Physico-chemical characteristics and sensory attributes of coffee beans submitted to two post-harvest processes

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Abstract

Post-harvest processes (PHP) interfere with the quality of the coffee beverage. Recently, biochemical phenomena and critical points concerning coffee quality in PHP were identified. The objective was to evaluate the chemical composition and sensory attributes of green beans and roasted coffee beans from natural (CN) and semi-dry (CD) PHP. Samples were processed by coffee growers from a Brazilian coffee-producing region. The physico-chemical variables of green and roasted beans and sensory attributes were grouped in order to apply a multiple factorial analysis. This analysis showed that the description of CN and CD coffees depended on the group of variables employed. Certain aroma and flavor precursors, such as sucrose, proteins and 5-CQA, were associated with the year of production, whereas lipids, phenolic compounds, caffeine and chlorogenic acids, were associated with the PHP. Effects attributed to the occurrence of germination during drying were observed in both processes and had reflexes on the sensorial attributes. The results of the samples prepared by the producers are similar to the results obtained in laboratory experiments by other authors. The same attributes were found in the description of both processes, suggesting that they depend on the content of precursors in the green coffee beans. The formation of the precursors was influenced by factors related to peeling and drying of the green coffee. The control of these favor factors enabled the success of each PHP.

Introduction

Taste and aroma are key sensory attributes for making coffee one of the most consumed beverages in the world. These attributes are formed from chemical compounds (precursors) present in green coffee beans [1, 2]. These chemical compounds are influenced by several factors, such as genetic origin [3], local production [4, 5] and agricultural practices

[6]. In addition, harvesting and post-harvest processes (PHP) have a crucial effect on beverage quality [7].

As with any other fruit, the best quality of the coffee fruit is reached when it is fully ripe [8, 9]. The flowering of the coffee plant occurs several times in the same crop, and it is common to find fruits in different stages of maturation at harvesting time. In general, harvesting occurs when more than 80% of the fruits have an intense red husk [10].

The harvested coffee is subjected to various post-harvested processes (PHP). Usually, dry and wet processes are used to process the harvested coffee manually or mechanically. These processes are distinguished primarily by presence or absence of husk and mucilage of the coffee beans during the drying. In the dry process, the harvested coffees are washed in water tanks, and without removing the husk and mucilage, they are spread directly on a patio or on suspended plastic screens for drying [1] Coffee produced in this way is known as natural coffee (CN).

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In the wet process, the harvested coffee is washed and peeled in machines and can follow two paths before spreading for drying. These processes are differentiated by the presence of mucilage on the parchment. When the husked coffee is sprinkled on the patio without previous removal of the mucilage, the coffee obtained is called peeled or semi-dry coffee (CD). However, when the mucilage is completely removed in the fermentation tank before drying, the coffee is named pulped coffee (CP) [7, 11].

The choice of process depends primarily on available structures, but often, it is determined by the difficulty of drying the coffee in the climatic conditions of the producing region. Economic profits or incentives to improve beverage quality can also determine the choice of the PHP [12].

The PHP interferes in the composition of the coffee beans and strongly impacts the attributes of the coffee beverage. The involvement of the husk and mucilage in the metabolic events that occur during PHP has recently been studied. Germination inhibitors in the coffee pulp were identified, and germination started when the pulp was removed before drying the coffee [1, 2]. The removal of the husk and pulp from the coffee in the CD process enabled germination as long as there was water available in the coffee beans. However, the presence of inhibitors in the CN process blocked the germination, and metabolic activities developed slowly [2].

When the germination metabolism is active, the mobilization and transformation of the carbohydrate, lipid and protein polymers begin, and the resulting products from these reactions become the aroma precursors. Among the main coffee aroma precursors are amino acids and soluble sugars, which are released into the endosperm during germination. The presence of sugars [13, 14] and lipids [12] were identified in PHP and were associated with a pleasant aroma, and the taste of the roasted coffee was connected with the beverage quality.

The amount and chemical nature of the precursors are fundamental for the formation of the sensory attributes of the coffee beverage [5, 7, 8]. The characteristics of the roasted bean, such as volume expansion, surface color [15] and acidity of the beverage, are associated with coffee bean formation and maturation [16, 17] and are indicators of the quality of the harvested and processed coffee beans.

