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Physical and chemical attributes of defective crude and roasted coffee beans

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Abstract

Defective coffee beans are widely known to negatively affect beverage quality. In Brazil, the defective beans represent a population of about 20% of the total coffee production. These defective beans are separated from the non-defective ones prior to commercialization in the international market and are dumped in the Brazilian internal market, thus depreciating the quality of the roasted coffee consumed in Brazil. In order to offer more attractive alternative uses for these beans, an assessment of their physical and chemical attributes is of relevance. In this study, physical attributes, such as bean and bulk densities, bean volume and colour, and also chemical attributes, such as caffeine, trigonelline and chlorogenic acids, were evaluated in defective and non-defective coffee beans, both in the crude and roasted state. With the determined physical and chemical attributes, it was possible to differentiate the types of defective beans, and it was also demonstrated that both black and sour beans roast to a lesser degree than the other types of beans, under the same roasting conditions.

Keywords: Defective coffee beans; Caffeine; Trigonelline; Chlorogenic acids

1. Introduction

The quality of coffee used for beverages is strictly related to the chemical composition of the roasted beans, which is affected by the composition of the green beans and post-harvesting processing conditions (drying, storage, roasting and grinding). The criteria commonly used to evaluate the quality of coffee beans include bean size, colour, shape, roast potential, processing method, crop year, flavour or cup quality and presence of defects (Banks, McFadden, & Atkinson, 1999). Among those, the last two are the most important criteria and are employed worldwide in coffee trading.

Flavour is the main and most important criterion for evaluating coffee quality. Brazilian coffees are officially categorized by reference to the following flavour scale (Banks et al., 1999; Clarke & Macrae, 1987):

(i) strictly soft: low acidity, mellow sweetness, pleasant feel of the mouth easiness:
(ii) soft: same characteristics as strictly soft, only less accentuated;
(iii) softish: same characteristics as soft, only less accentuated;
(iv) hard: lacks sweetness and softness;
(v) rioysh: iodine, inky flavour from microbe-tainted beans; and
(vi) rio: same characteristics as rioysh, only more accentuated.

This classification, also known as cup quality, is assessed using the brewing method of steeping (10 g of roast and ground coffee per 150 ml boiling water left for 5 min), with a medium roast coffee prepared in a sample roaster and with a relatively fine grind.

The term defect is used in commercial practice in reference to the presence of defective (black, sour or brown, immature, insect-damaged or bored) beans and also of extraneous matter (twigs, stones) in a given coffee sample. The New York Coffee and Sugar Exchange devised the "black bean count basis", according to which

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Table 1
Summary description of the type classification system

Type no.	Maximum allowable number of defects per 300 g sample
NY 2	6
NY 3	13
NY 4	30
NY 5	60
NY 6	120
NY 7	240
NY 8	450

Table 2
Equivalence ratings according to the type classification system

Defect type and quantity	Equivalency
1 Black bean	1 Defect
2 Sour beans	1 Defect
5 Immature beans	1 Defect
2/5 Insect damaged beans	1 Defect
1 Small stone	1 Defect
1 Large stone	5 Defects
1 Small twig	1 Defect
1 Large twig	5 Defects

all defects are accounted for in terms of equivalence to black beans. This is known as type classification, as shown in Table 1. For example, five insect-damaged beans correspond to one black bean, which is equivalent to one defect. A few examples of equivalence ratings for defective beans are presented in Table 2.

The presence of defects is quite relevant in establishing coffee quality, since they could be associated with specific problems during harvesting and pre-processing operations. Black beans result from dead beans within the coffee cherries (Clarke & Macrae, 1987) or from beans that fall naturally on the ground by action of rain or over-ripening (Mazzafera, 1999). The presence of sour beans can be associated with 'overfermentation' during wet processing (Clarke & Macrae, 1987), improper drying or picking of overripe cherries (Sivetz & Desrosier, 1979). Immature beans come from immature fruits. Immature-black beans are those that fall on the ground while immature, remaining in contact with the soil and thus subject to fermentation (Mazzafera, 1999).

