

EFFECTS OF CONVECTIVE ROASTING CONDITIONS ON MICROBIAL  
SAFETY OF COCOA BEANS\*

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**Abstract.** Cocoa beans (the Ivory Coast variety) were subjected to convective roasting at air temperatures of 135, 140 and 150°C, relative humidity (*RH*) of 0.35-0.45% or 2, 5 and 10%, and air constant flow rate (*v*) of 1 m s<sup>-1</sup>. Microbial contamination (total numbers of aerobic bacteria, numbers of spores) was estimated in raw and roasted cocoa beans. Results of the assays demonstrate that the most effective bactericidal temperature, independently from the relative humidity of air, appeared to be 150°C. However, the air humidity influenced the time of roasting at 150°C, providing sufficient reduction of microflora. To achieve satisfactory microbial safety as a result of roasting at 140°C, the beans required processing with so called "dry air" (*RH* of 0.4%) for 45 min. Roasting for 45 min at 135°C and *RH* of 2% reduced indigenous microflora of cocoa beans to 10<sup>4</sup> cfu per g.

**Key words:** cocoa beans, roasting, relative humidity of air, quality, microbiological safety

## INTRODUCTION

High quality and long shelf life of confectionery require appropriate quality of raw materials, including cocoa beans, an adequate method of processing, and safe level of microbial contamination. Live microorganisms that produce toxic products of metabolism and contribute to spoilage of foodstuffs are considered to be most hazardous [5].

Microbial purity of cocoa beans is affected by conditions of fermentation, drying, storage and transporting, etc. Microorganisms frequently attack the raw

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material at these steps, and therefore they are regarded as the crucial points of safety and quality control [2].

Due to low water content in cocoa beans (5-7%), bacterial and fungal spores dominate their microflora [6,18]. The contamination with filamentous fungi usually starts in damp stores (at 0-25°C), or during cleaning, sorting, drying and crushing. In factories, the air turned out to be the source of aerobic bacteria and fungal spores. Microorganisms that attack cocoa display high lipolytic activity, thus enhancing the content of free fatty acids and decreasing the technological quality of the material [18,20].

The best method to avoid proliferation of microflora existing on cocoa beans is to store the material below 18°C and to provide humidity of air less than 70%.

Inactivation of microorganisms that contaminate cocoa can be achieved during roasting at temperatures up to 160°C [3]. Usually, this process is carried out at 130-150°C for 15-45 min [7, 8]. During this treatment, the maximum temperature of beans ranges up to 120-140°C [1,3,16,17,19].

In the traditional method, whole beans are roasted. There are various techniques of thermal processing of cocoa beans. In one of them, the beans are roasted after preliminary humidification of their surface that finally facilitates removal of shells surrounding the core. The humidification of the bean surface is carried out either by sprinkling with water or by steaming. For the same purpose, circulating humid air can be employed [16,17].

Our studies were aimed at an assessment of the level of microbial contamination present in samples of cocoa beans, and an estimation of the viability of these microorganisms after convective roasting of the material, including processing with air having elevated humidity. The objective of the experiments was the determination of roasting conditions that provide both suitable physicochemical properties of the processed material and substantial microbial safety of the product.

## MATERIALS AND METHODS

### **Materials**

Cocoa beans (the Ivory Coast variety) from The Ivory Coast were applied in the studies. The cocoa beans were sorted after determination of their quality, and the medium-size fraction was selected for further experiments, to provide uniform processing of all roasted beans.

### **Roasting methods**

Samples of selected cocoa beans were subjected to convective roasting in flowing air, using the tunnel presented in Figure 1.

The applied air parameters were as follows:

- temperature of 135, 140 and 150°C,
- relative humidity (*RH*) ranging from 0.35 to 0.45%, and of 2, 5, and 10%,
- air flow rate (*v*) of 1 m per s.

A monolayer of beans in the amount of 200 g was roasted each time. The process was terminated when the water content of the material dropped to approximately 2%, since this value is considered to be optimal for further steps of cocoa processing, such as crushing or cocoa butter pressing [19].

