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Association of Altitude and Solar Radiation to Understand Coffee Quality

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Abstract: The consumer market has a strong tendency to consume specialty coffees, making it essential to understand the influence of environmental conditions, such as solar radiation and altitude, on coffee quality. This study aimed to analyze the physical and sensory quality of Arabica coffee as a function of different altitudes and incident solar radiation on the coffee tree. The study was carried out in the city of Manhuaçu-MG, Brazil. Three altitudes (950, 1050 and 1150 m above mean sea level) and two sides of coffee exposure to solar radiation (east face: morning sun and west face: afternoon sun) were studied in two post-harvest processing (natural and peeled cherry). Sensory attributes, granulometry and occurrence of coffee defects were evaluated, in order to verify if there was variation in the physical and sensorial characteristics of the coffee. It was found that at an altitude of 1150mamsl, on the exposed face of the plant that received the afternoon sun, there was the formation of better-quality coffee, when compared to the face that received the morning sun. On the other hand, at lower altitudes, coffees from the face of the plant exposed to the morning sun showed a greater association with physical and sensory quality parameters.

Keywords: *Coffea arabica* L.; sensory analysis; microclimate; irradiance; altitude

1. Introduction

Coffee stands out as one of the most appreciated prepared beverages in the world. According to data from the International Coffee Organization [1], in the agricultural year 2020-2021, the world consumed around 166.5 million 60 kg bags of coffee. However, to meet the current demands of the consumer market and achieve beverage quality standards, it is necessary to understand the edaphoclimatic factors involved in coffee production and their influence on the final quality of the beans [2–5].

In general, the sensory characteristics of the coffee tree are directly influenced by the cultivation environment (disposition of the plants in the area, spacing, arrangement of lines, geographic face and altitude of the place), genetic characteristics of the plant, harvesting and post-harvest procedure of the fruits, as well as the roasting and beverage extraction profile [3,4,6–11] demonstrating the complexity of achieving high standards of sensory quality in coffee beverages.

Among the highlighted factors, the effect of altitude and its association with temperature has been associated as one of the main phenomena linked to coffee quality [6–8,12–14], generally in higher altitude regions, the coffees tend to have more pronounced sensory notes of flavor, aroma and body when compared to lower-altitude coffees [7,12,15,16]. This occurrence may be related to the effects that solar radiation exerts on air and soil temperature, in addition to its influence on soil and plant microbiota.

Under milder temperature conditions, coffee beans mature more slowly, which favors the translocation of chemical compounds from the plant to the fruit, which creates sensory profiles unique to coffee [17–19] which can provide a natural terroir for coffee grown in this condition [20].

In this way, it is emphasized that in order to achieve the quality of the beverage, a complex and balanced combination between the management of the crop in line with the climatic, edaphic and microbiological characteristics of the coffee plantation is necessary [5,7–9,21].

It is also noteworthy that solar radiation, through the geographic position and altitude of the field, is one of the main variables associated with increased quality [6,7,9]. In higher altitude conditions, however, the lower exposure of tissues to solar radiation (from the slope where the plant is implanted or through the arrangement of cultivation lines) is associated with a marked reduction in temperature and an increase in leaf wetness, can become stress factors for the coffee plant [17], which can lead to a reduction in the sensory quality of the coffee.

Thus, the microclimate associated with altitude and solar radiation in the coffee tree might provide a difference in coffee quality. The objective of this work was to analyze the physical and sensory quality of Arabica coffee as a function of different altitudes and incident solar radiation on the coffee tree.

2. Materials and Methods

2.1. Geographical Description of the Area and Cultivar of Arabica Coffee under Study

The work was carried out in the city of Manhuaçu, located in the region of Matas de Minas, state of Minas Gerais, Brazil (Figure 1). Coffee fruits (*Coffea arabica* L.) of the cultivar Catuaí IAC 144 were harvested in three productive areas located at different altitudes: 950, 1050 and 1150 m above mean sea level (mamsl).

