidity level is also variable. Quilted pods, partially rotten pods and all-round pods with relatively high water contents as healthy pods. The values reached 9.13 ± 0.16 in storage 4. These values, which are rising at this stage, would be related to the moisture recovery during the storage of dried beans, as confirmed by Barel [35]. The lower water

content observed for healthy pods at all stages except the breaking stage could be explained by the quality of the beans. Within these, various biochemical reactions continue, taking into account the health status of cotyledon. In addition, defective beans have traces of mold or rot. The internal parts of these beans containing insects at any stage of development would be related to the chemical composition of the cocoa bean. In addition, microorganisms grow more in the presence of water

The statistical results of the fat content don't show a significant difference between the types of pods at storage 1 and 2. The contents at these 2 stages are approximately similar to those founded by Barel [36] which is 50 % fat. At the drying and breaking stage, the fat content is the same for all types of pods except healthy pods. These observed rates are lower than those founded by of Anna [37] in cocoa powders (0.7%). The breaking influences the sequence of operations and the final quality of the beans. The similarity of the values observed for breaking, fermentation, storage 4 and drying between defective pods could be explained by post-maturity harvests and insufficient fermentations. Barel [35] explains that drying beans and a metabolic evolution of seeds or microbial growth due to a lack of fermentation or maturity cause reactions that affect the quality of butter and cocoa components. The fat content is about 0.50g / 100g healthy pods at all stages are close to the fat contents of Elkhori *et al.* [38]. After fermentation and drying, the cocoa bean contains mostly raw materials fat, phenolic compounds and proteins. This explains the proportions of fat at different stages after fermentation. This would mean that during fermentation, the fat doesn't undergo significant transformation.

The level of protein doesn't vary at the storage 2 stage for all types of pods. At this stage, the protein levels are statistically identical. On the other hand, the rate is very variable and is the highest for healthy pods and then follows all-round pods from other stages. These levels, which vary from 12.23 ± 0.09 % to 15.87 ± 0.09 % for healthy pods, are greater than those obtained by Bertazzo *et al*. [39] in dried cocoa powder from the Dominican Republic (11.8 %).

Titratable acidity varies for all types of pods at all post-harvest stages of cocoa. This variation is highly significant at the drying stage where the amount of acid depends on each type of pod. The study shows that at all stages except storage 2 stage, the amount of acid is low for healthy pods. On the other hand, the amount of acid is greatest at the level of injured pods at all stages. This change in behavior can be explained by the

health status of the pods. These variations were reported by Nazaruddin *et al*. [40] and Lene [41]. In addition, Lopez *et al.* [42] explain that these changes are due to the variation of pH throughout the fermentative process, which reflects the variation of the amount of citric acid consumed by the yeasts. This naturally influences the rest of the other post-harvest stages. Injured, quilted, partially rotten pods and all-round pods have high levels at all stages than healthy pods. This acidity is linked to the presence of microorganisms that secrete a sufficient amount of acid. According to Nazaruddin *et al.* [40], defective beans are invaded by molds inside the same dried bean. The acidity of the beans is mainly due to the penetration of lactic acid (non-volatile acid) and then acetic acid (volatile acid) during the different phases of fermentation [36].

Lactic fermentation is undesirable by the quality of cocoa. Lactic acid penetrates inside the cotyledons and remains there permanently because of its very low volatility. Such fermentation thus generates acidic cocoa, whose prices are much depreciated on the market. In the drying stage where a highly significant difference is observed, the acid level is different even between the defective pods. In this respect, Barel [35] explains that there are considerable dispersions of acidity between the beans of the same group. In addition, beans with defects of the same intensity, the dispersion is still huge.

At the fermentation stage, pH healthy pods and all comers are identical. It also doesn't vary statistically for quilted pods ($2.68^{b} \pm 0.04$) and partially rotten pods ($2.71^{b} \pm 0.04$) at the same stage. These results are inferior to those founded by Nazaruddin *et al.* [40] of 4.73. According to these authors, the pH of a shelled cocoa is in the order of 6.5. For healthy pods, pH is the highest of all pod types while this value is low for injured and quilted pods at different post-harvest stages. The work of Nazaruddin *et al.* [40] is in line with this trend. pH variation in beans is thought to be related to differences in pods, hence the presence or absence of acid-producing microorganisms in the post-harvest process. This means that biochemical reactions using citric acid would have been initiated in the pods except for healthy pods during storage prior to the scraping operation. Therefore, Barel [22] concludes that the sanitary state of the pod modifies the pH of the beans as a result of changes in the pod.

