

Influence of roasting conditions on coloration of roasted cocoa beans

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Abstract

The Ivory Coast cocoa beans were roasted in a convective oven at 110, 135 and 150 °C, at the air flow rate of 1.0 m/s and relative air humidity (RH) of 0.8–0.4%, 2.0% and 5.0%. Pigmentation expressed as both OD_{460}/OD_{525} and a ratio of anthocyanins to yellow and brown pigments (F1/F3) and water content were assayed throughout cocoa roasting. The experiments provided evidence that higher humidity of air (particularly of 5.0%) was beneficial to the color of roasted cocoa beans. The beans roasted at 135 and 150 °C displayed desired coloration (OD_{460}/OD_{525} above 1.1, and F1/F3 below 0.33).

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1. Introduction

Roasting is the most important technological operation in processing of cocoa beans. It brings about formation of characteristic brown color, mild aroma and texture of roasted beans. Convective roasting is the most commonly used method of thermal processing of raw cocoa beans, which are exposed to temperatures of 130–150 °C for 15–45 min (Nebesny & Rutkowski, 1998; Świechowski, 1994, 1996; Wyczański, 1990). Properties of roasted beans, such as concentration of volatile flavor compounds, total acidity and fat content depend on roasting conditions, mainly temperature and time of the process. Other parameters of thermal processing of cocoa beans, such as humidity and flow rate of air also seem to affect the quality of final product. For instance application of air with the high relative humidity facilitated its circulation during the roasting and enabled easier separation of husk from the kernel (Benz, 2002; Finken, 1996; Minifie, 1981; Nebesny & Rutkowski, 1998; Świechowski, 1994, 1996).

Structure of pigment compounds in roasted cocoa beans has not been determined in all details. Polyphenols and anthocyanins of raw beans undergo different reactions during fermentation that lead to synthesis of flobafens, which contribute to the characteristic brown color of roasted beans. Oxidation and polymerization of polyphenols, degradation of proteins, Maillard reactions and dextrinization of starch yield other brown pigments, typical of roasted cocoa (Cros, Villeneuve, & Vincent, 1982a, 1982b; Haslam, 1982; Minifie, 1981; Nebesny & Rutkowski, 1998; Serra Bonvehi & Ventura Coll, 1997).

According to Özdemir and Devres (2000) and Demir, Celayeta, Cronin, and Abodayeh (2002), temperature is the main factor affecting coloration of roasted cocoa beans. Lee, Yoo, Lee, Kwon, and Pyun (2001) reported that dynamics of pigment formation upon roasting depended on gradient of temperature. Concentration of brown pigments peaked at 134 °C and gradually decreased when the temperature of thermal processing continued to rise.

Studies of McWeeny et al. (Martins, Jongen, & van Boeckel, 2001) provide evidence that 3-deoxyxylose

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and 3,4-dideoxyxylose-3-en were intermediates of color compounds synthesis. These two substances and other reactive precursors participate in reactions of condensation and polymerization that yield brown polymers, containing carbonyl, carboxyl, amino, amide, indole, pyrrole, ester, ether, methyl and hydroxyl groups.

Evaluation of color of roasted cocoa beans is one of methods of evaluation of their quality. However, none of currently applied methods provides information on aroma of cocoa. Also, that proposed by Serra Bonvehi and Ventura Coll (1997) is based on determination of pigments produced upon roasting. Nevertheless, this method was found to be accurate in terms of estimation of quality of the roasted material and, therefore, it was applied in presented studies, which aimed at finding the correlation between parameters of roasting (temperature and humidity of air) and coloration of roasted cocoa beans.

2. Materials and methods

The Ivory Coast cocoa beans (Forastero cultivar, Ivory Coast) were applied for the studies.

2.1. Roasting conditions

Raw cocoa beans were roasted in a forced air flow drying tunnel. The parameters of thermal processing were as follows:

- temperature of 110, 135 and 150 °C;
- air flow rate of 1.0 m/s which was regarded as the optimum flow rate, based on results of earlier studies carried out by the authors Krysiak, Iciek, and Motyl-Patelska (2003);
- relative air humidity of 0.8, 0.45 and 0.4% (“dry air” at 110, 135 and 150 °C, respectively), and 2.0% and 5.0% (at all three temperatures).

Presented parameters of thermal processing of cocoa beans refer to the air, which was in a direct contact with roasted beans. Process of roasting was conducted without air circulation. Measurements of used air parameters were also carried out (results not presented).