Typical defects, such as black, sour and immature beans, are known to affect beverage quality. According to Clarke and Macrae (1987), the black bean is usually associated with a heavy flavour and sour beans contribute to sour and oniony tastes. However, specific studies that correlate the presence of such defects with physical and chemical characteristics of the beans are still scarce. A few studies (Clifford et al., 1987; Clifford & Kazi, 1987; Menezes, 1994) have shown that the reduced contents of chlorogenic acids, and specifically the ratio between monocaffeoylquinic and dicaffeoylquinic acids, were related to the presence of immature beans. Mazzafera (1999) evaluated chemical attributes of immature-black and black beans in comparison to non-defective beans. Non-defective beans were heavier, more humid, and presented higher levels of sucrose, protein and total oil content than either immature-black or black beans.

The few data available in the literature for physical and chemical properties of defective coffee beans are scarce and restricted to crude beans. Data on these properties for roasted defective coffee beans are scarce, on non-existent. Thus, the aim of the present study was to carry out an evaluation of physical and chemical characteristics of defective (black, sour and immature) and non-defective coffee beans, prior to and after roasting.

2. Materials and methods

2.1. Material

Arabica green (crude) coffee samples were obtained from Santo Antonio Estate Coffee (Minas Gerais, Brazil). Seeds were subjected to selection in an electronic sorter. The beans rejected by the sorting machine were used in this study and will be herein designated as PVA mixture, which stands for "Preto, Verde e Ardido", the Brazilian denominations for black, immature and sour beans, respectively. This mixture consisted of 2.1% black, 21.1% immature, 50% sour and 26.8% non-defective beans by weight. Black, sour, immature and non-defective beans were manually separated from the PVA mixture. Samples of 100 randomly selected beans were separated from each lot (black, sour, immature, non-defective and PVA mixture) and roasted in a convective oven at 200 °C for 1 h. All samples (with respective replicates) were roasted simultaneously in a single batch in order to assure that the roasting conditions were the same for all of them.

2.2. Physical attributes

All analyses were performed for samples of 100 beans randomly selected from each lot. The average volumes of the beans were calculated from measurements of major, minor and intermediate diameters of individual beans and the assumption that each bean could be taken as half a triaxial ellipsoid (Dutra, Oliveira, Franca, Ferraz, & Afonso, 2001). Average bean density was evaluated as the ratio between the weight of the 100 bean sample and the sum of the volumes. Bulk volume was evaluated using a 50 ml graduated cylinder. Color was evaluated for both whole and ground coffee beans. The measurements were performed twenty times for whole beans and five times for ground beans for each sample, using a tristimulus colorimeter (Colortec PCM, Clinton, USA), with standard illumination D_{65}, and colorimetric normal observer angle of 10°. The measured values L^*, a^* and b^* were converted to chroma (c^*) and hue angle (h_{ab}) values.

2.3. Chemical attributes

Ground coffee samples (1 g) were extracted with distilled boiling water (100 ml) for 2 min. The extract was filtered under vacuum (Bell, Wetzel, & Grand, 1996). The extracts were analyzed by HPLC, using a Shimadzu Chromatograph (model LC-10VP), with a photo-diode array detection (PDA) system and a Supelco C_{18} column (5 μm, 150 mm × 4.6 mm), with a C_{18} pre-column. The mobile phase was comprised of methanol, water and acetic acid (15:85:1) at a flow rate of 1 ml/min. A caffeine, trigonelline and 5-caffeoyilquinic acid (5-CQA) standard solution was employed for the identification of their respective peaks and subsequent quantification. It is noteworthy that the analytical methodology is also capable of separating and detecting 3-CQA and 4-CQA isomers simultaneously with trigonelline, caffeine and 5-CQA. However, those isomers were extracted to a much less extent, not allowing quantification in most samples.

3. Results and discussion

Physical attributes are presented in Table 3. Regarding crude beans, it can be observed that black beans had lower values for both bean and bulk densities than did immature beans. Bean density values were in the same range as reported in the reviewed literature: 1200–1300 kg/m^3 (Clarke & Macrae, 1987; Dutra et al., 2001; Sivetz & Desrosier, 1979). There were significant decrease in both bean and bulk densities after roasting, due to the simultaneous increase in volume (due to increase in internal pressure) and decrease in mass (due to loss of volatiles). Measurements of bean volume show that black beans are significantly smaller than the other defective beans, and that defective beans are smaller than non-defective ones, prior to and after roasting. Furthermore, degrees of swelling were different among defects. Black beans presented the lowest increase in volume after roasting (~40%) compared to non-defective beans (~65%). According to Clarke and Macrae (1987), beans that swell less should roast more slowly. This was corroborated by the results obtained for weight loss. Variations in bean density and volume probably reflect bean porosity and compressibility of ground materials, thus being of consequence in commercial percolation.