In order to obtain the relative air humidity of 0.35-0.45% at 135°C inside the roasting tunnel, corresponding to so called “dry air”, the following equation was used:

$$RH_{135^{\circ}C} = \frac{RH_{20^{\circ}C} \cdot (P_{sat})_{20^{\circ}C}}{(P_{sat})_{135^{\circ}C}} \quad (1)$$

where:  $RH_{135^{\circ}C}$  – the relative humidity at 135°C (%),  $RH_{20^{\circ}C}$  – the relative humidity at 20°C, determined by using the measuring instrument (%),  $(P_{sat})_{20^{\circ}C}$  – water vapour at 20°C,  $2.337 \cdot 10^3$  Pa; value to be read from [15],  $(P_{sat})_{135^{\circ}C}$  – water vapour at 135°C,  $313 \cdot 10^3$  Pa; value to be read from [15].

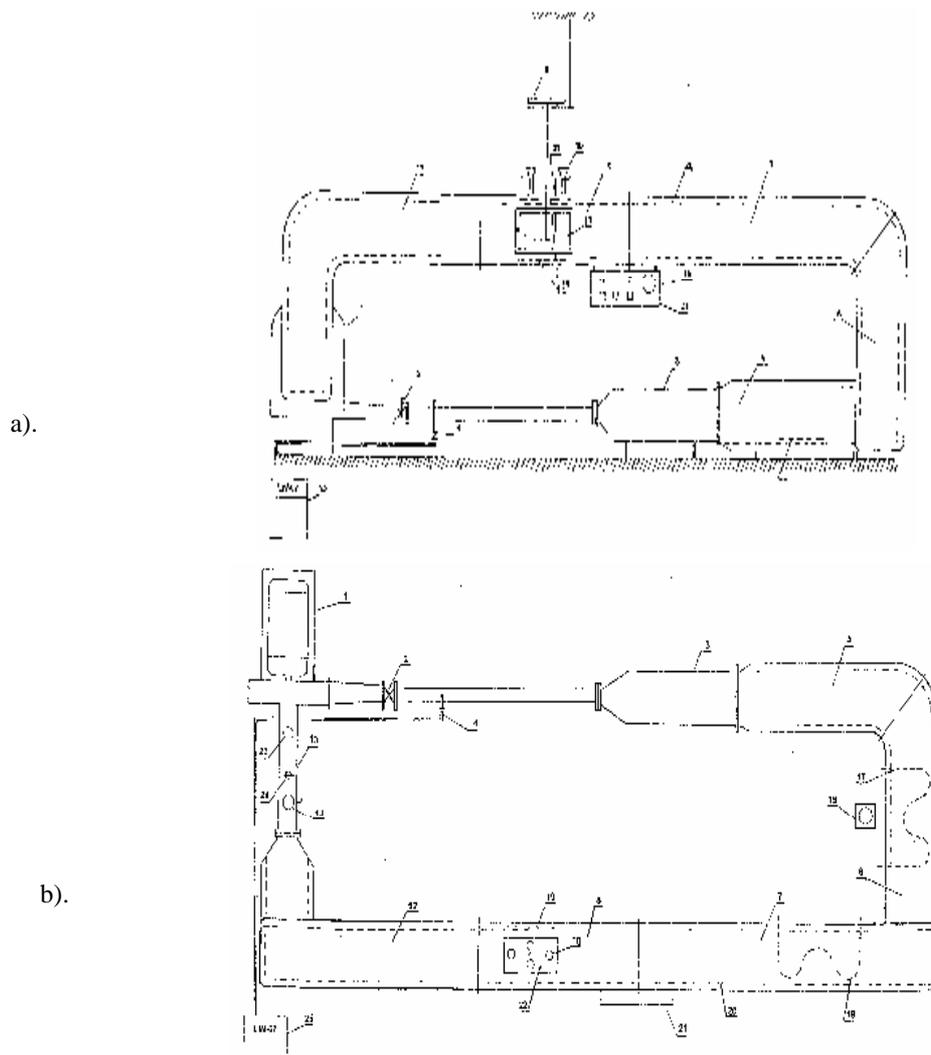
Air humidity was elevated using saturated steam produced in a steam generator (Fig. 1). The values of relative humidity of 2, 5 and 10% were shown by the Therm 2285-2B measuring instrument coupled with the FHA636-HR2 measuring probe. The measurements of relative humidity, temperature and flow rate of air were made with an accuracy of  $\pm 0.5\%$ ,  $\pm 1^{\circ}C$ , and  $\pm 0.05 \text{ m s}^{-1}$ , respectively.

