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Toxicological and Physicochemical Quality in the Production Units of Dried Mangoes in Burkina Faso

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Abstract The transformation of mango fruits into dried slices is a way of valuing this fruit. The requirements of good manufacturing practices (GMP) and batch monitoring are not systematically respected. The objective of this work was to study the main factors influencing the sanitary quality of dried mangoes produced in Burkina Faso, emphasizing the importance of implementing a quality approach within the drying units. A survey on dried mangoes units has been performed. Also, toxicological and physicochemical parameters of 60 dried mango samples produced in four towns in Burkina Faso (Bobo-Dioulasso, Banfora, Orodara and Toussiana) have been assayed. Standards methods were used to search each mycotoxins and heavy metals. The production characteristics of the dried mangoes unities were evaluated. The contents of aflatoxins B_1 (AFB_1), B_2 (AFB_2), G_1 (AFG_1), G_2 (AFG_2) and total aflatoxins (B_1+B_2+G_1+G_2) and heavy metals in dried mangoes were evaluated by methods standard. AFB_1, AFB_2, AFG_1 and AFG_2 aflatoxin levels were all below the quantization limit (LOQ). The physico-chemical results showed values between 3.33 to 4.94 for the pH. The humidity levels were between 6.12 to 17.44%. For organoleptic level, results showed a solid and orange-yellow appearance, a sweet and sour smell and taste, without foreign particles. The results showed the presence of heavy metals with values between 0.030 to 0.117 mg/Kg for Cd, 0.040 to 3.470 mg/Kg for Pb, 0.060 to 6. 850 mg/Kg for Cu, 0.370 to 20.740 mg/Kg for Mn and 0.307 to 1.707 mg/Kg for Co. The results obtained provided guidance to producers and researchers in Burkina Faso on the factors that can depreciate the quality of dried mangoes.

Keywords: *dried mangoes, quality, heavy metals, aflatoxins, Burkina Faso*

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1. Introduction

Dried mangoes are widely appreciated all over the world for their nutritional quality, their benefits effects on health as well as their organoleptic characteristics [1]. In Burkina Faso, dried mango is a strategic export product. It has an important economic, social and environmental role by contributing to the achievement of the national objectives of food security, job creation, and trade balance, preservation of natural resources and limitation of rural exodus [1,2]. Internationally, dried mangoes gave Burkina Faso the rank of fourth producer and third exporter in the world and significant shares in the main export markets [2]. In Burkina Faso, fruit production is dominated by mango, which accounted for more than half of the orchards and half of the orchards and national production. According to statistics from the 2008 General Census of Agriculture in 2020, the sector has a production potential of more than 600.000 tons per year with more than 2.2 million plants spread over an area of 12,250 ha [1]. The transformation of mango fruits into dried slices mangoes is a way of valuing this fruit. This transformed product has developed in West Africa since the early 1980s, particularly in Burkina Faso [3,4]. The first drying units were then set up with the support of public authorities and International organizations, aiming for an export market to the West countries. The actors of this transformation of the mango are quickly organized in groups of dryers [5,6,7]. Dried mangoes are products obtained after picking fully ripe mangoes and then drying them in an artisanal or modern way to express their most beautiful flavors [8,9].

These mangoes, organic or conventional, are mostly grown by small producers in the Hauts-Bassins and Cascades regions of Burkina Faso. By allowing the overproduction of fruits to be preserved, the drying of mangoes avoided waste at the production level and employs around a hundred women in the drying units [10,11,12]. The production of these dried mangoes is subject to cross-contamination due to non-compliance with the requirements related to the field of food production such as (raw material, medium, labour, equipment, technique, pest control and waste management) [13].

The equipment and practices used in manufacturing, packaging and cleaning can also lead to a loss of quality and limit the promotion of this product [9]. Standardization and certification contribute to a health and economic necessity by establishing rules aimed at guaranteeing consumer quality and safety as well as business competitiveness [14,15,16]. It has the advantage of homogenizing the quality of the products and the legal responsibility of the actors [17]. The standards cover vast and varied areas such as terminology, qualitative and quantitative compositions, food contact materials, etc. [18,19].

Units for drying, quality control and export of dried mangoes must guarantee the safety and wholesomeness of these products in order to comply with the requirements of the international market and meet the requirements of local consumption. The quality of an agri-food product necessarily involved mastering good hygiene (GHP) and manufacturing practices (GMP). The objective of this study was to analyze the hygiene, manufacturing practices and sanitary quality of dried mangoes produced in four localities in Burkina Faso in order to propose solutions for quality production.

2. Materials and Methods

2.1. Biological Materials

Dried mangoes collected from 30 small and medium-sized drying units, from the Hauts-Bassins and Cascades regions (Bobo-Dioulasso, Banfora, Orodara and Toussiana) of Burkina Faso. A total of sixty (60) dried mango samples were collected in 1000 g polyethylene bags and hermetically sealed and stored in a cooler, then transported to the laboratory for further analyses. The Figure 1 gave the dried mango samples.