Colour parameters for crude beans are presented in Fig. 1. An analysis of colour parameters for whole beans showed that luminosity values were higher for non-defective than for defective beans. Also, black beans presented the lowest values for luminosity in comparison with other defects, as expected. These results indicate that this parameter alone can be successfully employed to separate defective and non-defective beans prior to roasting. Luminosity values were higher for ground beans than for whole ones, indicating that the bean surface is darker than its interior. Differences in luminosity between surface and interior were more significant for defective beans than for non-defective ones. Regarding chroma or colour saturation measurements for whole beans, no significant differences were detected among non-defective beans, immature beans and the PVA mixture. Black beans had significantly lower chroma values than the others. After grinding, differences in chroma values were less significant. Only immature and non-defective beans had slightly smaller saturation values than the others. Values of hue angle (and corresponding colour hue) for whole beans were similar, except for black beans. Black beans had the highest hue value, which corresponded to a dark green, whereas the other beans had a yellowish-green hue. After grinding, no significant differences in hue angle were detected.

The effect of roasting on colour parameters can be viewed in Fig. 2. Luminosity values decreased as expected, for both whole and ground beans. Both black and sour beans had lower luminosity values than

Table 3
Physical attributes of defective and non-defective coffee beans

	PVA mixture	Black	Immature	Sour	Non-defective
Crude beans					
Bean density (kg/m^3)	1258 ± 37.8ab	1181 ± 47.6b	1279 ± 18.2a	1250 ± 2.6ab	1228 ± 17.6ab
Bulk density (kg/m^3)	632 ± 2.2ab	601 ± 5.1b	653 ± 12.3a	635 ± 26.4ab	599 ± 9.9b
Volume × 10^9 (m^3)	91.6 ± 0.7c	67.5 ± 5.1d	103 ± 1.6b	95.2 ± 2.0c	115 ± 3.7a
Roasted beans					
Bean density (kg/m^3)	604 ± 47.5b	751 ± 9.3a	676 ± 62.4ab	636 ± 19.3b	610 ± 14.6b
Bulk density (kg/m^3)	337 ± 1.4b	408 ± 1.6a	311.6 ± 3.9c	323 ± 6.3bc	330 ± 10.3b
Volume × 10^9 (m^3)	171 ± 8.8b	95.1 ± 3.0d	166 ± 6.7b	145 ± 5.2c	189 ± 9.0a
Dry matter loss (%)	11.7 ± 0.1b	9.1 ± 0.0d	12.3 ± 0.5b	10.5 ± 0.1c	13.3 ± 0.1a

Mean values with the same letter in the same line do not differ significantly by the Duncan test at 5% probability.