Table I: Ochratoxin A content (µg/kg) depending on the type of cocoa pods

Types of pods	Post-harvest stages of cocoa						
	Break	Ferm	Dry	st 1	st 2	st 3	st 4
HP	Nd	Nd	Nd	Nd	Nd	Nd	Nd
IP	$2.49^{c} \pm 0.1$	$2.26^{c} \pm 0.12$	$2.41^{c} \pm 0.09$	$2.37^{d} \pm 0.07$	$2.36^{d} \pm 0.06$	$2.55^{c} \pm 0.014$	$2.46^{c} \pm 0.19$
PQ	$0.72^{b} \pm 0.05$	$0.52^{b} \pm 0.04$	$0.63^{b} \pm 0.05$	$0.60^{c} \pm 0.05$	$0.59^{c} \pm 0.04$	$0.53^{b} \pm 0.06$	$0.47^{b} \pm 0.06$
PRP	$0.30^{a} \pm 0.05$	$0.27^{a} \pm 0.04$	$0.35^{a} \pm 0.06$	$0.38^{b} \pm 0.03$	$0.36^{b} \pm 0.03$	$0.34^{a} \pm 0.07$	$0.34^{ab} \pm 0.04$
ARP	$0.22^{a} \pm 0.03$	$0.18^{a} \pm 0.00$	$0.28^{a} \pm 0.07$	$0.22^{a} \pm 0.02$	$0.22^{a} \pm 0.02$	$0.24^{a} \pm 0.02$	$0.25^{a} \pm 0.01$

The averages followed by the same letter on the same column are not significantly different at P = 0.05.
Nd: not determined; Break: breaking; Ferm: fermentation; Dry: Drying; St 1: Storage during 1 month; St 2: Storage during 2 month; St 3: Storage during 3 month; St 4: Storage during 4 month.
HP: healthy pods; IP: Injured pods; QP: Quilted pods; PRP: Partially rotten pods; ARP: All-round pods.

Table II: Moisture content depending on the type of cocoa pods

Types of pods	Post-harvest stages of cocoa						
	Break	Ferm	Dry	st 1	st 2	st 3	st 4
HP	$20.45^{a} \pm 0.07$	$12.46^{a} \pm 0.05$	$7.09^{a} \pm 0.00$	$7.09^{a} \pm 0.01$	$7.1^{a} \pm 0.01$	$7.32^{a} \pm 0.05$	$8.15^{a} \pm 0.01$
IP	$20.33^{a} \pm 0.05$	$12.50^{ab} \pm 0.01$	$7.29^{b} \pm 0.01$	$7.38^{b} \pm 0.04$	$7.44^{b} \pm 0.05$	$7.61^{ab} \pm 0.02$	$8.83^{c} \pm 0.05$
PQ	$20.66^{a} \pm 0.03$	$12.58^{ab} \pm 0.04$	$7.52^{c} \pm 0.01$	$7.56^{c} \pm 0.06$	$7.59^{c} \pm 0.01$	$7.86^{bc} \pm 0.01$	$8.60^{b} \pm 0.00$
PRP	$20.62^{a} \pm 0.55$	$12.61^{b} \pm 0.03$	$7.66^{d} \pm 0.02$	$7.74^{d} \pm 0.06$	$7.78^{d} \pm 0.01$	$8.1^{c} \pm 0.09$	$8.81^{c} \pm 0.00$
ARP	$21.03^{a} \pm 0.58$	$13.38^{c} \pm 0.13$	$7.73^{e} \pm 0.06$	$7.80^{d} \pm 0.07$	$7.78^{d} \pm 0.00$	$8.7^{d} \pm 0.52$	$9.13^{d} \pm 0.16$

The averages followed by the same letter on the same column are not significantly different at P = 0.05.
Break: breaking; Ferm: fermentation; Dry: Drying; St 1: Storage during 1 month; St 2: Storage during 2 month; St 3: Storage during 3 month; St 4: Storage during 4 month.
HP: healthy pods; IP: Injured pods; QP: Quilted pods; PRP: Partially rotten pods; ARP: All-round pods.