Figure 1. Dried mango samples

2.2. Assessment of the Application of Good Hygiene (GHP) and Production Practices (GMP) for Dried Mangoes

The methodological approach was considered a field survey conducted in Banfora, Toussiana, Bobo-Dioulasso and Orodara. A questionnaire was used to evaluate practices. It was sent to dried mango producers. The quality of the raw material produced, the technological aspects of the drying units, the techniques related to the processing, packaging and storage of dried mangoes were evaluated. A diagnosis is carried out in the drying units and focused on the manufacturing process which generally included the different stages which go from the reception of fresh mangoes to the packaging and labeling of dried mangoes. The diagnosis was made using a previously developed grid on which all the stages of the production process as well as the aspects related to the 5M (Labour, Raw Material, Equipment, Environment and Method) method had to be noted.

2.3. Analysis of Physicochemical Parameters

Physico-chemical parameters such as pH, humidity were evaluated according to the official method described according to AOAC [20].

2.4. Sensory Analysis

A total of 15 panel members were trained to recognize the different characteristics of appearance, flavor and odor of dried mangoes and to measure their intensity with reference to the IOC standard “Guide for the Selection, Training and Monitoring of Mango Quality Tasters” [21,22].

2.5. Analysis of Toxicological Parameters

2.5.1. Heavy metals Analysis

Total Cadmium (Pb), Lead (Pb), Mercury (Hg) and Arsenic (As) contents of mangoes were analyzed. Dry mangoes were ground in a tungsten carbide ring mill. The extraction solution was a mixture of HNO_3 - $HClO_4$ (1/1 V/V). A quantity of 5 g powdered sample was mixed with 50 ml of the extraction and heated until complete evaporation. A volume of 10 ml HCl (10% V/V) was then added to the residue which was decanted and transferred to a 50 ml flask. The method described by Awofolu [23] was adopted for the acid digestion of the samples. The determination of heavy metals was performed by atomic absorption spectrometer (Varian, Model Flame AAS SpectrAA 220 FS. Spectra AA4.0, The Netherlands).

2.5.2. Detection and Quantification of Aflatoxins

A quantity of 25 g of each sample were weighed and ground until a fine powder was obtained allowing the release of toxins. Thus, 5 g of each powder obtained were introduced into a bottle and then added 125 ml of the extraction solution previously prepared. The whole was stirred for 20 min at 250 rpm. After the extraction, a blotting paper was used to filter the obtained solution. The filtrate was vortexed for 5s. A volume of 15 ml of the filtrate was taken and then supplemented with a phosphate saline buffer (PBS) up to 45 ml. Purification was carried out using Immuno-affinity columns type and then 30 ml were introduced into each column. The solution was drained allowing the toxins to be trapped by the column membrane. A volume of 1.5 ml of methanol was introduced into the column. The whole was drained then 0.5 ml of distilled water was added. The resulting mixture was run for quantification. The quantification was made using the standards for aflatoxins B_2 (AFB_2) and B_1 (AFB_1) and G_1 (AFG_1) and G_2 (AFG_2) according to Regulation (EC) n°1881/2006 setting maximum levels for certain contaminants in foodstuffs [24].

2.6. Data Analysis

The statistical analyses were performed using Excel 2013 and SPSS Version 20 software (SPSS Inc., Chicago, USA). The dendogram and analyses of variance (ANOVA) were performed with XLSTAT-Pro 7.5. Averages, standard deviation and least significant difference between averages were determined ($p<0.05$). Newman-Keuls correlations between physicochemical and toxicological values were estimated for all factors studied. The R 3.1.2 software was used for principal component analysis.

3. Results and Discussion

3.1. Diagnosis of Prerequisites

The interview with staff on their knowledge of Good Hygiene Practices/Good Manufacturing Practices (GHP/GMP) in the audited units showed that 98% of staff have a good knowledge of hygiene, thanks to the external capacity building received by some actors.

3.2. Characteristics of Processing Units

The results showed that 85% of the production units studied use ATESTA dryers type and 15% use tunnels. The number of employees varied. A percentage of 42.5% of dried mango production units' employ between 150 and 200 people and 57.5% of them employ between 50 and 80 people. No surveyed unit employing more than 200 persons. This is justified insofar as the units have a high production capacity and given their semi-modern nature in most cases not requiring a large labor force.

3.3. Hygienic State

The hygienic state at the level of the dried mango production chain and the cause-effect analysis have been evaluated according to the Ishikawa method or 5M (Labour, Raw Material, Equipment, Environment and Method) method.

Figure 2 summarized the difficulties encountered in the production units selected and classified according to the diagram in fishbone or 5 M (Labour, Raw Material, Equipment, Environment and Method) method.

For control of the raw material (**M1**): Fresh mangoes should be of good quality because we start from a good quality raw material to have a good quality product (traceability concept). The Figure 2 showed the operations of reception, sorting and storage of fresh mangoes.