Air temperature was measured by YCY meter (type YC-262 with NiCr–NiAl sensor), and the rate of its flow was determined using the coupled THERM 2285-2B meter equipped with 9915 S120 sensor (produced by AHLBORN).

The relative humidity of “dry air” was calculated based on the equation (presented for the temperature of 110 °C)

$$RH = 100 \times \frac{Y' \times P}{0.622 \times (P_{\text{sat}})_{110^\circ\text{C}} + Y' \times (P_{\text{sat}})_{110^\circ\text{C}}}$$

where RH—relative air humidity [%], Y' —absolute air humidity at 20 °C [kg H₂O/kg dry air]; 0.0087729 kg H₂O/kg dry air; P —pressure of saturated steam [Pa]; 101×10^3 Pa; $(P_{\text{sat}})_{110^\circ\text{C}}$ —pressure of steam at 110 °C [Pa]; 143.2653×10^3 Pa (Dobrzycki et al., 1973).

Air humidity was increased using saturated steam produced in steam generator. Relative humidity of this air was determined using the coupled THERM 2285-2B meter equipped with FHA636-HR2 sensor (produced by AHLBORN).

The precision of measurements of temperature, air flow rate and its humidity was ± 1 °C, ± 0.05 m/s and $\pm 0.5\%$, respectively.

2.2. Roasting of the cocoa beans

Approximately 200 g portions of cocoa beans with the uniform size were poured into the roasting chamber through the upper slot and placed on the perforated plate (coupled with scales) on completion of setting of air's temperature, humidity and rate of flow. To determine effects of the applied roasting conditions on the dynamics of changes in the color of the beans, the whole portions of roasted cocoa were taken off the chamber after determined time limits, e.g., after 15 or 20 min. Process of cocoa beans roasting was terminated when the water content of roasted material was 2% (optimal in terms of its grinding and fat extraction) (Nebesny & Rutkowski, 1998; Wyczański, 1990).

Next, the roasted cocoa beans were cooled to approximately 20 °C, dehulled, ground in electric grinder (produced by Niewiadów) for 20 s, sieved manually through 20 mesh sieve and tested for water content and intensity of brown color.

2.3. Analytical methods

Pigment compounds were determined according to the method of Serra Bonvehi and Ventura Coll (1997), based on measurements of brown pigments (products of anthocyanins conversion) at 460 and 525 nm. Brown pigments were extracted (45 min shaking) with 50 ml of 12 N HCl/CH₃OH (1 ml l⁻¹) from 2 g of ground cocoa bean kernels. The extract was filtered through Whatman 541. Aliquot of the filtrate (4 ml) was placed in 25 ml volumetric flask and filled with extraction solvent to the mark. Absorption of the solution in the flask was measured at 460 and 525 nm on Specoll 11 spectrophotometer (produced by Carl Zeiss Jena) equipped with vacuum photocell to detect of sensitive to light with range $\lambda = 340$ –620 nm, and the correlation between results of these measurements and solid substance content in the roasted cocoa beans was calculated. According to the authors, OD₄₆₀/OD₅₂₅ should not be less than 1 for a good quality cocoa (in terms of its color), i.e., properly fermented and roasted.

Another indicator of cocoa quality was found to be a ratio of the contents of anthocyanins and hydroxycinnamic acids derivatives (F1), red dyes (F2) and yellow and brown dyes (F3). These fractions were separated by column chromatography. Filtered extract (2 ml) was applied on a previously conditioned column (1.50 cm i.d.) containing 1.5 g of the mixture of Silica G, Silica gel 60 and Polyclar AT (2/14/4). Fractions of monomer anthocyanins, red polymers, and yellow and brown polymers were eluted with 12 N HCl/CH₃OH (1 ml l⁻¹), 50% formic acid, and pure formic acid, respectively (25 ml of each solvent). Absorbances were measured at 525 nm against the corresponding blanks, and the percentage content of each fraction in the total absorbance was calculated. The content of each fraction per solid substance of roasted cocoa beans was also determined. Results of this assay were presented as F1/F3 ratio, which should not exceed 0.3 (Serra Bonvehi & Ventura Coll, 1997) for good quality cocoa (in terms of its color).

Water content in roasted cocoa beans was estimated according to A.O.A.C. (1996).

Triplicate samples were prepared for each determination listed above. Experimental results are presented as means \pm SD; SD ranged from 3% to 4%.