Table III: Fat content depending on the type of cocoa pods

Types of pods	Post-harvest stages of cocoa						
	Break	Ferm	Dry	st 1	st 2	st 3	st 4
HP	$0.55^{b} \pm 0.06$	$0.5^{b} \pm 0.1$	$0.53^{b} \pm 0.04$	$0.48^{a} \pm 0.03$	$0.47^{a} \pm 0.16$	$0.47^{c} \pm 0.00$	$0.44^{b} \pm 0.06$
IP	$0.42^{a} \pm 0.04$	$0.4^{ab} \pm 0.01$	$0.31^{a} \pm 0.03$	$0.35^{a} \pm 0.07$	$0.26^{a} \pm 0.09$	$0.23^{a} \pm 0.01$	$0.22^{a} \pm 0.05$
PQ	$0.36^{a} \pm 0.06$	$0.31^{ab} \pm 0.09$	$0.35^{a} \pm 0.01$	$0.38^{a} \pm 0.06$	$0.34^{a} \pm 0.07$	$0.28^{ab} \pm 0.06$	$0.23^{b} \pm 0.02$
PRP	$0.37^{a} \pm 0.02$	$0.32^{ab} \pm 0.03$	$0.42^{a} \pm 0.12$	$0.4^{a} \pm 0.05$	$0.39^{a} \pm 0.14$	$0.3^{ab} \pm 0.00$	$0.26^{ab} \pm 0.06$
ARP	$0.39^{a} \pm 0.01$	$0.28^{a} \pm 0.09$	$0.43^{a} \pm 0.03$	$0.44^{a} \pm 0.02$	$0.42^{a} \pm 0.04$	$0.32^{b} \pm 0.05$	$0.34^{ab} \pm 0.12$

The averages followed by the same letter on the same column are not significantly different at P = 0.05.
Break: breaking; Ferm: fermentation; Dry: Drying; St 1: Storage during 1 month; St 2: Storage during 2 month; St 3: Storage during 3 month; St 4: Storage during 4 month.
HP: healthy pods; IP: Injured pods; QP: Quilted pods; PRP: Partially rotten pods; ARP: All-round pods.

Table IV: Proteins content depending on the type of cocoa pods

Types of pods	Post-harvest stages of cocoa						
	Break	Ferm	Dry	st 1	st 2	st 3	st 4
HP	$15.87^{d} \pm 0.09$	$14.49^{d} \pm 0.15$	$13.86^{e} \pm 0.13$	$12.23^{c} \pm 0.09$	$14.65^{a} \pm 0.2$	$15.24^{d} \pm 0.19$	$14.13^{c} \pm 0.04$
IP	$10.56^{a} \pm 0.33$	$10.3^{a} \pm 0.14$	$9.18^{a} \pm 0.17$	$9.02^{a} \pm 0.07$	$12.46^{a} \pm 2.76$	$10.84^{a} \pm 0.11$	$9.35^{a} \pm 0.14$
PQ	$12.44^{b} \pm 0.13$	$12.08^{b} \pm 0.09$	$11.76^{b} \pm 0.03$	$12.01^{c} \pm 0.06$	$14.13^{a} \pm 0.07$	$11.14^{a} \pm 0.15$	$13.47^{bc} \pm 0.02$
PRP	$13.48^{c} \pm 0.29$	$12.22^{b} \pm 0.29$	$12.11^{c} \pm 0.07$	$11.28^{b} \pm 0.15$	$13.42^{a} \pm 0.15$	$11.79^{b} \pm 0.02$	$13.22^{b} \pm 0.15$
ARP	$12.46^{b} \pm 0.08$	$13.91^{c} \pm 0.02$	$13.05^{d} \pm 0.07$	$12.19^{c} \pm 0.14$	$14.29^{a} \pm 0.19$	$13.2^{c} \pm 0.08$	$13.36^{b} \pm 0.54$

The averages followed by the same letter on the same column are not significantly different at P = 0.05.
Break: breaking; Ferm: fermentation; Dry: Drying; St 1: Storage during 1 month; St 2: Storage during 2 month; St 3: Storage during 3 month; St 4: Storage during 4 month.
HP: healthy pods; IP: Injured pods; QP: Quilted pods; PRP: Partially rotten pods; ARP: All-round pods.