The primary sensory attributes of coffee beverage are quantified by descriptive techniques where the attributes are individually evaluated [18, 19] and the beverage receives an overall quality score [4].

The definition of the attributes of the coffee beverage is a difficult and complex task due to the interactions between aroma and flavor precursor compounds during the roasting [16]. The presence of different flavor precursors and flavors in the PHP processes determine the aromatic profile of the beverage [20]. The CN coffee beverage has a strong coffee aroma, moderate acidity, intense body and pleasant sweetness. On the other hand, in the CD coffee beverage are present a weak coffee aroma and body of medium intensity, and the acidity and sweetness are lower than in the CN coffee beverage [21].

Currently, electronic devices (electronic nose and tongue) have been constructed to mimic human activities in food quality assessments, such as control of coffee roasted coffee [22, 23]. However, the use of these devices for the sensorial evaluation of coffee is still limited to identifying the presence of coffee beverage defects [24]. But, when the purpose of the study is to describe the qualitative and quantitative aspects of the sensory attributes of a product it is recommended to apply a descriptive sensory method [25].

Chemometric techniques for data reduction are useful for classifying and identifying the quality and characteristics of a product [26]. Neural network and PLS-DA techniques were applied to classify the genetic and geographic origins of the coffee [5, 27] and support vector machines were used to identify geographical classification of green arabica coffee [28].

A successful description of PHP applied coffee is based on data sets that combine results from various analytical techniques [19]. In such cases, chemometric techniques are needed to determine the most important characteristics that need to be measured to indicate the influence of the PHP. Exploratory multivariate techniques, such as principal component analysis (PCA) and multiple factor analysis (MFA), have been commonly used to evaluate the performance of these groups of variables [29, 30]. PCA is used to reduce the dimensionality of a data set, and MFA enables the simultaneous analysis of multiple data sets, structured in groups, in which each group of variables is balanced. MFA has been used to describe coffees from different regions [19, 31], cultivars of tomatoes [32] and grapes varieties [33].

The objective of this study was to evaluate the influence of PHP in the physico-chemical characteristics of green and roasted coffee beans and the sensory attributes of natural (CN) and semi-dry (CD) coffees. An MFA was used to evaluate the influence of the groups of variables on the quality of the coffee produced in each process. The main innovation of this study was that the preparation of the coffee samples was undertaken by the producers who participated in the coffee quality competition.

Materials and methods

Coffee samples

A total of 169 coffee samples were collected in the coffee region of Paraná-Brazil from the 2004 crop (79 samples) and 2005 crop (90 samples). The samples were processed by the CN process (56 samples in 2004 and 64 samples in

2005) and by the CD process (23 samples in 2004 and 26 samples in 2005). The results were presented according to their process and the respective year of harvesting, e.g., CN04, CN05, CD04 and CD05.

All of the procedures of PHP were performed by the producers on their properties with the available infrastructures (Fig. 1). During these harvesting years, producers presented their samples in the coffee quality competition promoted by an official organization of the local coffee industry. The members of this committee were responsible for removal of the husk, parchment and defective beans. Coffee beans were stored in paper bags in a dry place (25 ± 2 °C) after passing through a # 16 coffee sieve.