### Analyses

Determinations of water content and microbiological purity were executed for all samples of raw and roasted cocoa beans. Water content assays were carried out using the thermogravimetric method, according to the Polish Standard PN-A-76101:1998 [10].

### Microbiological analysis

The samples of cocoa beans were analyzed for total numbers of aerobic bacteria and their spores, dominating the microflora of roasted cocoa. These tests were performed according to the Polish Standards: PN-A-88033:1998, PN-ISO 4833 [11,12]. The number of aerobic bacteria was assessed using the agar plating medium containing yeast extract and glucose. The colonies were counted after 48 hrs of incubation at 28°C, and the results were expressed as cfu (colony forming units) per g of cocoa beans.



**Fig. 1.** Schematic diagram of a tunnel for thermal processing of cocoa beans: a) front view, b) top view  
 1 – fan, 2 – throttle, 3 – heater, 4 – steam supply inlet with regulating valve, 5 – section of air parameters control, 6 and 7 – sections for equalising air velocity profiles, 8 – measuring section, 9 – balance, 10 – bean batching funnels, 11 – plate, 12 – section of air removal, 13 – recirculated pipe, 14 – air offtaking pipe, 15 and 16 – autotransformers, 17–19 – additional heaters, 20 – insulation, 21 – control panel, 22 – temperature probe (sensor), 23 – pipe with valve to inlet fresh air, 24 – valve for regulating recirculation of air, 25 – steam generator

The number of aerobic spores was determined after 10 min of incubation of the samples at 80°C (heat shock), and the results were expressed as cfu per g of the beans.

The viability of bacterial vegetative cells and spores after each roasting experiment is a percentage value and denotes the ratio of their numbers after (N) and before (N<sub>0</sub>) roasting.

Triplicate samples of cocoa beans were roasted in given conditions. Results displayed in tables are means ± standard deviation (the latter did not exceed 3-4%).

## RESULTS AND DISCUSSION

Studies on the influence of convective roasting on microbiological purity of roasted cocoa beans were conducted at 135, 140 and 150°C, and at relative air humidity of 0.35-0.45%, or enhanced to 2, 5 and 10%. Results of the experiments are collected in Tables 1 and 2.

**Table 1.** Microbiological contamination of cocoa beans roasted in “dry” air (RH of 0.35-0.45%) using the convective method

No	Roasting temperature (°C)	Roasting time (min)	Water content (%)	Number of bacterial cells cfug <sup>-1</sup>	N/N <sub>0</sub> * (%)	Number of spores cfug <sup>-1</sup>	N/N <sub>0</sub> * (%)
0	Raw beans at an initial temperature of 20°C	–	5.30	4.8 x 10 <sup>6</sup>	100.00	1.4 x 10 <sup>6</sup>	100.00
1	135 ± 1 RH = 0.45%	35	2.07	2.5 x 10 <sup>5</sup>	5.20	2.1 x 10 <sup>5</sup>	16.10
2		30	2.05	5.0 x 10 <sup>5</sup>	10.40	5.1 x 10 <sup>5</sup>	39.20
3	140 ± 1	40	2.00	1.4 x 10 <sup>5</sup>	2.92	1.5 x 10 <sup>5</sup>	11.54
4	RH = 0.40%	45	1.95	9.3 x 10 <sup>4</sup>	1.96	1.2 x 10 <sup>5</sup>	9.23
5		50	1.82	5.1 x 10 <sup>5</sup>	10.63	4.7 x 10 <sup>5</sup>	36.15
6	150 ± 1 RH = 0.35%	30	1.90	3.0 x 10 <sup>4</sup>	0.63	8.0 x 10 <sup>4</sup>	6.15

\*N<sub>0</sub> – number of bacteria in raw beans; N – number of bacteria in roasted beans.