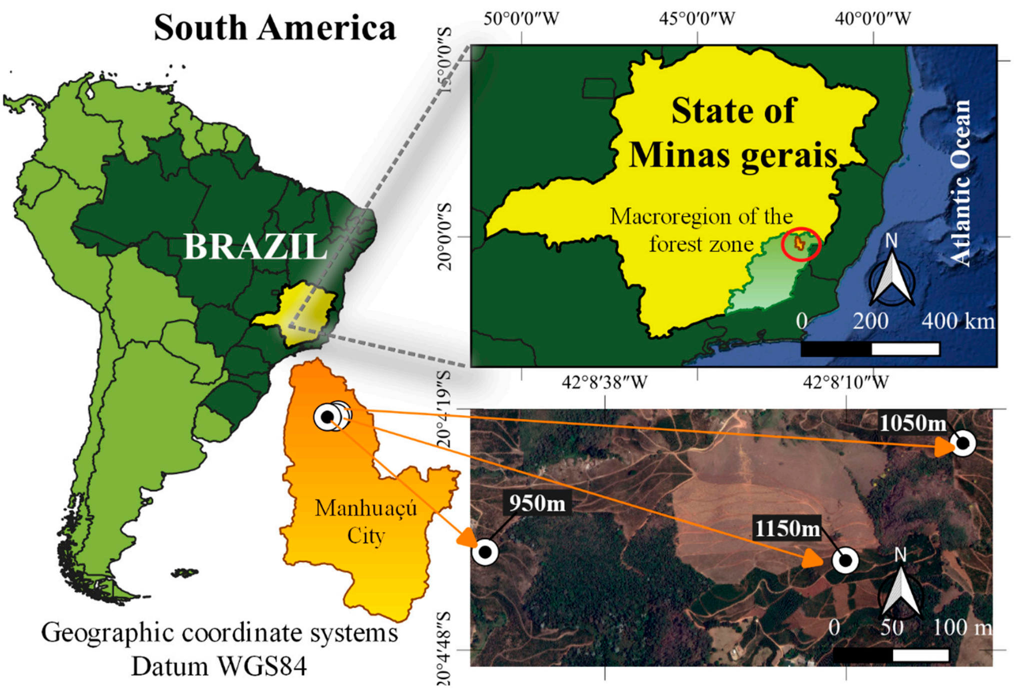

Figure 1. Geographical location map of the experimental area.

The Arabica coffee cultivar Catuaí IAC 144 stands out for its small size, high productive vigor, susceptibility to coffee rust *(Hemileia vastatrix*), medium grain size and good sensory quality of its grains [22].

2.2. Climatic Characteristics and Cultural Treatments of Coffee

For the three altitudes studied, the climate is characterized as hot and humid, with annual precipitation around 1200 to 1300 mm and average annual temperature around 19.8 °C, 20 °C, 20.3 °C, for the altitudes of 950mamsl, 1050mamsl and 1150mamsl respectively. The experimental plots were in the fourth productive year after the production pruning and were implanted in contour lines, with the planting lines diagonally in relation to the trajectory of the sun. This fact causes a difference in the incidence of sunlight on each side of the plants throughout the day.

The fertilization management of the experimental plots was carried out by sampling and soil analysis and according to the recommendations proposed by Martinez and Neves [23] for the cultivation of Arabica coffee. Liming was carried out in June, with the premise of raising the base saturation of the soil to 60%, as proposed by Martinez and Neves [23]. The other cultural treatments of the experimental stands were carried out according to the manual for recommending cultural practices for coffee cultivation described by Sakiyama et al. [22].

2.3. Harvest and Post-Harvest of Coffee Cherries

In each area, a sampling of 10 L of cherry coffee was carried out to differentiate the developed coffee fruits according to the face of the plants exposed to incident solar radiation. In this sense, the fruits developed on the east side (morning sun) and on the west side (afternoon sun) were collected.

The coffee was harvested manually through selective harvesting, selecting only the fruits in the cherry stage. Ten liters of cherry coffee fruits were collected on each face of the plant exposure for the three studied altitudes. Afterwards, the samples were divided into sub-samples of five liters and the fruits were submitted to two types of post-harvest processing: dry (natural coffee) and wet (peeled cherry coffee). Dry processing was carried out in order to direct the newly harvested fruits, in their natural form, immediately to the drying process. In wet processing, before the drying step, the coffee fruits were subjected to mechanical peeling, with removal of the exocarp. Drying was carried out on a suspended terrace, with constant rotation, until the coffee reached a water content of 12% (wet base.). The determination of the ideal moisture was made with the portable grain moisture meter model AL-102, from Agrologic. Subsequently, processing was performed.