Chemical compounds

5-O-Caffeoylquinic acid (5-CQA), caffeine, glucose, trigonelline and gallic acid were purchased from Sigma-Aldrich. Potassium sulphate, copper sulphate, sodium hydroxide and petroleum ether were purchased from Quimex (São Paulo, Brazil). Sulfuric acid, zinc sulfate, sodium carbonate, anhydrous disodium phosphate, sodium and potassium tartrate, anhydrous sodium sulfate and sodium arsenate were purchased from Merck. HPLC grade acetonitrile (J.T. Baker, State of Mexico, Mexico), methanol (Nuclear, São Paulo, Brazil), acetic acid (Merck, Darmstadt, Germany) were also used.
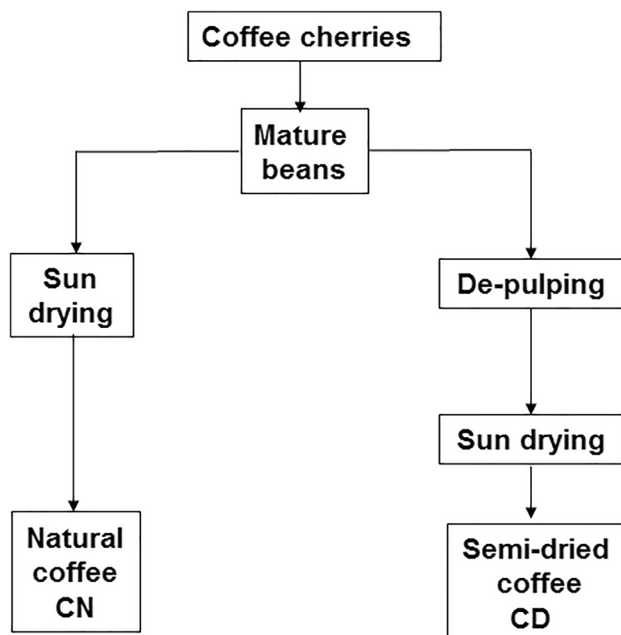

Fig. 1 Schematic plan of the post-harvest processes practiced by coffee producers

Physico-chemical analysis of green coffee beans

For the physico-chemical analysis the green coffee beans were frozen with liquid nitrogen and ground (0.5 mm particles) in a disc mill (PERTEN 3600). The ground samples were stored at − 18 °C.

The respective moisture and proteins of the green coffee beans was determined, as described by the AOAC [34]. Phenolic compounds were determined using gallic acid by the Folin Ciocalteau reagent [34]. Lipids were extracted with petroleum ether for 16 h after the ground green coffee (2 g) was oven dried at 105 °C for 3 h [34]. Trigonelline, caffeine and 5-caffeoylquinic acid (5-CQA) were determined according Kitzberger et al. [35] and the methodology described in Scholz et al. [31] was used to determine sugar determinations (reducing and total sugars) and the results were expressed in g 100 g^{-1} of coffee. Total chlorogenic acids were evaluated according to Clifford and Wight [36]. Ground coffee was stirred with 70% isopropyl alcohol and the absorbance was read at 406 nm. A solution of 5-CQA (20–100 µg mL^{-1}) was used as standard. The apparent density and titratable acidity the green coffee were determined according to Franca et al. [9] and Ramalakshmi et al. [17] respectively.

The physico-chemical determinations were performed in two replicates, and the results were expressed on a dry basis. This group of physico-chemical variables was called FGV.

Physico-chemical analysis of roasted beans

The roasted beans' total weight loss after roasting [15], roasted coffee density and volume expansion [9] were determined. Titratable acidity, pH, and solids totals were measured for the beverage [3]. The color of roasted and ground coffee was measured with a colorimeter (Byk Gardner, model PCB-6805) previously calibrated with white and black standards and configured for D65 and a 10° angle illuminant. This group of roasted coffee variables was named FGT.

Beverage preparation and sensory analysis

Green coffee was subjected to a medium roasting process (Roaster Rod-Bel) until the desired weight was achieved [8]. Samples were tested no later than two days after roasting. The beverage for descriptive sensory analysis was prepared with roasted and ground coffee beans (70 g L^{-1} of boiling water). After a 1-min extraction, the beverage was filtered (Mellita filter paper) directly into a thermo flask. The beverage was served in disposable cups (30 mL at 50–60 °C) to 8

trained tasters in individual cabins with natural light no more than 20 min after the preparation.

Four coffee beverages were presented in a randomized complete block design in each session. The intensities of sensory attributes, including turbidity, coffee aroma, green aroma, sweet aroma, body, sweet taste, acid taste, grassy taste, bitter taste and astringency, were evaluated using a 10 cm scale, and the minimum and maximum attribute intensities are anchored at the ends of the scale [16]. This group of sensory attributes variables was identified as SENS.

Statistical analyses

Analysis of variance was applied to the physico-chemical of green and roasted coffees and sensory attributes variables. A Tukey test was applied for mean comparisons.