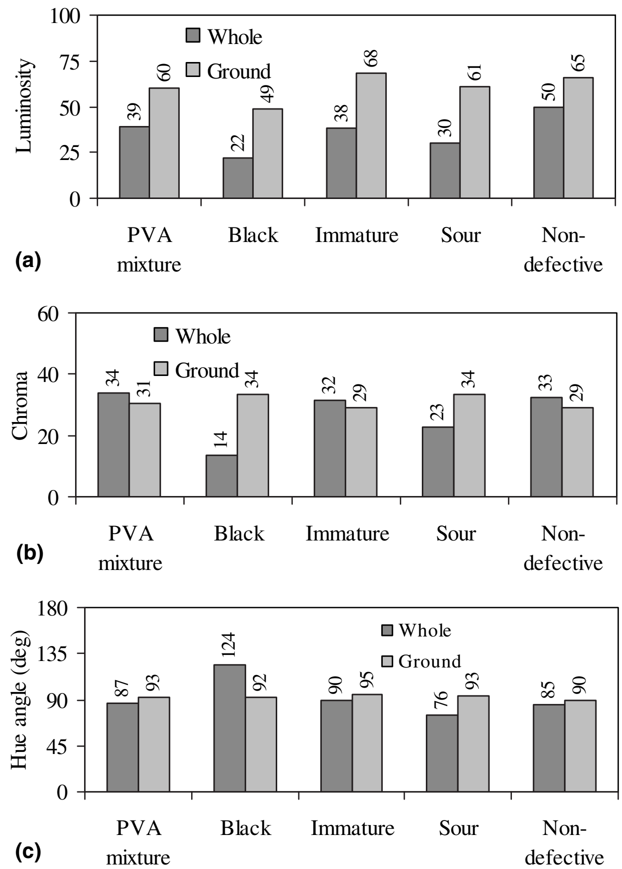

Fig. 1. Colour parameters for crude beans: (a) luminosity; (b) chroma; (c) hue angle.

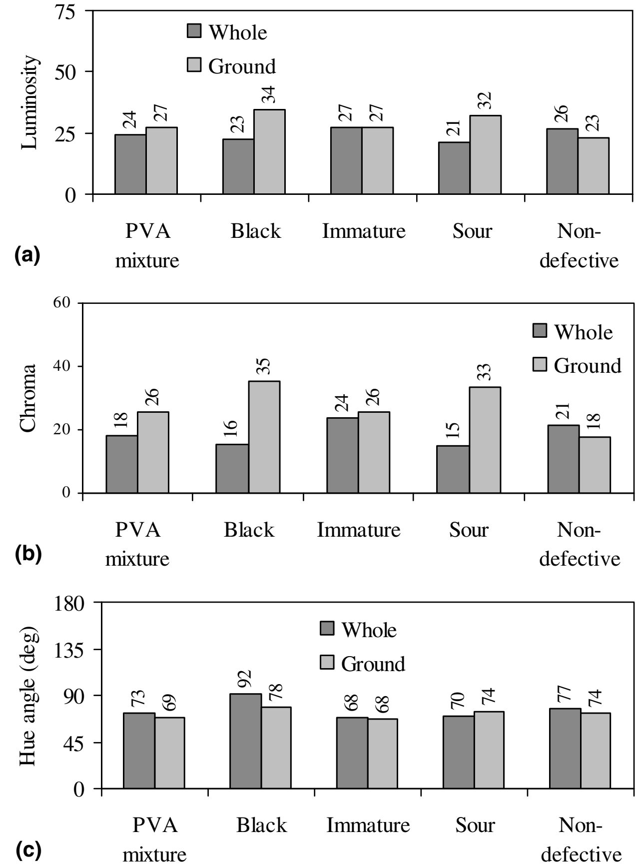

Fig. 2. Colour parameters for roasted beans: (a) luminosity; (b) chroma; (c) hue angle.

non-defective and immature beans. After grinding, luminosity values for black and sour beans increased. These results showed that the bean surface was still darker than its interior after roasting, thus indicating that these beans were roasted to a lighter degree than the others. Non-defective and immature beans did not have significant differences in luminosity values between whole and ground beans, indicating that the beans attained a uniform colour after roasting. Chroma values diminished after roasting, except for black beans. This should be expected as beans become darker. Again, a comparison between whole and ground beans shows significant differences only for black and sour beans, indicating non-uniformity of colour. Whole black beans had the highest values of hue angle after roasting, maintaining a greenish hue. The other beans became brown. After grinding, no significant differences in hue angle were detected.

The results obtained for chemical attributes of crude and roasted beans are presented in Table 4. According to the literature (Macrae, 1985) caffeine levels in crude coffee should vary considerably, even within the same species. Reported mean values are 1.2% db for Arabica (0.6–1.9% range) and 2.2% db for Robusta. No differences in caffeine contents were encountered among the defective beans. However, both the non-defective beans and, consequently, the PVA mixture, had lower caffeine contents than the defective ones, individually. Roasting did not significantly affect caffeine levels of either black or sour beans. The fact that the caffeine content remained relatively constant for both black and sour beans upon roasting is an indication that, under the same conditions of roasting for all types of beans, black and sour beans were roasted to a lesser extent than the other types. This is corroborated by the dry matter loss data presented in Table 3 and by the colour parameters presented in Fig. 2.