2.4. Physical Analysis of Coffee Beans

The physical analysis of the coffee was carried out through the evaluation of defects and granulometry. The physical analysis of the coffee was carried out through the evaluation of defects and granulometry. As for the defects, the presence of brocade was evaluated, which is characterized by the presence of grains damaged by the action of the coffee borer (*Hypothenemus hampei* Ferrari), shell grains that result from the separation of imbricated grains and hollow grains, which is defined as an abnormality in the formation of the grain of these fruits. In the granulometric classification, the percentage of coffee retained in the Pinhalense brand sieves at different thicknesses was quantified, as follows: sieve 18 (P18); sieve 17 (P17); sieve 16 (P16); sieve 15 (P15); sieve 14 (P14); sieve 13 (P13); sieve 12 (P12), according to the normative instruction of the official Brazilian classification, methodology proposed by Brazil [24].

2.5. Sensory Analysis of Coffee Beans

For sensory analysis, the samples of green coffee beans (sieve size 16 above) were sent to the Coffee Analysis and Research Laboratory—LAPC, at the Federal Institute of Espírito Santo, Venda Nova do Imigrante campus, where the roasting took place. Grinding and tasting the samples, according to the methodology of the Specialty Coffee Association (SCA), weighted according to the recommendation of Pereira et al. [25]. Sensory analysis was performed by seven evaluators accredited by the Specialty Coffee Association (SCA).

It is noteworthy that in the sensory analysis of coffee, according to the SCA method, scores ranging from 6.00 to 9.75 points are given for ten evaluated attributes: fragrance/aroma, flavor, acidity, body, uniformity, clean cup, overall, aftertaste, balance, sweetness, global score. In addition, to determine an overall score for the evaluated coffee, the sum of the scores for the individual attributes is calculated. According to the score obtained, the coffee can be classified as: below special (<80), very good (80–84.99), excellent (85–89.99) and exceptional (90.00 to 100) [26]. Considering that the scores referring to uniformity and clean obtained standardized scores equal to ten for all samples, they were not used for statistical analysis.

2.6. Statistical Analysis

For the statistical analysis of the sensory characteristics, a completely randomized design was considered in a 3 × 2 factorial scheme (three altitudes and two sides of exposure of the plant to solar radiation), with seven replications (seven evaluators accredited by the SCA), totaling 35 experimental units (Supplementary Material). An analysis of variance was performed for each type of post-harvest processing. When a significant difference was observed, the means were compared using the Tukey test at 5% probability.

To analyze the correlation of groups of sensory variables and for groups associated with grain size, and to validate the application of principal component analysis, Pearson's correlation was performed. It is noteworthy that as the data referring to the sensorial characteristics of the coffee were obtained considering only the beans retained in the sieves 16 above [26], it was decided not to carry out the correlation study between the variables referring to the size of the coffee beans.

In addition, for each post-harvest processing (dry and wet), a principal component analysis was performed, based on the correlation matrix, in order to verify the dispersion of sampled coffees at the three altitudes and on both sides of the exposure of the plant to solar radiation [27]. Analyses were performed with the free R software [28].

3. Results

Figure 2 shows the average dispersion of the studied treatments for sensory attributes in wet processing (Figure 2A,B) and dry processing (Figure 2C,D). Based on the study of behavior, it was possible to observe that for wet processing (Figure 2A) the sensory profiles of coffees were less grouped when compared to dry coffees (Figure 2A,B).

It was also observed that the coffees at the attitude of 1150mamsl afternoon sun (Figure 2D) and 1150mamsl morning sun (Figure 2C) in wet processing were the ones with the highest and lowest balance among all sensory attributes studied, respectively (Figure 2A). Coffees measuring 1050mamsl in the morning sun (Figure 2A,C) stood out for presenting greater dispersion for the attributes of body and aftertaste although at the same altitude, on the face that receives the afternoon sun, they stood out for being superior in flavor and acidity (Figure 2A).

For coffees from dry processing (Figure 2C,D), there was a greater balance between treatments regarding the dispersion of attributes, with emphasis on a greater association of the aroma attribute and body for coffees at an altitude of 1150mamsl in the afternoon sun, morning sun of 1050mamsl and morning sun of 950mamsl, being the smallest association of the afternoon sun coffee of 950mamsl with most sensory attributes (aroma, uniformity, body, general and acidity) and coffee coming from the altitude of sun at 1150mamsl with aroma and flavor attributes (Figure 2C,D).