Figure 2. Reception, sorting and storage of fresh mangoes (Legend: A: Receipt of fresh mangoes; B: Sorting damaged mangoes; C: Storage and ripening of sorted mangoes)

For control of the premises (**M2**): The results revealed that 8% of the dried mango production buildings have earth floors (cement). A percentage of 92% of the buildings, on the other hand, all the workshops have coverings (tiles) covering the ground. Furthermore, 100% of buildings have easily cleanable doors and windows and contain mosquito nets and the majority of buildings have ceilings, i.e. 85%; and only 15% of buildings have no ceilings.

In addition, 96% of production buildings are located in a residential area, compared to 4% of units in an industrial area. Similarly, 98% of the buildings do not have a waste management procedure or a wastewater disposal system. According to the survey data, most of the drying units have a maintenance plan for their premises (95%) and only at the beginning and end of the season, while a minority (5%) of mango drying units have a maintenance plan during the mango season. Cleaning or disinfection operations are rarely carried out (45%).

For mastery of equipment (**M3**): the results revealed that the producers surveyed milk the dried mangoes in a plastic container (plastic basin, knives, plastic bucket, etc.) i.e. 100%, probably because the plastic equipment are more accessible from the point of view of availability and cost. Moreover, the drying of fresh mangoes is achieved only by 95% in an improved ATESTA dryer and 5% in a tunnel dryer. The ATESTA (Solar Energy and Appropriate Technology Workshop) dryer or Gas dryer with natural convection is a gas dryer used mainly for drying fruits especially mangoes but it can be used for any product. Developed for Burkina Faso and Madagascar, this dryer can be used in all countries.

For control of methods (**M4**): This step concerns placing in hurdles and drying of mangoes. After placing the mango slices on a rack, the racks are placed in the dryer. The drying process can last between 18 and 24 h, depending on the technology used, the drying period, the variety of mango and the skills of the operator. Placing the cut mangoes on the racks is important because it has an impact on the quality of the product, the quantity of mango that will be dried in one cycle and the uniformity of the drying. Drying consists in eliminating by progressive and partial evaporation of the water of constitution of the fruits by the combined action of the air and the heat while preserving its organoleptic qualities and its microbiological stability: one observes a transfer of heat and a water transfer. The amount of dried mango produced in one cycle depends on the load introduced into the dryer. It is therefore necessary to load the racks to the maximum that is to say to leave only very small spaces between the pieces.

For labor control (**M5**): Personal hygiene is not respected in 38% of the units surveyed and staff clothing is not appropriate (20%). Generally, 55% of cases, staff training in cleaning/disinfection, maintenance, etc. is absent. In addition, we note the absence of complaint posters for staff in 68% of cases. The Figure 3 showed the state of hygiene of the premises within the dried mango units surveyed.

Figure 3. Hygiene of premises within the dried mango units surveyed (Legend: D: Raw material washing hall; E: Drying enclosure; F: Sorting rooms; G: Dried mango classification premises)

The Figure 4 showed the use of appropriate clothing for staff.

Figure 4. Appropriate staff attire (Legend: H: Pulping and cutting; I: Enclosing of cut mangoes; J: Dryer control (temperature, drying level, functionality); K: Sorting and classification of dried mangoes)

3.4. Traceability and HACCP System

Most units do not have a simple traceability system: it is remarkable that most quality managers do not have a great idea about traceability (which is used only in 10% of the dried mango units surveyed), nor about the HACCP system which is almost absent (15% of units implement a HACCP system).

The Figure 5 showed the potential causes of malfunctions in the implementation of GHPs/GMPs.