The data groups of physico-chemical characteristics of the green and roasted coffee beans and sensory attributes variables were subjected to an MFA. This technique consists of two steps. In the first step, the multiple correspondence analysis (MCA) were applied to the tables of the groups of qualitative variables. In the second step principal component analysis was applied (PPCA) to the groups of quantitative variables. PPAC results were used for global analysis that simultaneously enables the groups of variables and the samples to be associated. RV coefficient is used to evaluate the link between groups of variables. This coefficient is obtained from the linear correlation coefficients between two groups of variables. Values above 0.8 indicate that the global factor represents the trend in the individual analysis of each group of variables. Further information on multiple factor analysis can be found in Pagès [30] and Kennedy and Heymann [37].

The statistical analysis were performed using a Statistical XLSTAT- Statistical Data Analysis for Excel software.

Results and discussion

Physico-chemical characteristics and sensory attributes of natural (CN) and semi-dry (CD) coffees

The coffee samples prepared by the producers were evaluated by innumerable variables that represent the quality of PHP. The proteins, lipids, total sugars, sucrose, chlorogenic acids, phenolic compounds, trigonelline contents, green coffee density and titratable acidity of the CN and CD coffees produced during the 2 years presented significant differences. Caffeine and 5-CQA contents did not show significant differences between the processes over the 2 years of production (Table 1).

The roasting of the green coffee was controlled visually by brown color development. CN and CD coffees showed significantly different total weight loss to achieve a similar

Table 1 Mean values of green and roasted coffee physico-chemical characteristics (g 100 g^{-1}) and sensory attributes of natural coffee (CN) and semi-dry coffee (CD) processes

Processes	CN04	CN05	CD04	CD05	$p < 0.05$
Green coffee bean					
Pro	15.01 b	15.49 a	15.10 b	15.51a	0.043
Lip	13.55 a	13.49 a	13.39 ab	12.96 b	0.016
TS	8.58 b	9.85 a	9.01 b	10.09 a	< 0.0001
Sac	8.36 b	9.43 a	8.80 b	9.65 a	< 0.0001
RS	0.20 b	0.42a	0.21 b	0.44 a	< 0.0001
CQA	7.9 b	8.06 a	7.40 b	7.38 b	< 0.0001
PC	5.30 a	5.32 a	5.12 a	5.12 a	0.045
Trig	1.19 a	1.06 b	1.15 ab	1.06 b	< 0.0001
5-CQA	5.64 a	5.46 a	5.540 a	5.26 a	0.104
Caf	1.23 a	1.22 a	1.21 a	1.22 a	0.889
DV	0.642 ab	0.640 b	0.646 ab	0.651 a	0.019
Acv**	195.16 ab	202.04 a	191.19 b	188.08 b	0.00088
Roasted coffee bean					
PP	14.99 b	15.79 a	15.13 b	15.12 b	< 0.0001
DT	0.364 a	0.361 a	0.365 a	0.376 a	0.142
VE	53.57 a	53.06 a	54.13 a	50.70 a	0.591
L*	26.48 a	26.23 a	26.32 a	25.81 a	0.262
pH	5.03 a	5.00 a	5.01 a	4.99 a	0.037
Acb**	13.99 ab	13.83 b	14.47 a	14.03 ab	0.039
Brix	1.52 ab	1.61 a	1.46 b	1.52 ab	0.001
Sensory attributes					
Turb	4.28 b	4.61 a	4.22 b	4.55 a	< 0.0001
Arc	4.25 ab	4.19 b	4.48 a	4.37 ab	0.031
Arv	2.63 a	2.58 a	2.51 a	2.45 a	0.548
Ado	3.88 b	3.62 c	4.17 a	3.71 bc	< 0.0001
Body	4.24 a	4.86 a	4.15 a	4.23 a	0.595
Sdo	2.64 ab	2.55 b	2.76 a	2.61 ab	0.043
Saci	3.88 c	4.62 a	4.35 b	4.50 ab	< 0.0001
Sv	3.00 a	3.17 a	3.05 a	2.94 a	0.379
Sam	4.38 a	4.29 a	4.28 a	4.21 a	0.433
Sads	3.33 b	3.58 a	3.28 b	3.47 ab	0.005