**Table 2.** Microbiological contamination of cocoa beans roasted in air with elevated humidity by means of the convective method

No.	Roasting temperature (°C)	Relative humidity of air (%)	Time (min)	Water content (%)	Number of bacteria cfug <sup>-1</sup>	N/N <sub>0</sub> (%)	Number of spores cfug <sup>-1</sup>	N/N <sub>0</sub> (%)
0	Raw beans at an initial temperature of 20°C	–	–	5.30	4.8 x 10 <sup>6</sup>	100.00	1.4 x 10 <sup>6</sup>	100.00
1	135 ± 1	0.45	35	2.07	2.5 x 10 <sup>5</sup>	5.21	2.1 x 10 <sup>5</sup>	16.15
2		2 ± 0.5	35	2.40	3.3 x 10 <sup>5</sup>	6.87	3.0 x 10 <sup>5</sup>	23.07
3			45	2.10	8.1 x 10 <sup>4</sup>	1.69	1.6 x 10 <sup>5</sup>	12.31
4		5 ± 0.5	60	1.95	8.5 x 10 <sup>5</sup>	17.71	8.1 x 10 <sup>5</sup>	62.31
5		10 ± 0.5	45	2.40	1.6 x 10 <sup>6</sup>	33.33	1.5 x 10 <sup>6</sup>	115.38
6	140 ± 1	0.4	30	2.00	1.4 x 10 <sup>5</sup>	2.92	1.5 x 10 <sup>5</sup>	9.23
7		2 ± 0.5	40	2.05	6.5 x 10 <sup>5</sup>	13.54	5.5 x 10 <sup>5</sup>	42.31
8			45	1.98	2.1 x 10 <sup>5</sup>	4.44	4.0 x 10 <sup>5</sup>	30.76
9	5 ± 0.5	2 ± 0.5	50	1.91	3.8 x 10 <sup>5</sup>	7.92	3.1 x 10 <sup>5</sup>	23.84
10			40	2.20	2.6 x 10 <sup>5</sup>	5.42	2.8 x 10 <sup>5</sup>	21.53
11			50	2.10	5.7 x 10 <sup>4</sup>	1.19	8.8 x 10 <sup>4</sup>	6.76
12	150 ± 1	0.35	30	1.90	3.0 x 10 <sup>4</sup>	0.63	8.0 x 10 <sup>4</sup>	6.15
13		2 ± 0.5	30	2.07	1.0 x 10 <sup>4</sup>	0.21	1.6 x 10 <sup>4</sup>	1.23
14		5 ± 0.5	30	2.08	1.9 x 10 <sup>6</sup>	39.58	1.8 x 10 <sup>6</sup>	138.46
15			45	1.90	2.0 x 10 <sup>4</sup>	0.44	1.8 x 10 <sup>4</sup>	1.38

Bactericidal impact of convective roasting with “dry” air is shown in Table 1. The killing effect is contingent on temperature and humidity of air, and on the time of processing. The same result, namely the twofold reduction in logarithmic scale of the number of bacteria, can be achieved by roasting either at 140°C for

45 min, or at 150°C for 30 min. An extension of the time of processing at 140°C to 50 min gave rise to activation of the spores that 10 times enhanced the number of bacteria (to  $10^5$  cfu per g of beans).

These findings indicate that roasting at 140°C and *RH* of 0.4%, conducted for longer than 45 min, negatively affects the microbial safety of the product. The activation of spores and increase in the total number of bacteria were observed in the samples roasted for 50 min. This result is bothersome since bacteria proliferating in the roasted material undoubtedly worsen its quality. The dormant forms of spores are activated due to thermal treatment of the cocoa beans, and their water content of 1.82%, lower than that recommended of 2% [8,9,16,17,19], is presumably beneficial for this process. A similar phenomenon was observed when the samples of cocoa beans were roasted using continuous microwaving. A decline in water content markedly below 1.9% enhanced the number of aerobic bacterial spores from  $8.3 \cdot 10^4$  to  $3.1 \cdot 10^5$  cfu g<sup>-1</sup> [13,14].