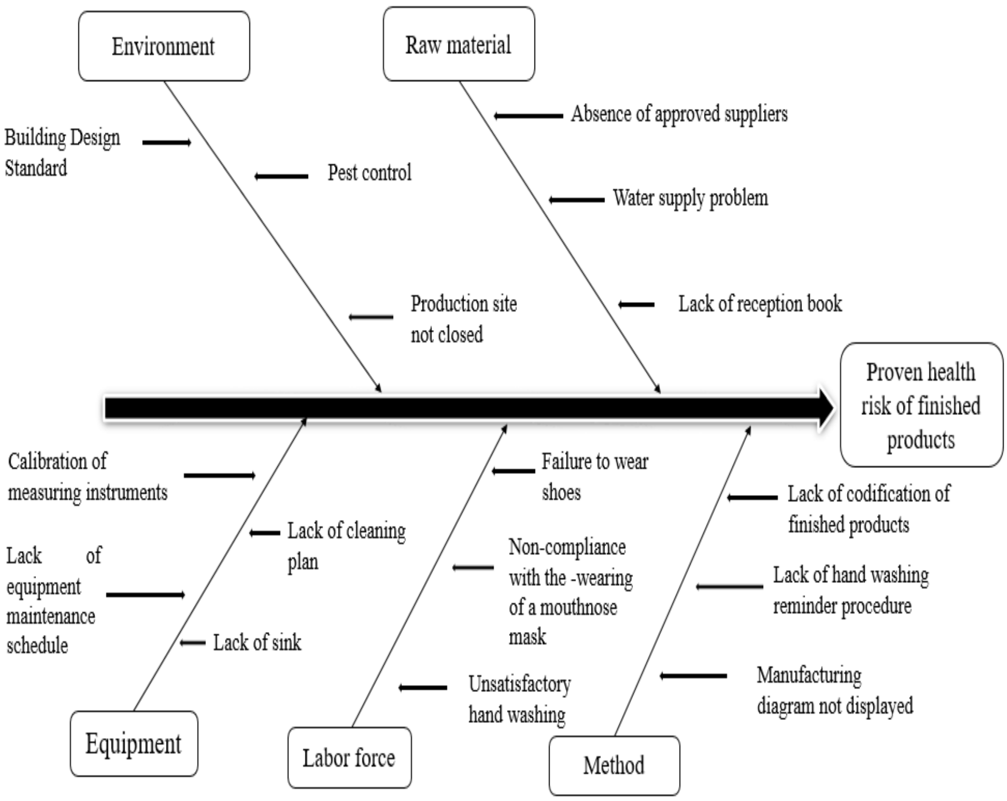

Figure 5. Potential causes of dysfunctional GHP/GMP implementation

3.5. Diagnosis of Prerequisites

The quality manager must establish a maintenance plan for the premises, preferably preventive, applied between two production campaigns: repair of paint and floors, replacement of cracked, lose or damaged tiles [22]. Cleaning or disinfection operations contributed to the preventive control of product contamination (fresh mangoes and dried mangoes). In fact, a permanent cleaning or disinfection program must be applied within the drying units during the campaign as well as between two production campaigns. This program therefore ensures that all parts of the unit are treated appropriately [25]. The premises must be maintained by the personnel working there and supervised by the designated team leader. Supervision concerns the indication of times and methods of cleaning to be applied [26]. According to the Specific Technical Regulations (STR) for the certification of dried mango and the general principles of food hygiene for the design of dried mango enterprises, the floors of food production buildings must be made of resistant, durable, impermeable and cleanable materials that cannot lead to contamination of the environment or food [27]. As for the structures inside food production establishments, they should be built solidly of durable materials and be easy to maintain, clean and disinfect [28]. In production premises for products that are sensitive (dried mangoes) to microbial development, it is recommended to place particular emphasis on air quality, which is a vector of particulate and microbial contamination [29]. In this study, the presence of water flash can result from the use of water in the process of cleaning and disinfection. Finally, Quittet and Nelis [27] suggested avoiding stagnation of water, except when it is voluntarily sought by wetting the soil, for technological reasons.

The packaging material (packaging) is one of the most important sources of microbial and chemical contamination of dried mangoes. Similar results were reported by Birali *et al.* [30] which attested that handling equipment is one of the most important sources of microbial contamination. Equipment in direct contact with fresh mangoes and dried mangoes must be designed in such a way as to allow good control and daily cleaning [25]. With regard to cleaning and disinfection products, the majority of units (82%) use approved products. This does not prevent a significant number of units (18%) from using non-approved products and sometimes hot water only. Cleaning-disinfection products must comply with food-related regulations [31]; disinfectants must also have been the subject of a marketing authorization like fungicides, bactericides or virucides [25]. The cleaning, disinfection and rinsing operations aim, respectively, to eliminate dirt, to destroy microorganisms and eliminate residues of the chemicals used. Cleaning methods and materials will depend on the nature of the food business [27]. According to Barro *et al.* [29], cleaning and disinfection operations involve three types of actions: mechanical, thermal and chemical. Thus, in general, reusable equipment and containers must guarantee proper cleaning, disinfection and maintenance to avoid contamination and must be free of toxic effects for the use for which they are intended [28]. However, the effectiveness of the natural substances used by the producers questioned, such as the bio-pesticides used.

In addition, people who are in direct contact with fresh mangoes must be subject to well-established regulations posted inside the unit. Strict measures must be taken for the effective application of cleanliness measures. These measures must encompass all the points that can affect the quality of the raw materials as well as that of the dried mangoes [2]. Indeed, staff must wear work clothes (blouses or coveralls), kept clean, and wash their hands when leaving the toilet before returning to the workstation. Tobacco should be banned and drinking water dispensers should be made available to workers [32]. The results showed that 100% of mango growers do not eat or smoke during production. In addition, 68% of producers allow outsiders (visitors) to circulate in the production room, which is justified by the absence of a prohibition pictogram. Note that 98% of producers clean their hands with cold water and soap before producing dried mangoes, while 2% do not. In addition, 100% of respondent's wear hairnets, mouth-nose masks, gown or other personal protective equipment during production. Furthermore, 100% of manufacturers do not carry jewelry items. Drinking and smoking are prohibited in food production areas. Any human circulation can be a source of contamination by the air movements it caused [27]. Indeed, humans are the main source of microorganisms in all cases where bio-contamination must be controlled [29]. Bio-contamination caused by personnel can have two origins: nasopharyngeal and cutaneous. According to these authors, this is remedied by wearing a mask, gloves, caps, work clothes and finally by training in hygiene rules. Finally, wearing jewelry items is prohibited because in addition to falling in and/or on food, they carry pathogenic germs [27]. Traceability and the application of the principles of the HACCP system to the production of dried mangoes will allow the units to establish a control system, aimed at controlling all the factors involved in the technological process, with a view to obtaining healthy and good quality dried mangoes [2].