Table V: Titratable acidity content depending on the type of cocoa pods

Types of pods	Post-harvest stages of cocoa						
	Break	Ferm	Dry	st 1	st 2	st 3	st 4
HP	$24.73^{a} \pm 0.64$	$22.53^{a} \pm 0.68$	$22.63^{a} \pm 1.07$	$22.27^{a} \pm 1.06$	$24.91^{bc} \pm 7.21$	$31.88^{a} \pm 1.23$	$22.27^{a} \pm 3.32$
IP	$35.69^{d} \pm 0.05$	$36.14^{d} \pm 0.6$	$37.55^{e} \pm 0.57$	$43.69^{c} \pm 3.21$	$34.24^{d} \pm 0.67$	$42.17^{b} \pm 1.08$	$45.53^{d} \pm 0.86$
PQ	$31.15^{c} \pm 0.92$	$29.92^{b} \pm 0.58$	$35.38^{d} \pm 1.09$	$41.09^{c} \pm 0.80$	$30.34^{cd} \pm 0.54$	$40.51^{b} \pm 0.51$	$42.83^{c} \pm 2.34$
PRP	$31.07^{c} \pm 0.14$	$30.85^{b} \pm 0.58$	$32.15^{c} \pm 1.17$	$31.35^{b} \pm 1.09$	$22.41^{ab} \pm 1.25$	$31.64^{a} \pm 0.85$	$40.5^{bc} \pm 0.56$
ARP	$29.38^{b} \pm 0.14$	$29.68^{b} \pm 0.62$	$29.8^{b} \pm 0.18$	$30.08^{b} \pm 0.67$	$18.44^{a} \pm 0.18$	$31.98^{a} \pm 5.41$	$37.96^{b} \pm 1.35$

The averages followed by the same letter on the same column are not significantly different at P = 0.05.
Break: breaking; Ferm: fermentation; Dry: Drying; St 1: Storage during 1 month; St 2: Storage during 2 month; St 3: Storage during 3 month; St 4 : Storage during 4 month.
HP: healthy pods; IP: Injured pods; QP: Quilted pods; PRP: Partially rotten pods; ARP: All-round pods.

Table VI: pH depending on the type of cocoa pods

Types of pods	Post-harvest stages of cocoa						
	Break	Ferm	Dry	st 1	st 2	st 3	st 4
HP	$3.19^{d} \pm 0.1$	$3.17^{c} \pm 0.12$	$4.98^{c} \pm 0.14$	$5.02^{d} \pm 0.08$	$4.85^{e} \pm 0.04$	$4.58^{d} \pm 0.18$	$4.7^{d} \pm 0.07$
IP	$2.02^{a} \pm 0.02$	$2.27^{a} \pm 0.15$	$3.11^{a} \pm 0.18$	$3.48^{a} \pm 0.17$	$3.3^{a} \pm 0.03$	$2.45^{a} \pm 0.02$	$2.68^{a} \pm 0.03$
PQ	$2.42^{b} \pm 0.04$	$2.68^{b} \pm 0.04$	$3.94^{b} \pm 0.06$	$3.81^{b} \pm 0.22$	$3.85^{b} \pm 0.03$	$3.29^{b} \pm 0.26$	$3.01^{b} \pm 0.12$
PRP	$2.94^{c} \pm 0.04$	$2.71^{b} \pm 0.04$	$4.06^{b} \pm 0.43$	$4.03^{b} \pm 0.01$	$4.23^{c} \pm 0.01$	$4.14^{c} \pm 0.12$	$3.97^{c} \pm 0.21$
ARP	$2.96^{c} \pm 0.03$	$3.00^{c} \pm 0.03$	$4.03^{b} \pm 0.01$	$4.15^{c} \pm 0.05$	$4.35^{d} \pm 0.03$	$4.31^{c} \pm 0.04$	$4.61^{d} \pm 0.06$

The averages followed by the same letter on the same column are not significantly different at P = 0.05.
Break: breaking; Ferm: fermentation; Dry: Drying; St 1: Storage during 1 month; St 2: Storage during 2 month; St 3: Storage during 3 month; St 4: Storage during 4 month.
HP: healthy pods; IP: Injured pods; QP: Quilted pods; PRP: Partially rotten pods; ARP: All-round pods.

CONCLUSION AND RECOMMANDATION

Defects and anomalies in cocoa pods strongly influence the physicochemical characteristics and occurrence of OTA. This influence is manifested by an increase in Ochratoxin A (OTA) content for all pods injured during the post-harvest cocoa process. These lower levels than those of injured pods are as important for both quilted pods as for all the rest of the defective pods. The proteins and fat contents are a function of the health status of the pod at all stages. Healthy pods have the highest value while other types of pods have lower levels. As for the acidity, it is noted that healthy pods contain less acid than other types of pods. In addition, the humidity level that is at the breaking stage the same for all pods is close to 7 after drying. This rate becomes more and more important during prolonged storage.

The lowest water levels are noticeable at the level of healthy pods at each stage.

In view of these conclusions, it is clear that it is important to properly sort the pods immediately after harvesting the cocoa and to retain only healthy pods for a cocoa of good market quality and therefore more competitive in the international market. The Ivorian peasant world would also better organize itself in order to reduce the time between harvesting and breaking operations in order to limit the risk of degradation of the pods. Therefore a rigorous control process of breaking could produce a significant reduction in OTA contents in cocoa products.

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