Trigonelline values, measured for crude beans, are the same as reported in the literature (Macrae, 1985), approximately 1%. However, black beans had lower values (~0.8%). After roasting, trigonelline levels decreased as expected. According to Macrae (1985), a 50% to 80% degradation should be expected, depending on both time and temperature of roasting. Even though the percent degradation values encountered in this study fall within the range reported by Macrae (1985), trigonelline degradation was significantly less accentuated for the black beans than for others. Since roasting conditions were exactly the same for all samples, this result also dem-

Table 4
Chemical attributes of coffee beans

	PVA mixture	Black	Immature	Sour	Non-defective
Crude beans					
Caffeine (% dgb)	0.94 ± 0.09b	1.36 ± 0.04a	1.23 ± 0.02a	1.27 ± 0.02a	0.92 ± 0.22b
Trigonelline (% dgb)	0.81 ± 0.07b	0.81 ± 0.02b	1.00 ± 0.00a	0.99 ± 0.02a	0.98 ± 0.02a
5-CQA (% dgb)	2.46 ± 0.28b	1.83 ± 0.06c	3.18 ± 0.15a	3.34 ± 0.03a	3.18 ± 0.11a
Roasted Beans					
Caffeine (% drb)	0.91 ± 0.04b	1.57 ± 0.07a	0.75 ± 0.05c	1.45 ± 0.00a	0.83 ± 0.1bc
Caffeine (% dgb)	0.79 ± 0.04b	1.38 ± 0.06a	0.64 ± 0.04c	1.26 ± 0.00a	0.70 ± 0.08bc
% loss	16.0	−1.5	48.0	0.8	24.0
Trigonelline (% drb)	0.22 ± 0.00c	0.37 ± 0.01a	0.16 ± 0.01d	0.30 ± 0.00b	0.21 ± 0.02c
Trigonelline (% dgb)	0.19 ± 0.00c	0.33 ± 0.01a	0.14 ± 0.01d	0.26 ± 0.00b	0.18 ± 0.01c
% degradation	77	60	86	74	82
5-CQA (% drb)	0.15 ± 0.01c	0.39 ± 0.02a	0.16 ± 0.01c	0.27 ± 0.00b	0.21 ± 0.06bc
5-CQA (% dgb)	0.13 ± 0.01c	0.34 ± 0.02a	0.14 ± 0.01c	0.24 ± 0.00b	0.18 ± 0.05bc
% Degradation	95	81	96	93	94

Mean values with the same letter in the same line do not differ significantly by the Duncan test at 5% probability; dgb = dry green basis; drb = dry roasted basis.

onstrates that black beans were roasted to a lesser extent than the others.

According to the reviewed literature, 5-CQA levels should be in the range of 3–5% db (Clifford, 1985). In this study, measured levels were lower, with the differences being attributed to differences in extraction methodologies. Regardless of that, black beans had significantly lower levels of 5-CQA than the others (Table 4). Also, degradation of 5-CQA occurred to a smaller extent for black beans than the others. Again, these results demonstrate that, under the same roasting conditions, black beans should roast to a smaller degree than the other types of beans.

It is noteworthy that, in this study, the non-defective beans were separated from the defective ones and, hence, their measured physical and chemical attributes are truly those of healthy good mature beans. This makes then unsuitable for direct comparison with data previously reported in the literature, since most of the literature data are related to attributes of coffee beans from commercial batches, for which the beans were not separated into defective and non-defective types. Furthermore, the proportions of defective beans within the batches were usually not accounted for in those reports.

4. Conclusions

Physical and chemical attributes of defective coffee beans were evaluated for both crude and roasted beans. The determined attributes allowed differentiation of the studied types of defective and non-defective beans. Black beans were the defective types that had the most distinct characteristics. Black beans were also demonstrated to roast to a much smaller degree than the other types, under the same conditions of roasting. Sour beans will also roast to a smaller degree but not as distinctly as the black beans. Aside from their inherent quality, the fact that these defective beans will roast to a smaller degree will contribute to depreciation of the beverage quality when they are mixed with other types of beans.

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