3.6. Toxicological Quality of Dried Mango Samples

3.6.1. Research for Aflatoxins

The search for mycotoxins revealed the presence of AFB_1, AFB_2, AFG_1 and AFG_2. The contents of AFB_1, AFB_2, AFG_1 and AFG_2, in the dried mangoes were all lower than the quantization limit (LOQ) and the total Aflatoxins (B_1+B_2+G_1+G_2) was not determined. Other studies had detected AFB_1, AFB_2, AFG_1 and AFG_2 in dried foodstuffs [33,34,35]. Drying mangoes is very important in tropical regions because it is an effective means of preservation. But most often, the producers do not respect the basic rules of hygiene. In general, the production of dried mangoes is practiced in an unhealthy environment where the mastery of good hygiene practices by producers is not the best shared thing. The tools used are often too soiled. Post-drying treatments such as packaging and often inadequate storage can also be the cause of this contamination. An effort must be made at unit level in terms of training and awareness raising on good hygiene practices if we want to have quality dried mangoes that meet standards. Drying should be improved to reduce contamination through the application of good hygiene and processing practices. The identification of critical points would be necessary for mastering the diagram of the artisanal processing of dried mangoes and the protection of consumer health [2].

The results of the toxicological analysis of the dried mango samples are recorded in Table 1.

Table 1. Concentration of aflatoxins in dried mangoes

	Aflatoxins (µg/g)					
Code of samples	AFB1	AFB2	AFG1	AFG2	AFT (B1+B2+G1+G2)	Decision
AC2	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
AC5	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
DB1	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
DB2	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
FB1	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
FB2	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
FB4	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
KA1	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
KA3	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
KA4	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
KA5	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
UR1	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
UR3	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
UR4	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
UR5	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
US1	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
US3	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
US4	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
US5	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
YE2	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
YE3	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant
YE1	< LOQ	< LOQ	< LOQ	< LOQ	n/a	Compliant

LOQ: Quantization limit; n/a: Not determined.

3.6.2. Characterization of Heavy Metals and Physicochemical Quality of Dried Mangoes

3.6.2.1. Characterization of Heavy Metals in Dried Mangoes

The results of the heavy metal analysis were compared to the Burkinabe standard. Comparing the average values of trace metals found in the dried mango samples, the analysis of variance showed that the total trace metal content was significantly different ($p = 0.004$) in the dried mangoes sampled in the different cities.

3.6.2.2. Physicochemical Quality of Dried Mangoes

Water content in the mango drying process is an important aspect for good preservation. The humidity of the dried mangoes was between 6.12 to 17.44 g/100g with an average value of 6.750 g/100g. These values are better than those found by Kameni *et al.* [36] (about 15%). Solar drying gave a value of 1.59% lower than the 2.21% found for oven drying which is close to that found by Millogo (2.32%) [24]. Dried mangoes are slightly acidic with a pH between 4.87 and 5.33 with an average value of 5.12. It kept relatively well at room temperature. The relatively low pH <4.5 helped to limit the proliferation of fungi and predispose to good microbiological stability of the products at room temperature. The pH values obtained in the present study are similar to those found by Liu *et al.* [37] in four Chinese mango varieties (between 3.95 and 5.58), Afifa *et al.* [38] in mangoes from Bangladesh between 4.35 and 4, 71 and Elsheshetawy *et al.* [39] in Egyptian varieties (between 3.6 and 5.1). These water contents are significantly lower than those found by Sawadogo [40] which were 14 to 20% for the dried Amélie variety. These humidity levels are also lower than those of Zongo [41] which were 20.30% for the Amélie variety, 17.23% for the Lippens variety and 10.90% for the Brooks variety. These differences in results are mainly explained by the variability of drying conditions (type of dryer and drying time) and the thickness of the mango slices. Indeed, the samples of this study were dried for 22 hours in a Céas Atesta type dryer unlike those of Zongo [41] which underwent a drying period of 15 to 18 hours in a Tunel type dryer. These results also differed from those obtained by Sawadogo [40] who used a tent and pyramid type dryer over a period of 48 to 72 h. The differences ($p = 0.004$) in the results observed between the samples of different varieties could be explained by the level of maturity of the fresh products. According to Kameni *et al.* [36], products from fruits at advanced maturity retain more water than fruits at commercial or physiological maturity. The contents of metallic trace elements (mg/kg) in the dried mango samples, the pH and the humidity are recorded in Table 2.