When studying the coffees at each altitude obtained in the sensory evaluation, it was found that there was no difference between the faces of the plant's exposure to incident solar radiation at altitudes 950mamsl and 1050mamsl, both for the peeled cherry (Figure 3A) and for the coffee natural (Figure 3B). On the other hand, at the highest altitude (1150mamsl) there was a higher overall score of coffees on the exposed face of the plant that received the afternoon sun (west face) (Figure 3).

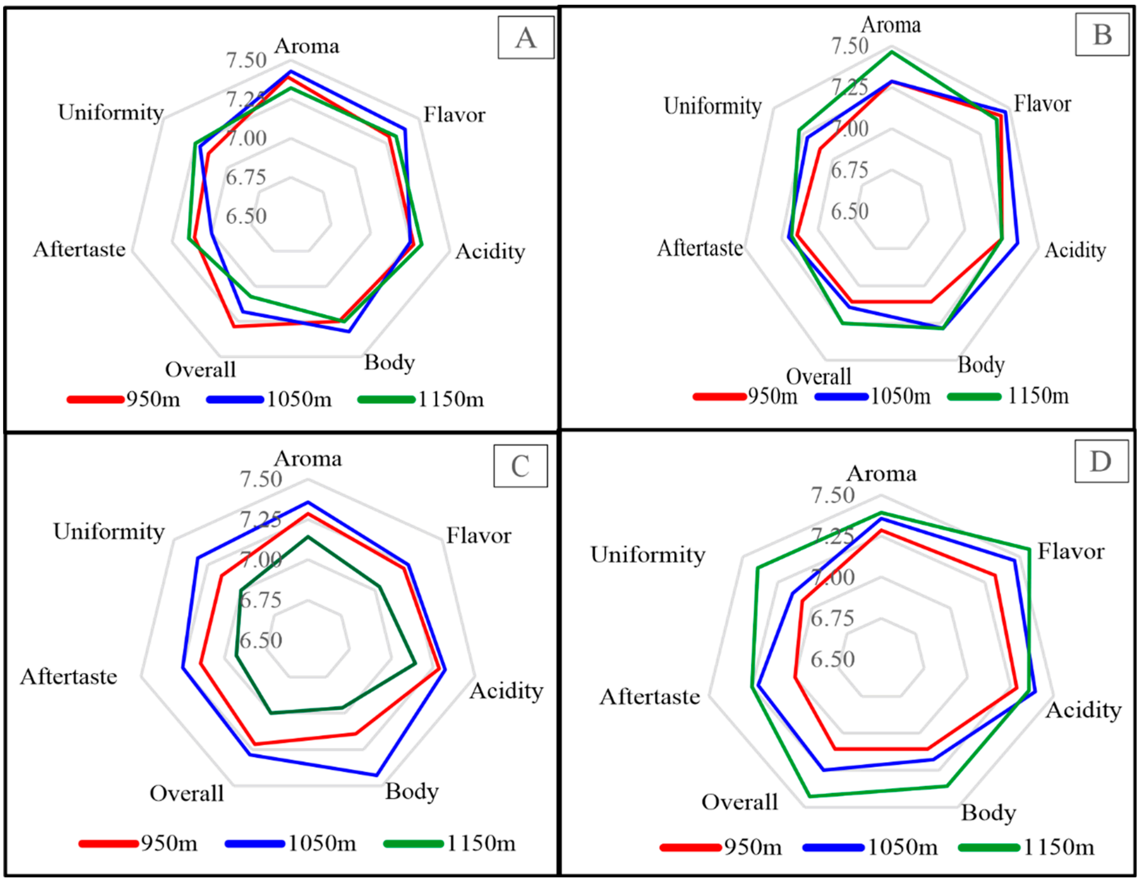

Figure 2. Average dispersion of aroma, flavor, acidity, body, overall, aftertaste and uniformity of coffees from three altitudes (950mamsl, 1050mamsl and 1150mamsl) on the face of the plant exposed to morning sun (**A**,**C**) and afternoon sun (**B**,**D**) in post-harvest wet (**A**,**B**) and dry (**C**,**D**) processing.