3. Results

Figs. 1, 3 and 5 present alteration in color of roasted cocoa beans, expressed as OD₄₆₀/OD₅₂₅, as a function of the relative air humidity (RH of 0.8–0.4%, 2.0% and 5.0%) at temperatures of 110, 135 and 150 °C. Figs. 2, 4 and 6 depict the dependence of F1/F3 (as a visualization of changes in pigment concentration) on the same parameters of thermal processing. Figs. 7 and 8 show the influence of air temperature on OD₄₆₀/OD₅₂₅ and F1/F3 at the relative air humidity of 5.0%. The air flow rate was kept constant at 1.0 m/s throughout all roasting batches.

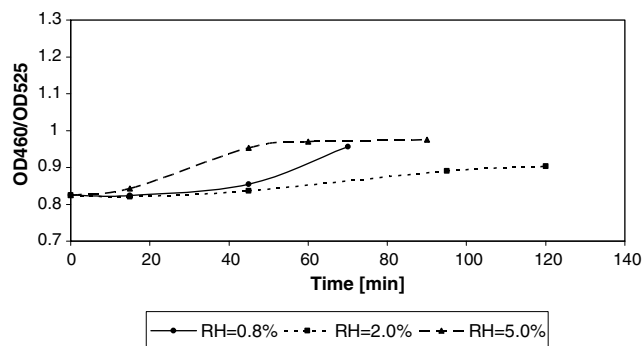


Fig. 1. Dependence of brown pigments ratio (OD₄₆₀/OD₅₂₅) in roasted cocoa beans on the relative humidity of air and time of roasting at $T = 110$ °C and at air flow rate of $v = 1.0$ m/s.

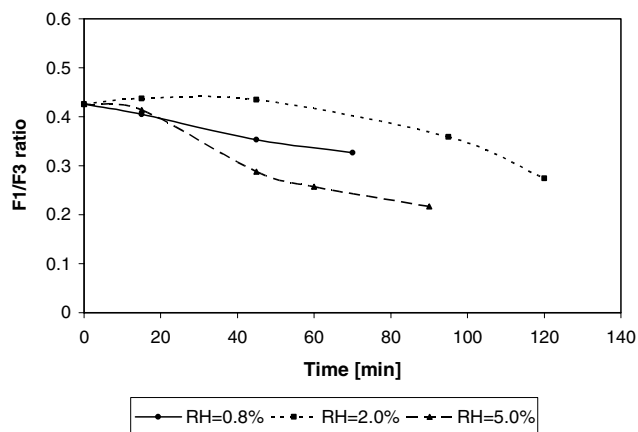


Fig. 2. Dependence of brown pigments ratio (F1/F3) in roasted cocoa beans on the relative humidity of air and time of roasting at $T = 110$ °C and at air flow rate of $v = 1.0$ m/s.

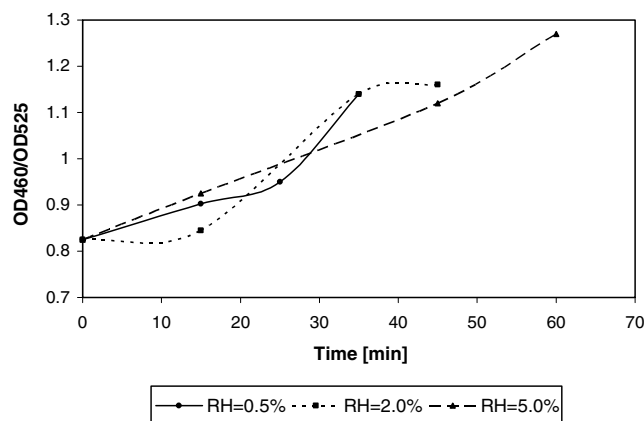


Fig. 3. Dependence of brown pigments ratio (OD₄₆₀/OD₅₂₅) in roasted cocoa beans on the relative humidity of air and time of roasting at $T = 135$ °C and at air flow rate of $v = 1.0$ m/s.

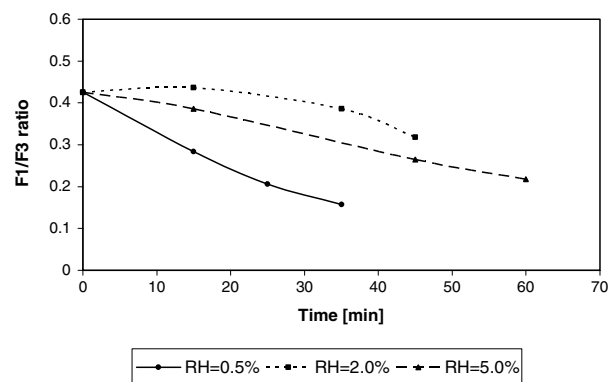


Fig. 4. Dependence of brown pigments ratio (F1/F3) in roasted cocoa beans on the relative humidity of air and time of roasting at $T = 135$ °C and at air flow rate of $v = 1.0$ m/s.