Table 2. Heavy metals and physicochemical content of dried mango samples in four citizen of Burkina Faso

	heavy metals					Physicochemical parameters	
Code of samples	Cd (mg/Kg)	Pb (mg/Kg)	Cu (mg/Kg)	Mn (mg/Kg)	Co (mg/Kg)	pH	Humidity (%)
KA2	0.117 ± 0.02^{a}	0.347 ± 0.01^{a}	2.923 ± 0.01^{g}	8.313 ± 0.03^{fd}	1.537 ± 0.01^{c}	4.250 ± 0.01^{e}	12.360 ± 0.01^{b}
FB4	0.100 ± 0.01^{abcd}	0.333 ± 0.03^{ab}	6.850 ± 0.01^{a}	9.197 ± 0.01^{fd}	1.003 ± 0.04^{i}	4.940 ± 0.01^{a}	10.307 ± 0.01^{h}
US2	0.107 ± 0.03^{ab}	0.223 ± 0.01^{efg}	2.740 ± 0.01^{h}	13.470 ± 0.01^{b}	1.640 ± 0.01^{b}	3.860 ± 0.02^{j}	17.443 ± 0.01^{a}
DB2	0.070 ± 0.03^{abcde}	0.320 ± 0.01^{b}	4.930 ± 0.04^{c}	8.970 ± 0.01^{gh}	1.367 ± 0.02^{d}	4.050 ± 0.01^{g}	10.887 ± 0.03^{fg}
UR3	0.090 ± 0.02^{abcd}	0.247 ± 0.01^{de}	1.427 ± 0.01^{m}	11.770 ± 0.03^{d}	1.537 ± 0.01^{c}	4.240 ± 0.01^{e}	9.223 ± 0.01^{j}
US3	0.097 ± 0.01^{abcd}	0.257 ± 0.01^{cd}	2.480 ± 0.03^{i}	8.397 ± 0.01^{d}	1.347 ± 0.01^{d}	3.810 ± 0.01^{j}	12.170 ± 0.01^{c}
UR5	0.083 ± 0.01^{abcd}	0.013 ± 0.02^{j}	4.953 ± 0.01^{c}	13.890 ± 0.01^{b}	1.517 ± 0.01^{c}	3.933 ± 0.01^{j}	10.960 ± 0.01^{f}
FB3	0.077 ± 0.02^{abcd}	0.273 ± 0.01^{c}	4.337 ± 0.01^{d}	6.290 ± 0.02^{mn}	1.640 ± 0.01^{d}	4.680 ± 0.01^{b}	7.067 ± 0.01^{o}
KA3	0.080 ± 0.02^{abcd}	0.253 ± 0.03^{cd}	3.723 ± 0.02^{d}	8.377 ± 0.01^{d}	1.273 ± 0.01^{d}	4.230 ± 0.01^{e}	8.230 ± 0.01^{m}
UR4	0.077 ± 0.02^{abcd}	0.223 ± 0.01^{efg}	2.330 ± 0.01^{e}	9.560 ± 0.02^{d}	1.707 ± 0.01^{f}	4.243 ± 0.01^{e}	7.270 ± 0.02^{n}
US4	0.073 ± 0.01^{abcd}	0.277 ± 0.02^{c}	1.240 ± 0.01^{j}	20.740 ± 0.01^{f}	1.127 ± 0.01^{a}	3.560 ± 0.01^{m}	12.203 ± 0.01^{c}
US1	0.083 ± 0.01^{abcd}	0.237 ± 0.01^{de}	5.660 ± 0.02^{n}	6.620 ± 0.03^{m}	1.067 ± 0.02^{g}	4.223 ± 0.01^{e}	8.160 ± 0.01^{m}
YE1	0.053 ± 0.01cde	0.210 ± 0.01^{fg}	2.177 ± 0.01^{b}	12.687 ± 0.01^{c}	1.500 ± 0.01^{c}	4.360 ± 0.01^{d}	6.750 ± 0.02^{p}
KA1	0.102 ± 0.01^{abcd}	0.233 ± 0.02^{def}	1.443 ± 0.01^{k}	7.230 ± 0.01^{l}	1.323 ± 0.01^{de}	3.580 ± 0.01^{lm}	11.470 ± 0.01^{o}
KA5	0.087 ± 0.01^{abcd}	0.240 ± 0.01^{de}	1.143 ± 0.02^{m}	8.573 ± 0.02^{hi}	0.957 ± 0.03^{i}	3.720 ± 0.01^{k}	10.320 ± 0.01^{h}
AC2	0.063 ± 0.02^{bcde}	0.240 ± 0.02^{de}	1.840 ± 0.01^{o}	10.150 ± 0.0^{e}	0.847 ± 0.01^{j}	4.240 ± 0.01^{e}	7.250 ± 0.02^{n}
YE2	0.033 ± 0.01^{f}	0.233 ± 0.01^{de}	5.657 ± 0.02^{l}	9.180 ± 0.01^{fg}	0.720 ± 0.01^{kl}	3.570 ± 0.01^{lm}	11.267 ± 0.01^{e}
US5	0.057 ± 0.01^{cde}	0.073 ± 0.03^{g}	2.940 ± 0.01^{b}	8.120 ± 0.01^{ij}	1.520 ± 0.02^{c}	4.557 ± 0.01^{c}	6.117 ± 0.01^{r}
AC3	0.077 ± 0.01^{abcd}	$0.253 \pm 0,01^{def}$	3.070 ± 0.01^{g}	6.550 ± 0.02^{m}	0.307 ± 0.0^{1o}	3.963 ± 0.01^{hi}	8.363 ± 0.01^{l}
FB2	0.073 ± 0.02^{abcd}	0.233 ± 0.01^{cd}	1.440 ± 0.02^{m}	7.360 ± 0.01^{l}	1.363 ± 0.02^{d}	3.620 ± 0.01^{hi}	10.307 ± 0.02^{h}
FB1	0.103 ± 0.02^{abcd}	0.200 ± 0.01^{i}	0.307 ± 0.01^{q}	5.960 ± 0.01^{no}	1.277 ± 0.01^{ef}	3.990 ± 0.01^{h}	7.340 ± 0.01^{n}
AC4	0.087 ± 0.01^{abc}	0.207 ± 0.02^{def}	0.880 ± 0.01^{p}	7.890 ± 0.01^{jk}	0.567 ± 0.02^{m}	3.987 ± 0.01^{hi}	7.340 ± 0.01^{n}
AC5	0.067 ± 0.03^{abcd}	0.253 ± 0.01^{cd}	0.067 ± 0.01^{r}	7.547 ± 0.01^{kl}	0.683 ± 0.01^{l}	3.720 ± 0.01^{k}	8.940 ± 0.01^{k}
KA4	0.060 ± 0.02^{bcde}	0.247 ± 0.01^{de}	0.080 ± 0.01^{r}	7.550 ± 0.03^{kl}	0.683 ± 0.03^{l}	3.613 ± 0.01^{lm}	9.870 ± 0.02^{i}
YE3	0.033 ± 0.01^{ef}	$0,400 \pm 0.02^{j}$	2.127 ± 0.01^{k}	13.750 ± 0.01^{b}	0.367 ± 0.01^{n}	3.343 ± 0.01^{o}	10.800 ± 0.01^{g}
DB1	0.060 ± 0.03^{bcde}	0.243 ± 0.01^{de}	0.073 ± 0.02^{r}	7.490 ± 0.01^{kl}	0.703 ± 0.01^{l}	4.160 ± 0.01^{f}	6.313 ± 0.01^{q}
AC1	0.057 ± 0.01^{cde}	0.163 ± 0.01^{h}	1.760 ± 0.01^{l}	5.750 ± 0.01^{o}	0.760 ± 0.04^{k}	3.493 ± 0.01^{n}	9.160 ± 0.01^{j}
UR1	0.030 ± 0.02^{f}	0.040 ± 0.01^{j}	0.060 ± 0.01^{r}	0.370 ± 0.02^{p}	0.413 ± 0.01^{n}	3.620 ± 0.01^{l}	6.240 ± 0.01^{q}