Means followed by the same letter do not differ by line and Tukey's test at 5%

Pro proteins, *Lip* lipids, *TS* total sugars, *Sac* sucrose, *RS* reducing sugars, *CQA* chlorogenic acids, *PC* phenolic compounds, *Trig* trigonelline, *5-CQA* 5-caffeoylquinic acid, *Caf* caffeine, *DV* green coffee density, *Acv* titratable acidity of green coffee, *PP* total weight loss, *DT* density of roasted coffee, *VE* volume expansion of coffee, *L** luminosity, *pH* pH of the beverage, *Acb* titratable acidity of the beverage, *Brix* soluble solids of the beverage, *Turb* turbidity, *Arc* coffee aroma, *Arv* grassy aroma, *Ado* sweet aroma, *Sdo* sweet taste, *Saci* acid taste, *Sv* grassy taste, *Sam* bitter taste, *Sads* astringency

**ml of NaOH 0.1N 100 ml^{-1} of beverage

color. The instrumental color of the roasted coffee showed no significant differences in the luminosity (L *) between the coffee produced by different processes and in 2 consecutive years.

Comparing the total weight loss and the luminosity of the coffees from different processes, the CN05 coffees presented greater weight loss to reach the same luminosity as other coffees (Table 1). The pH of the beverage was similar in the coffees of the CN and CD processes and between the 2 years. CD05 coffees presented the lowest titratable acidity and a higher solids value than the other coffees (Table 1).

In the sensory evaluation, coffee and sweet aromas and sweet and acid tastes presented significant differences between the years and processes. The other sensory attributes were considered to be similar by the tasters (Table 1).

Relationship between groups of variables in a MFA

When the groups of variables are evaluated independently, the resulting information regarding the processes is partial, due to the predominance of one group of variables over the others [30]. MFA is a technique that enables the simultaneous analysis of the groups of variables acquired on the same set of samples without the predominance of a group of variables in the description of the samples because the influence is balanced.

In MFA applied to PHP, the first eigenvalue of FGV (7.06) of the PPCA is greater than the eigenvalue of FGT (5.72) and SENS (3.37). The balance of the variables corrected the dominant effect of the FGV group in the construction of the first axis of MFA. The successive eigenvalues of each group of variables decreased rapidly. The first two dimensions of the MFA comprise 87.51% of variance (Table 2).

MFA is the transposition of the axes of PPCA into a global plan. The quality of this transposition can be evaluated by the contribution to the formation of factors and the RV coefficient. The F1 was formed with the contribution of the FGV (33.46%) and SENS (31%) groups and F2 was formed with the contribution of the FGT group (37.73%). These contributions indicate that the information contained in each group of variables was transposed into MFA. The RV coefficient between MFA and FGV (RV = 0.96), FGT (RV = 0.98) and SENS (RV = 0.94) were above 0.80. These values indicate that the data contained in the individual PCA were transposed to MFA without significant loss of information, so that the MFA translates the trend in the tables of

each group of variables [37]. The difference between two groups of variables was sufficiently important to justify the use of MFA to highlight the common and specific characteristics of each group of variables [30]. The FGV was correlated with FGT (RV = 0.95), while the SENS showed correlation with FGT (RV = 0.89). These values suggest that roasted coffee characteristics depend on green coffee physico-chemical characteristics that ultimately determine the sensory attributes of the beverage [3, 5].

Description of natural (CN) and semi-dry coffee (CD) processes

The qualitative variables (CN and CD processes) were analyzed by correspondence analysis (MCA). The effectiveness of the MCA is evaluated by the contribution of the group of variables in the formation of the factors. In this case, CN04, CD04 and CD05 processes were associated with F1 with contributions of 28.96%, 20.75% and 31.95%, respectively, and CN04 process showed contribution of 43.74% to F2.

The relationship between the PCA projections of the individual groups and those projections resulting from MFA (centroid) for the evaluated processes and years is shown in Fig. 2. The distance between the centroid and PPAC points indicates the influence that individual groups of variables (FQV, FQT and SENS) would exert on the descriptions of the CD and CN coffees if they were used separately.