According to literature, the Ivory Coast cocoa beans should be roasted for approximately 35 min at 135°C [8,9]. These conditions provide the desired physicochemical properties of the material, and its final water content of approximately 2%. Our experiments showed that processing carried out under the recommended conditions yielded similar humidity (2.07%) of the roasted beans, but the residual numbers of bacterial cells and spores were too large to be acceptable. Only 84-95% of microorganisms were inactivated (one logarithmic cycle) during roasting under these conditions, whereas processing at 150°C for 30 min eliminated 99.37 and 93.85% of bacteria and their spores, respectively. Our results are in accordance with observations of Kosewska [4], who found that as much as 90 and 99% of bacteria could be killed due to roasting at 135 and 165°C, respectively.

Our further experiments were focused on the effect of the relative air humidity on thermal inactivation of microflora of cocoa beans. This aspect is of importance since circulating humid air is a potential heating medium for cocoa roasting and, furthermore, the humidification of the beans' surface, providing warm and humid atmosphere, usually takes place during large scale processing of cocoa.

The results of microbiological tests made on samples of cocoa beans roasted at 135, 140 and 150°C, and at *RH* of 2-10%, are shown in Table 2. The data indicate that at 135°C the best microbiological quality was achieved after 45 min of processing at *RH* of 2%. The residual numbers of bacteria and their spores were  $8.1 \cdot 10^4$  and  $1.6 \cdot 10^5$  cfu g<sup>-1</sup>, respectively. Enhancement of the relative air humidity to 5 and 10% corresponded to an increase in the numbers of residual bacteria, to  $8.5 \cdot 10^5$  and  $1.6 \cdot 10^6$  cfu g<sup>-1</sup>, respectively, despite longer time of roasting. This fact presumably results from the slightly lower temperature of the shell of the cocoa beans as compared to that of its core, due to slower evaporation of water from the surface

of the cocoa bean brought about by the cooling effect caused by the presence of humidity in the air used for roasting. According to the following equation, the portion of heat delivered to the material upon convective roasting is used both for its heating and water evaporation.

$$Q_{\text{of convection}} = Q_{\text{of heating}} + Q_{\text{of water evaporation}}$$

When the temperature of the heating medium (air with certain humidity) is kept invariable (thus  $Q_{\text{of convection}}$  is constant), and the relative air humidity is elevated (thus  $Q_{\text{of water evaporation}}$  is decreased), thus  $Q_{\text{of heating}}$  of the inside part of material has to increase. The continued diffusion results in transfer of humidity and heat to the surface of the material, bringing about a rise in its temperature coupled with water evaporation.

Our studies demonstrated that cocoa beans roasted at 135°C and *RH* of 10% for 45 min contained virtually the same population of bacteria and their spores as found before the thermal processing. Although the final humidity of cocoa beans roasted under these conditions was similar to that after 35 min of roasting at 135°C and *RH* of 2%, because of the elevated steam content in the hot air the temperature of the beans' surface was not high enough to inactivate the contaminating microorganisms.

These findings indicate that roasting of cocoa at 135°C and *RH* above 2% is not sufficiently effective when the elimination of microflora is the criterion of assessment. Presumably, the stronger bactericidal effect requires longer time of processing, but this solution is economically unprofitable.

The satisfactory killing effect can be attained by convective roasting of cocoa beans for 50 min at 140°C and *RH* of 5% (Tab. 2). These conditions gave rise to virtually 99% drop in the total number of bacteria (to  $5.7 \cdot 10^4$  cfu g<sup>-1</sup>), similarly to roasting for 45 min (5 min difference in time) at 135°C and *RH* of 2%.