The same letters in a column are not significantly different at the 5% threshold according to the Newman-Keuls test
Cd: Cadmium; **Pb**: Lead; **Cu**: Copper; **Mn**: Magnesium; **Co**: Cobalt.

3.7. Principal Component Analysis of Heavy Metals, pH and Humidity

Principal component analysis of the dried mango samples was performed using a biplot consisting of two axes (F1 and F2) which explained 51.99% of the variability of the study samples. The main axis F1 explained 31.77% of this variability and the secondary axis F2 20.22%. A first group consisting of Pb, Cd, Mn and Cu which is linked to the main axis F1 and a second group which included the Co which is linked to the secondary axis F2 are determined by the two axis.

The observations made on the main axis revealed that the samples from Bobo and Orodara are simultaneously contaminated by Pb, Cd, Mn, Cu and with an acid pH. While that carried out on Banfora made it possible to distinguish a contamination of the samples of dried mangoes in Co and a relatively acceptable humidity. The comparison of the total heavy metal contents in the dried mangoes with respect to the NBF standards shows that the Pb, Cd, Mn and Cu contents in the Dried Matter (DM) produced, 75.65% of the Dried Matter (DM) exceed the threshold set at 0.004; 0.006 and 0.014 mg/kg DM respectively for Cd, Pb, and As [28]. Samples from Bobo-Dioulasso recorded the level of Cd, Pb, Cu, Mn and Co contamination at 0.107; 0.333; 5.660; 1.640 mg/kg and 1.707 Dried Matter (DM), respectively. Compared to the samples from Banfora, the levels of contamination in Cd, Pb, Cu, Mn and Co are 0.073; 0.13; 0.88; 6.620 and 0.367 mg/kg Dried Matter (DM), respectively. However, samples from Orodara, are recorded the level of contamination in Cd, Pb, Cu, Mn and Co at values of 0.080; 0.253; 3.723; 8.377; 1.273 mg/kg DM, respectively. The average levels of MTEs in dried mangoes are found in the order: Mn>Cu>Co>Pb>Cd. This trend indicates that dried mangoes have a high Mn retention capacity, followed by Cu, Co and then Pb and Cd. It can be observed that all dried mango samples have a higher retention capacity for metals.

The Ascending Hierarchical Classification (HAC) indicates on the basis of the heavy metals and overall physicochemical that the samples of dried mangoes taken from the two regions of Burkina Faso are divided into twenty-eight groups according to origin. The classes of dried mangoes are formed by the samples coming from two groups whose heavy metals content, pH value and humidity differ from all the samples.