Results presented in Fig. 1 indicate that changes in coloration of cocoa beans roasted at 110 °C depended on air humidity. The rate of these variations was

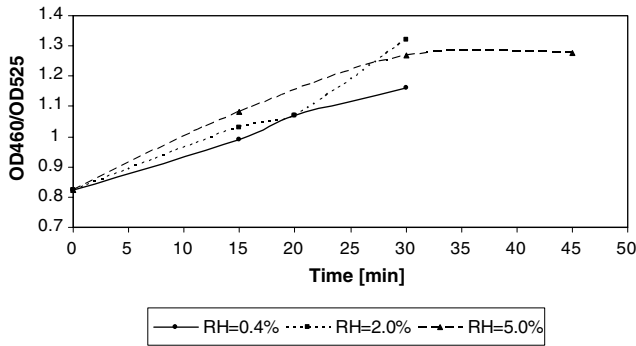


Fig. 5. Dependence of brown pigments ratio (OD460/OD525) in roasted cocoa beans on the relative humidity of air and time of roasting at $T = 150\text{ }^{\circ}\text{C}$ and at air flow rate of $v = 1.0\text{ m/s}$.

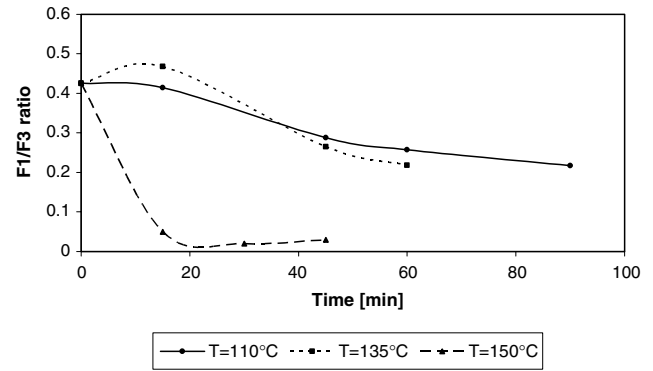


Fig. 8. Dependence of brown pigments ratio (F1/F3) in roasted cocoa beans on the temperature of air and time of roasting at $\text{RH} = 5.0\%$ and at air flow rate of $v = 1.0\text{ m/s}$.

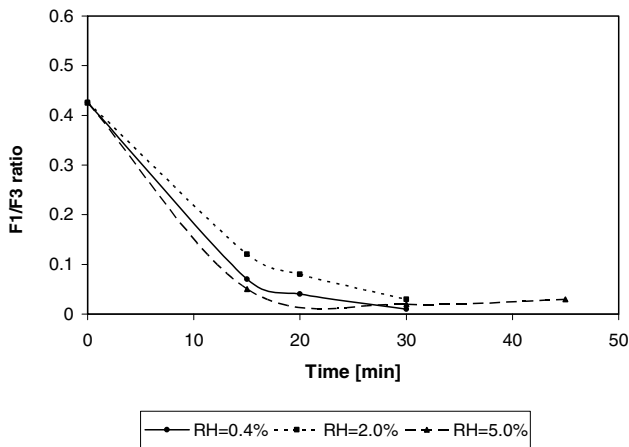


Fig. 6. Dependence of brown pigments ratio (F1/F3) in roasted cocoa beans on the relative humidity of air and time of roasting at $T = 150\text{ }^{\circ}\text{C}$ and at air flow rate of $v = 1.0\text{ m/s}$.

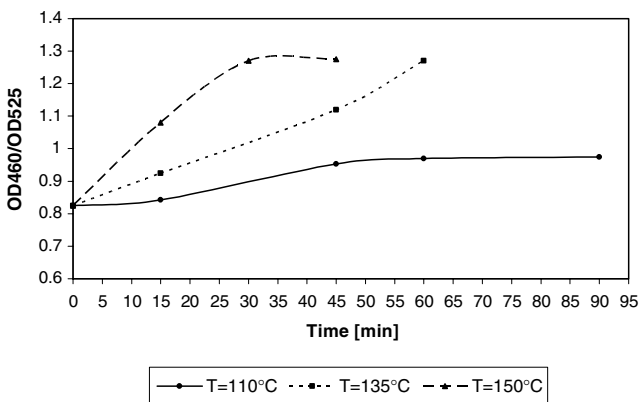


Fig. 7. Dependence of brown pigments ratio (OD460/OD525) in roasted cocoa beans on the temperature of air and time of roasting at $\text{RH} = 5.0\%$ and at air flow rate of $v = 1.0\text{ m/s}$.

the lowest for RH of 2.0%. In these conditions, $\text{OD}_{460}/\text{OD}_{525}$ was close to 0.9 after 120 min of roasting.