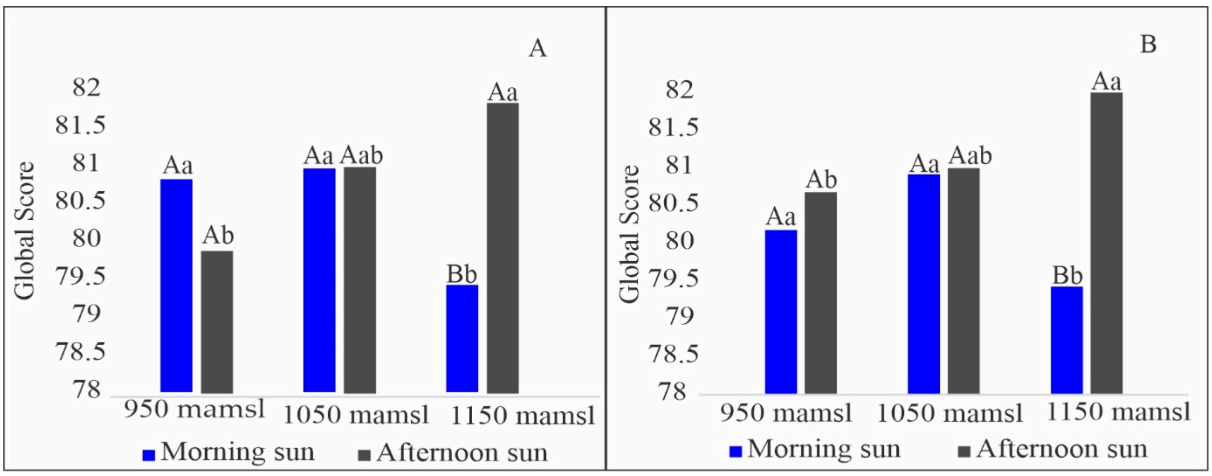

Figure 3. Global coffee score as a result of plant exposure to solar radiation, at altitudes of 950, 1050 and 1150 msnl, in two post-harvest processing, wet (**A**) and dry (**B**). Means followed by the same capital letter ("A" or "B") between altitudes and lowercase ("a", "ab" or "b") between post-harvest processing do not differ by Tukey's text by 5% probability.

Furthermore, when comparing the coffees developed on the exposed face of the plant that received the morning sun, there was a higher global score at altitudes of 950mamsl and 1050mamsl (lower altitudes) (Figure 3). On the other hand, the coffees on the exposed side of the plant that received the afternoon sun had a higher overall score at the altitude of 1150mamsl (highest altitude) when compared to 950mamsl (lower altitude).

Averages followed by the same letter, capitalized for the face of plant exposure to solar radiation and lowercase for altitudes, do not differ from each other at the 5% probability level by the Tukey test.

Regarding the estimation of correlation between the sensory characteristics studied, it was observed for the hulled cherry coffee from wet processing (Figure 4A), there were only four significant correlations between the sensory attributes of the coffee tree, namely: aroma and overall (73 %), body and uniformity (69%), body and overall score (82%) and uniformity and overall score (71%). As for natural coffee, from dry processing, there were 23 significant correlations of the 28 possible combinations between sensory attributes, with emphasis on the correlations between aroma and global score (98%), aroma and acidity (95%), general score and overall score (98%), uniformity and overall score (95%) and uniformity and body (95%) (Figure 4B).