3.8. Sensory Analysis of Dried Mangoes

The Figure 6 showed us the principal component analysis of metal trace elements, moisture and pH in the dried mangoes.

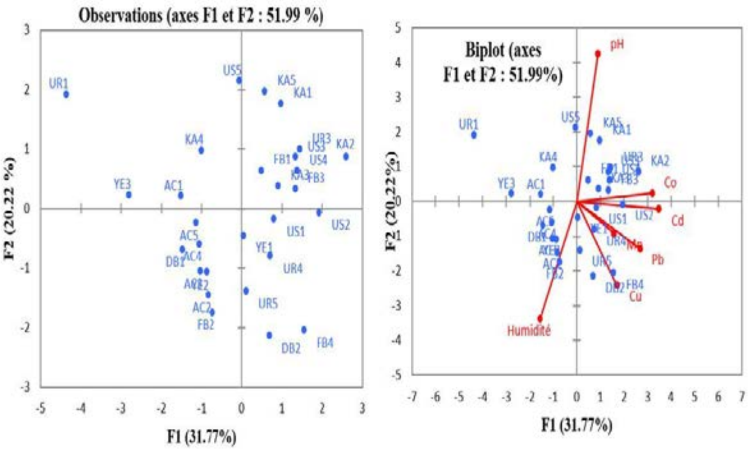

Figure 6. Principal component analysis of heavy metals, moisture and Ph

The Figure 7 showed the profile of the classes.

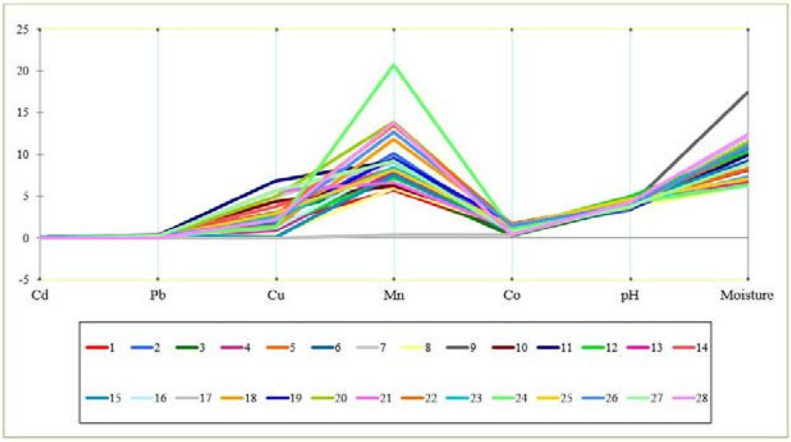

Figure 7. Class profil

The results of the organoleptic analyzes are recorded in Table 3.

Table 3. Results of sensory analysis of dried mangoes

Aspect	Smell	Flavor	Labeling
Solid, brown, orange-yellow and without foreign particles, Flexible slightly sticky, fairly dry	Characteristic of the designated product (fresh mango)	Sweet, sour and characteristic of the product	No label
Solid, brown, orange-yellow and without foreign particles, Flexible Slightly sticky, fairly dry	Characteristic of the designated product (fresh mango)	Sweet, sour and characteristic of the product	No label

In view of this table, we can say that from the point of view of smell, taste and texture there are no differences between the sample dried in the oven and that dried in the sun. The only difference observed is at the level of the color, it is brown for the sample dried in the sun. This brown coloration is probably said to be a non-enzymatic browning reaction following heat. The browning factors are, among other things, the degree of ripening, the drying technology, the treatment time, the smoke from the burnt gases. Regarding smell, the mango slices were free from foreign odors. The smell is characteristic of mango (presence of mango aroma).

4. Conclusion

This study aimed to diagnose the hygiene and manufacturing practices of dried mangoes in the dried mango production units of Banfora, Orodara, Bobo-Dioulasso and Toussiana, and to evaluate the sanitary quality in relation to normative and regulatory requirements. The results showed that the majority of the manufacturing units are of the semi-modern type and do not comply with the standards, in general with regard to the installations, layout, sanitation, hygiene practices and manufacturing. The equipment used is rudimentary. Staff are poorly educated and routine, and have not been trained in hygiene standards or various procedures. The contents of AFB1, AFB2, AFG1 and AFG2 were all lower than the LOQ. The physico-chemical results show values between 3.33 to 4.94 for the pH. The humidity levels were between 6.12 to 17.44%. For heavy metals, dried mangoes have a high Mn retention capacity. Efforts should be made to develop this specialty and produce on a large scale dried mangoes of guaranteed quality that can meet both local and international market requirements. An introduction to the application of good hygiene practices and good manufacturing practices is a preliminary step that would allow manufacturing units, concerned with improving the quality of dried mangoes, to offer consumers healthy products while making against competition. Consequently, this approach presupposes the assistance of a labor force trained and capable of meeting certain requirements in the face of the continual quest for quality.

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