The largest divergences between the descriptions with the individual group of variables occur only in coffees from the CD process, suggesting that descriptions with the SENS variables would diverge from the descriptions with the FGV and FGT variables. These divergences were corrected when the MFA was applied and thus enabled the description of coffees with all variables simultaneously.

MFA showed that coffee CD04, CD05 and CN04 were associated with the of FGV and SENS groups. Conversely, CN05 coffee is related to the FGT group due to the higher contributions of this group of variables to the F1 factor formation (Table 2).

The projection of the variables (Fig. 3a) and the CN and CD processes (Fig. 3b) in the space formed by F1 and F2 of the MFA allows for a description of the relation between

Table 2 Eigenvalues (AV) and cumulative variance (VA %) of the partial PPCA in an MFA

	FGV		FGT		SENS		MFA	
	AV	VA (%)	AV	VA (%)	AV	VA (%)	AV	VA (%)
F1	7.06	58.83	3.37	48.12	5.72	57.19	2.69	48.73
F2	4.22	96.96	2.71	86.88	3.13	88.52	2.14	87.51
F3	0.73	100.00	0.92	100.00	1.15	100.00	0.69	100.00

FGV group of physical–chemical variables of green coffee, *FGT* group of physical–chemical variables of the roasted coffee, *SENS* group of sensory attributes variables

Fig. 2 Projections of the natural (CN) and semi-dry (CD) processes on the space formed by F1 and F2 of PPCA and MFA
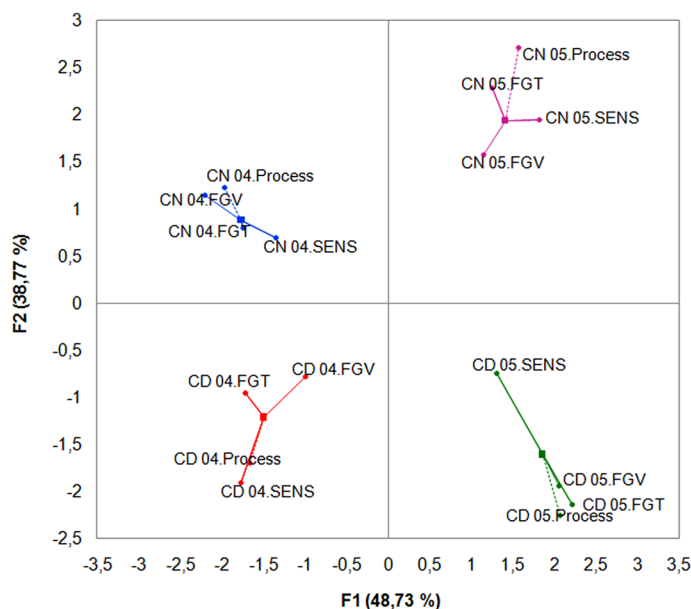
the variables and the factors, and an association between the variables and the processes.

The variables of the individual group and their relationships to F1 and F2 of MFA were shown in Table 3. The variables forming the MFA factors were sufficiently different to promote separations between the coffees produced in the 2 years and those submitted to one of the PHP.

Coffees produced in the 2004 crop and in the 2005 crop were separated by F1; coffee from the 2004 crop was associated with F1 negative, while the coffees from the 2005 crop were associated with F positive, regardless of the process to which they were submitted. Conversely, the CN and CD processes were associated with F2 negative and F2 positive, respectively.

Annual coffee harvests were submitted to the CN or CD process. In the MFA, the separation of the annual crop occurred due to the F1 forming variables, demonstrating the influence of environmental conditions on the content of the compounds and the intensity of the sensory attributes associated with F1.

Coffees from the 2005 crop presented higher sugar (TS, Sac and RS) and proteins contents than those harvested in the 2004 harvest (Fig. 3a, b), regardless of the process used. In addition, the coffees of the 2005 harvest presented a lower 5-CQA and trigonelline contents. These results suggest that these compounds were strongly influenced by environmental conditions. Chemical composition of the coffee beans, especially sugars, are related to fruit development [38, 39] and depends on the local environmental conditions of the year of production [40].