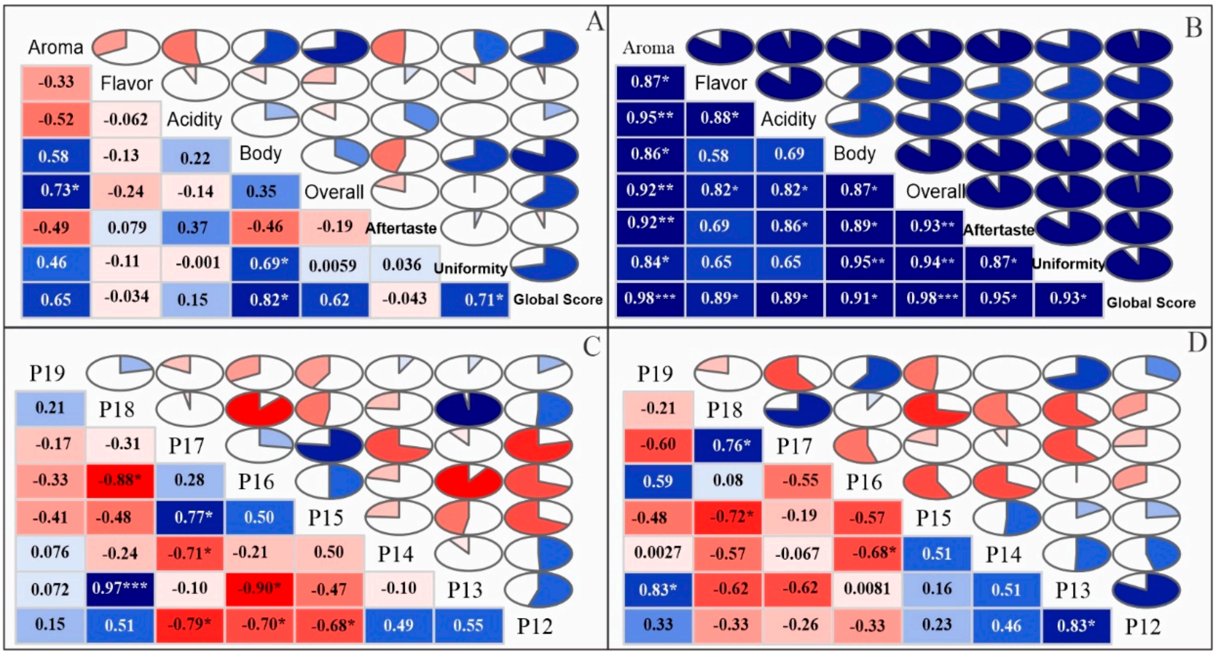

Figure 4. Estimates of the Pearson correlation coefficients of the variables that constitute the sensory characteristics group (fragance/aroma, uniformity, flavor, body, overall, aftertaste, balance and global score) and grain size (18 sieve (P18); 17 sieve (P17); 16 sieve (P16); 15 sieve (P15); 14 sieve (P14); 13 sieve (P13); 12 sieve (P12)), respectively for post-processing of wet harvest (**A**,**C**) and dry harvest (**B**,**D**). On the lower diagonal are represented the correlation and significance estimates by the t test, significant at 5% (*), 1% (**) and 0.1% (***).

For grain size, there were correlations between sieve 12 and sieve 17 (−79%), sieve 12 and sieve 16 (−70%) and sieve 12 and sieve 15 (−68%) in hulled coffees (Figure 4C), as well as a correlation of 97% between sieves 18 and 13 and −88% between sieves 18 and 16. However, for natural coffee, there was no established pattern between the largest and smallest sieves, highlighting the correlations between sieves 12 and 13 (83%), sieve 13 and 19 (83%), sieve 15 and 18 (−72%) and sieve 18 and 17 (76%) (Figure 4D).

By analyzing the main components, it was possible to verify that the first two components explained 64.99%, 95.72%, 68.73% and 65.66% of the variation in the global score of the data, for the sensory and physical characteristics (size of grains and defects) of the different altitudes and face of exposure of the plant to the sun in the two types of post-harvest processing (wet and dry), respectively (Figures 5 and 6).