At RH of 5.0%, the rise in $\text{OD}_{460}/\text{OD}_{525}$ was the fastest and this index achieved its maximum of 0.95 after 45 min. Such rapid generation of pigments presumably resulted from faster increase in temperature of cocoa bean kernels.

When the beans were exposed to the relatively “dry air” (relative humidity of 0.8%), a rise in $\text{OD}_{460}/\text{OD}_{525}$ during 45 min was small (from 0.83 to 0.86) but this ratio continued to grow and after 60 min it achieved a value of 0.96. Despite this 10–16% increase, the quality of roasted cocoa beans (in terms of its color) was not good because $\text{OD}_{460}/\text{OD}_{525}$ should be at least 1.1 (Serra Bonvehi & Ventura Coll, 1997).

Values of $\text{OD}_{460}/\text{OD}_{525}$ for cocoa beans roasted at 135 and 150 °C exceeded 1.1, and apparently depended on temperature and relative humidity of air. They were 1.12 and 1.26 after roasting at 135 °C and at RH of 2.0 and 5.0%, respectively, and 1.25 and 1.30, when cocoa beans were processed at 150 °C (at the aforementioned air humidities, respectively). When RH was 0.45–0.4%, the $\text{OD}_{460}/\text{OD}_{525}$ values were approximately 1.15, independently on temperature of air (135 °C and 150 °C). The plots presenting changes in $\text{OD}_{460}/\text{OD}_{525}$ at these temperatures (Figs. 3, 5 and 7) were similar, in contrast to the plot depicting alterations in this index at 110 °C. $\text{OD}_{460}/\text{OD}_{525}$ was 1.1 after roasting at 135 °C for 35 min, and at 150 °C after 20 min.

The relative air humidity of 5.0% brought about a gradual increase in concentration of pigments in roasted cocoa beans, independently on temperature, whereas RH of 2.0% caused a rapid rise in $\text{OD}_{460}/\text{OD}_{525}$ after 15 min (Figs. 3 and 5).

Cocoa beans roasted at 135 and 150 °C were superior in terms of coloration to that processed at 110 °C.

The second approach of evaluation of dynamics of brown color formation, based on assays of a ratio of anthocyanins (F1) to yellow and brown pigments (F3), revealed the similar dependence of F1/F3 on roasting conditions as that found for $\text{OD}_{460}/\text{OD}_{525}$. However,

the index F1/F3 continued to diminish during roasting of cocoa beans due to a drop in anthocyanins content (F1) and a concomitant rise in concentration of brown and yellow pigments (F3). According to Cros, Villeneuve, and Vincent (1982b), $F1/F3 \leq 0.33$ implies the good color of roasted cocoa beans. Values of F1/F3 for all samples of roasted cocoa beans prepared in our laboratory ranged from 0.03 to 0.33 (Figs. 2, 4, 6 and 8). They were the lowest for samples processed at 150 °C and the highest (0.22–0.33) after roasting at 110 °C, but all of them demonstrated the satisfactory properties of roasted material.

4. Conclusions

Our experiments revealed that:

1. Roasting of cocoa beans at 110 °C resulted in the least advanced brown pigments formation (a rise in OD_{460}/OD_{525} from 0.83 to 0.96, and a drop in F1/F3 from 0.426 to 0.217–0.33), independently of humidity of air.
2. More pronounced changes in pigments content were achieved during roasting at 135 and 150 °C (OD_{460}/OD_{525} of 1.15–1.27 at both temperatures), independently on RH. The increase in a content of brown pigments was faster at the latter temperature.
3. The coefficient F1/F3 achieved the lowest values (it dropped from 0.426 to 0.03) when cocoa beans were processed at 150 °C, whereas roasting at 135 °C reduced its value from 0.43 to 0.16.
4. The rise in relative air humidity from 2.0% to 5.0% was beneficial for brown pigments formation (OD_{460}/OD_{525} of 0.9 and 1.27, and F1/F3 of 0.27 and 0.03, respectively).

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