Immature coffees have incomplete cell wall structures, and the gas formed during the roasting expands the cell due to a lack of cell wall resistance, reducing the density

of the roasted coffee beans [15]. Additionally, immature green coffee beans have a high content of 5-CQA [9].

Coffee harvested from the 2005 crop reached a better maturation than in the 2004 crop because it presented lower a content of 5-CQA and roasted coffee beans presented a darker coloration (low L* value), higher acidity (low pH) and lower volume expansion, suggesting complete coffee bean maturation [8, 9].

The beverages of the coffee from the 2005 crop were associated with intense turbidity, high acid taste and astringency, and full-bodied texture. These attributes were accompanied by a low intensity of bitterness and sweet taste and aroma (Table 3). Conversely, coffee beverages from the 2004 crop had a high intensity of sweet aroma and sweet and bitter tastes.

Therefore, the results of coffee harvested in the 2 years point to the strong effect of environmental conditions on these characteristics and the evaluated sensory attributes.

Coffee from the CN and CD processes and each year of production were separated. CN processes were associated with F2 positive and CD processes with F2 negative, regardless of the crop year (Fig. 3b). Considering the variables forming the factor F2 positive, the green coffee beans of the CN processes (CN04 and CN05) presented high lipids, caffeine, phenolic compounds, chlorogenic acids contents and titratable acidity compared to the CD processes. The roasted coffee beans of the CN processes showed a greater weight loss to reach the desired color and showed a higher Brix value.

The green coffee beans of the CD processes (CD04 and CD05) presented a high density of green and roasted coffee beans and a high acidity in the beverage. The primary
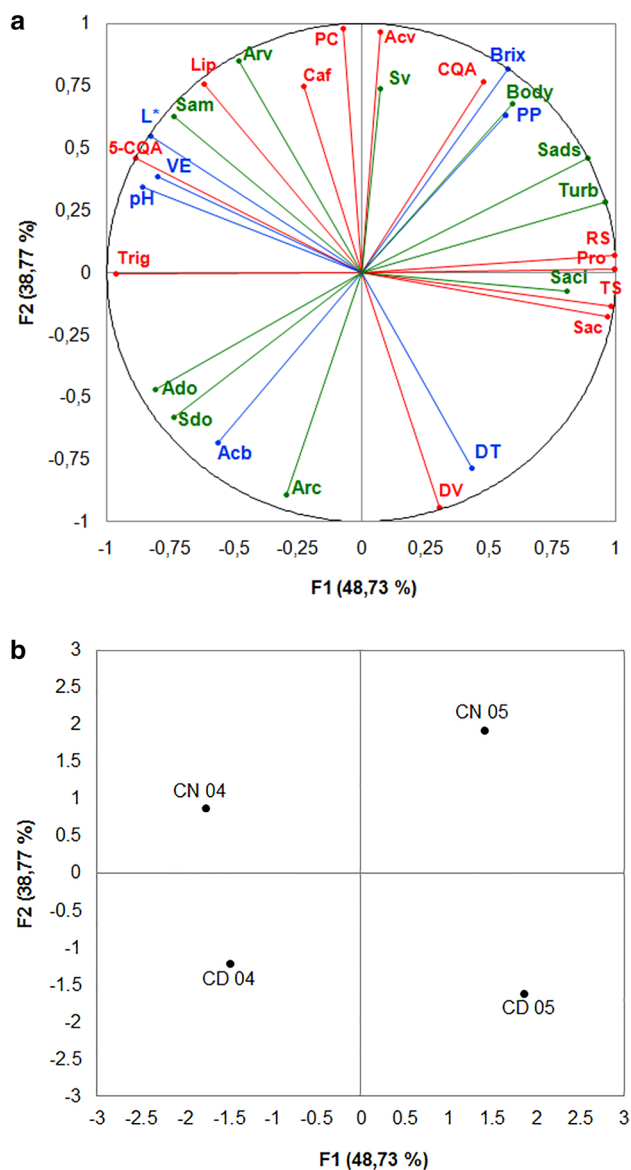
Fig. 3 Representation of MFA of variables (**a**) and processes (**b**) projected on the space of F1 and F2

attributes of CD coffees were high coffee and grassy aromas, low body and grassy taste.