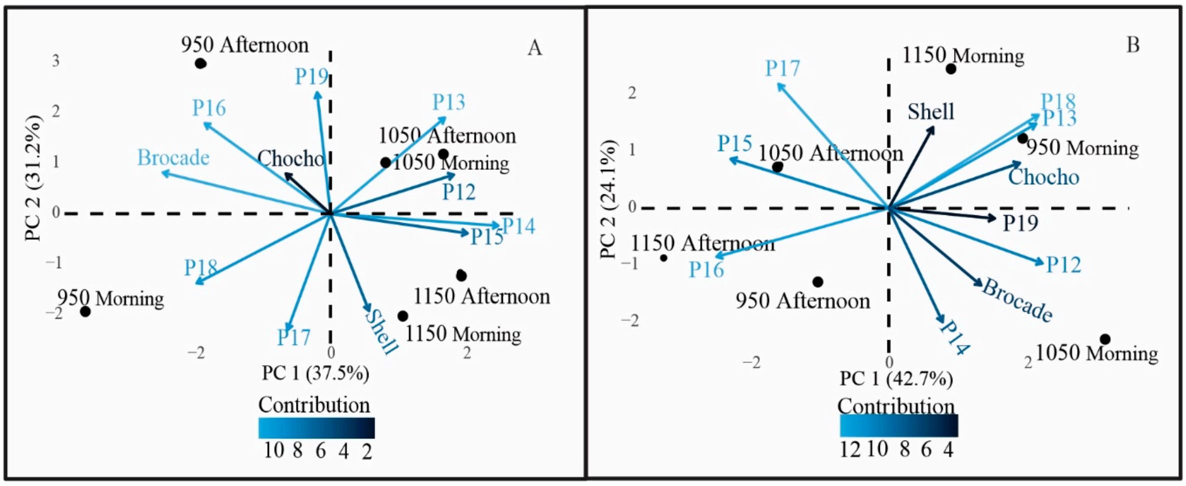

Figure 5. Graphic dispersion of six treatments at three different altitudes (950, 1050 and 1150mamsl) and two faces of plant exposure to solar radiation (morning sun and afternoon sun), in relation to the first main components based on sensory characteristics in the two types of post-harvest processing: wet (**A**) and dry (**B**).

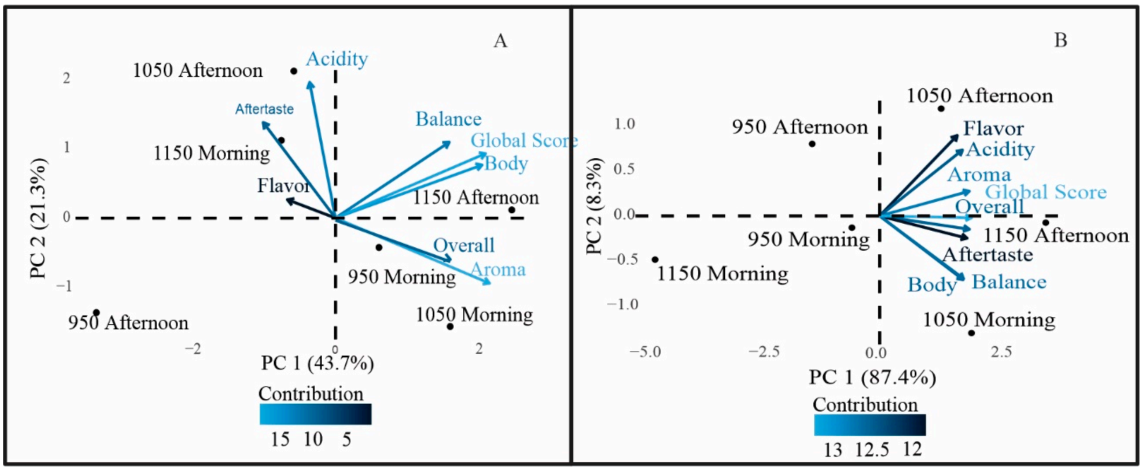

Figure 6. Graphical dispersion of six treatments at three different altitudes (950, 1050 and 1150mamsl) and two regions of the plant exposed to the sun (morning sun and afternoon sun in relation to the first main components based on sensory characteristics in both types of post-harvest processing: wet (**A**) and dry (**B**).

Due to the scatter plot of the scores of the first two main components for the three altitudes and for the two faces of exposure of plants to solar radiation, it was found that the treatment of 950mamsl of altitude on the face of exposure to the afternoon sun showed dispersion opposite to sensory characteristics (Figure 5A).

As well as for dry processing, there was an association between the treatment of 1150mamsl of altitude due to afternoon sun exposure with the characteristic of the global score, in wet processing (Figure 5A), as well as a good association between coffee from the altitude of 1150mamsl with the aftertaste characteristic and inverse with the characteristic's uniformity, global score, body, aroma and overall.

For the coffees in the natural group (dry processing), it was possible to verify that the treatment in the morning sun of 1150mamsl was opposite to the sensory characteristics studied (Figure 5B). It was also observed that the treatment of 1050mamsl of altitude on the face of the afternoon sun exposure presented similar characteristics of acidity and flavor independent of the studied post-harvest processing (Figure 5). The treatment referring to the altitude of 1050mamsl on the face of the morning sun exposure, showed good association with body and uniformity when coming from dry processing (Figure 5B) and aroma and overall, when coming from wet processing (Figure 5A).