The safe level of residual microflora existing on roasted cocoa beans ( $1 \cdot 10^4$  cfu g<sup>-1</sup>) was also achieved after 30 min of processing at 150°C and *RH* of 2%, thus in 5 min shorter time as compared to roasting at 135°C and *RH* of 0.45%, that left even more bacteria ( $2.5 \cdot 10^5$  cfu g<sup>-1</sup>). To derive a similar bactericidal effect (the final number of bacteria of  $2.1 \cdot 10^4$  cfu g<sup>-1</sup>) at 150°C, but at *RH* of 5%, the processing of cocoa beans had to last 15 min longer, i.e. 45 min, like roasting at 135°C and *RH* of 2%. This comparison suggests that the effectiveness of cocoa roasting at the elevated *RH* (of 5%), with respect to removal of microbial contamination, stems from the applied high temperature of air.

Conditions of convective roasting providing satisfactory microbial safety of roasted cocoa beans are shown in Table 3.

**Table 3.** Convective roasting conditions providing microbial safety of cocoa

No	Roasting temperature (°C)	Relative humidity of air (%)	Time (min)	Water content (%)	Number of bacteria cfu g <sup>-1</sup>	N/N <sub>0</sub> (%)	Number of spores cfu g <sup>-1</sup>	N/N <sub>0</sub> (%)
1	140 ± 1	0.40	45	1.95	9·10 <sup>4</sup>	1,96	1.2·10 <sup>5</sup>	9.23
2	150 ± 1	0.35	30	1.85	3·10 <sup>4</sup>	0.63	8·10 <sup>4</sup>	6.15
3	135 ± 1	2.0	45	2.1	8.1·10 <sup>4</sup>	1.69	1.6·10 <sup>5</sup>	12.3
4	150 ± 1	2.0	30	2.07	1·10 <sup>4</sup>	0.21	1.6·10 <sup>4</sup>	1.23
5	150 ± 1	5.0	45	1.90	2.1·10 <sup>4</sup>	0.44	1.8·10 <sup>4</sup>	1.38

### CONCLUSION

1. Microbial contamination of roasted cocoa beans depends on conditions of convective roasting. Roasting conditions providing suitable microbiological safety of the product are as follows:

- dry air (*RH* of 0.4%) at 140°C for 45 min;
- dry air (*RH* of 0.35%) at 150°C for 30 min;
- humid air with *RH* of 2% at 135°C for 45 min;
- humid air with *RH* of 2% at 150°C for 30 min;
- humid air with *RH* of 5% at 150°C for 45 min.
- In all the cases, the rate of air flow was 1 m s<sup>-1</sup>.

2. These results indicate that 150°C appeared to be the most effective bactericidal temperature, independently from relative humidity of air, applied as a heating medium. However, the required time of roasting at 150°C was contingent upon the air humidity.

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## WPŁYW WARUNKÓW KONWEKCYJNEGO PRAŻENIA NA CZYSTOŚĆ MIKROBIOLOGICZNĄ ZIARNA KAKAOWEGO

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**Streszczenie.** Ziarno kakaowe odmiany Ivory Coast poddane zostało procesowi konwekcyjnego prażenia. Stosowano temperaturę powietrza 135°, 140°, 150°C, wilgotność względną powietrza z zakresu 0,35-0,45% oraz 2, 5, 10% i stałą prędkość przepływu  $v = 1 \text{ m}\cdot\text{s}^{-1}$ . W surowym, jak i wyprażonym w różnych warunkach powietrza ziarnie określano poziom mikrobiologicznych zanieczyszczeń (ogólną liczbę bakterii tlenowych; liczbę przetrwalników). Na podstawie uzyskanych wyników stwierdzono, że najskuteczniejszą temperaturą pod względem efektu bakterioobójczego, niezależnie od zastosowanej wilgotności względnej powietrza tylko w różnych czasach, była temperatura 150°C. Dla temperatury 140°C jakość mikrobiologiczną określaną jako bezpieczną uzyskiwano w warunkach tzw. „powietrza suchego” ( $RH = 0,4\%$ ) i w czasie 45 minut. Poziom mikroflory wynoszący  $10^4 \text{ jtk}\cdot\text{g}^{-1}$  ziarna zapewniały także temperatura powietrza 135°C,  $RH = 2\%$  i czas 45 min.

**Słowa kluczowe:** ziarno kakaowe, prażenie, wilgotność względna powietrza, jakość, bezpieczeństwo mikrobiologiczne