The characteristics of green and roasted coffee beans and sensory attributes found in coffees from PHP can be attributed to the germination metabolism and water stress that occur during these PHP [39–42]. In the CN, the presence of husk inhibits the germination and the macromolecules of the endosperm remain nearly intact in the end of process. During roasting, these compounds were less reactive, and, consequently the formation of volatile compounds responsible for aroma and taste were low.

In addition, larger molecules (polymers), such as phenolic compounds, have been observed to be responsible

for the green aroma and taste found in the beverages [8, 9]. Astringency caused by phenolic compounds can be reduced when the polymers were degraded in the germination [43, 44]. In the CN coffee, these compounds have been altered and the astringency can still be perceived.

In the CD coffee, the removal of the husk and residues of the pulp activate the germination that makes the degradation of the polymers possible. Studies have shown that CD coffees have a lower amount of water-soluble galactomannan than the CN, which was associated with cell wall degradation [14].

Such compounds as lipids [45] and proteins were also hydrolyzed in germination [46]. All of these compounds result in small molecules that during the roasting can form a greater number of volatile compounds [47]. The precursors present in the green coffee beans in each PHP are different, and different aromatic compounds are formed during the roasting. The combination of these volatile compounds will result in the specific aromatic profile and sensory attributes of the CD and CN processes.

Conclusions

The innovative evaluation of the coffees processed by producers in 2 consecutive years showed the influence of the PHP on the physico-chemical characteristics of the green and roasted coffee beans and on the sensory attributes. The differences found between the processes were maintained in the 2 years indicating the efficiency of the evaluated variables and the use of MFA in this separation. The application of the MFA showed that the description of the characteristics of the processes depends on the set of variables and the process. The greatest divergence of descriptions was observed when CD coffee was described by sensory variables. Additionally, this study also showed that sucrose, proteins and 5-CQA contents were associated with the year of production, whereas lipids, phenolic compounds, caffeine and chlorogenic acids contents were associated with the processes. It was also noted that the same attributes occurred in the description of both processes, suggesting that they depend on the content of precursors in the green coffee beans. Interestingly, the coffee samples prepared by the producers presented similar results to the laboratory samples, indicating that the reactions were determined by the process conditions, regardless of the amount processed. Finally, the formation of the precursors was influenced by the factors linked to peeling and drying of green coffee. These factors are the primary critical points that must be controlled to assure the success of each PHP.

Table 3 Variables forming F1 and F2 factors of MFA

	F1 negative	F1 positive
Crop	2004	2005
FGV	5-CQA, Trig	TS, Sac, RS, Pro
FGT	L*, VE, pH	–
SENS	Sam, Sdo, Ado	Turb, Saci, Sads
	F2 negative	F2 positive
PHP	CN	CD
FGV	Lip, Caf, PC, CQA, Acv	DV
FGT	Brix, PP	Acb, DT
SENS	Arv, Arc	Sv, Body

FGV group of physical–chemical variables of green coffee beans, *FGT* group of physical–chemical variables of the roasted coffee beans, *SENS* group of sensory variables, *Pro* proteins, *Lip* lipids, *TS* total sugars, *Sac* sucrose, *RS* reducing sugars, *CQA* Chlorogenic acids, *PC* phenolic compounds, *Trig* trigonelline, *5-CQA* 5-caffeoylquinic acid, *Caf* caffeine, *DV* green coffee beans density, *Acv* titratable acidity of green coffee bean, *PP* weight loss, *DT* density of roasted coffee beans, *VE* volume expansion of coffee beans, *L** luminosity, *pH* pH of the beverage, *Acb* titratable acidity of the beverage, *Brix* soluble solids of the beverage, *Turb* turbidity, *Arc* coffee aroma, *Arv* aroma of green grass, *Ado* sweet aroma, *Sdo* sweet taste, *Saci* acid taste, *Sv* grass taste, *Sam* bitter taste, *Sads* astringent taste

Compliance with ethical standards

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