In general, regardless of the post-harvest processing adopted, the treatment referring to an altitude of 1150mamsl on the face of exposure to the afternoon sun was closer to most of the sensory attributes analyzed, although the coffees with an altitude of 950mamsl in the afternoon sun showed an opposite association with the sensory attributes of coffee, including the global score.

Regarding physical characteristics (size) and grain defects, it was noted that, in both types of post-harvest processing, the treatment of 1150mamsl of altitude on the face of the morning sun exposure was close to the shell defect (Figure 6).

It was also possible to observe that for the hulled cherry coffee (Figure 6A), the altitudes of 1050mamsl and 1150mamsl on both sides of exposure of the plants to the sun were well grouped, with 1050mamsl being well associated with the sieves 12 (p12) and 13 (p13) and 1150mamsl showed good association with sieves 14 (p14), 15 (p15) and bark. On the other hand, the coffees from treatments at 950mamsl in the morning sun were well associated with the 18 sieve (p18) and were placed far away at 950mamsl in the afternoon sun, which correlated well with the 16 sieve (p16) and chocho grain.

Natural coffees, coming from the face of the plant exposed to the afternoon sun, were directly associated with the characteristics of sieve 15 (p15) and 16 (p16) and inversely with sieves with greater grain granulometry (Figure 6B). Coffees of 950mamsl in the morning sun correlated well with empty beans and sieve 13 (p13) and 18 (p18), coffees of 1050mamsl were better associated with brocade and sieve beans 12 (12) and 1150mamsl with husk and sieve beans 18 (p18).

4. Discussion

It is possible to observe a quality gain for the coffees due to the exposure of the plants to the afternoon sun at higher altitudes (Figures 2 and 3). In the literature, it is highlighted that coffees from colder and higher regions have higher quality scores than coffees from warmer regions, confirming similar results presented [3,4,7,18,29].

Such behavior occurs because, normally at altitude, the translocation of sugars and chemical compounds to the fruit occurs more slowly and efficiently than in warmer and lower regions [7,18,29–31].

Zaidan et al. [6], Sobreira et al. [2] and Pereira et al. [7] highlight that the altitude, intensity and duration of radiation in the coffee tree canopy are determining factors for fruit quality. It is important that normally at high altitudes, the genotypic response of Arabica coffee to quality is more intense than in low-altitude regions [2,3,5,18,32]. Sobreira et al. [2] corroborates this information and mentions that coffee genotypes in general tend to have greater quality potential when grown at higher altitudes.

The lower response to quality at lower altitudes can also be explained by the interaction between the genotype and the environment, which under such conditions is not able to maximize its genetic potential associated with quality [2–5], affecting the formation of more adequate biochemical and physiological events, resulting in slower fruit maturation periods, which affects the adequate formation of physical compounds, chemical, volatile and non-volatile, which are directly related to coffee quality [30,33,34]. The combination and proper balance of these compounds are essential for the coffee to have its maximum quality gain, thus explaining the presence of afternoon sun coffees at 1050 and 1150mamsl and morning sun coffees at 1050mamsl of altitude (Figures 2A,B and 3A,B).

In addition to maximizing the genetic potential of the coffee tree [2–5] and more uniform fruit maturation [30,31], it is possible to associate quality gains at higher altitudes with the presence of microorganisms beneficial to the coffee tree [9].

The presence of these microorganisms in the soil and their association with the quality of the drink is linked to the intensity and duration of stresses on the plant and the concentrations of organic matter and nutrients in the soil. Thus, the lower the stress associated with the plant and the more balanced the soil, the greater the probability of the beneficial action of the microbiota and, concomitantly, the greater the community of microorganisms that favor quality [9,35–38].

However, when analyzing coffees from an altitude of 1150mamsl (higher) in the region of the plant predominantly exposed to the morning sun, the worst sensory quality is observed, regardless of the post-harvest procedure. Such behavior for this specific environment may have occurred due to the microclimatic conditions that occur inside the coffee plantation, when cultivated at altitudes above 1000mamsl.

In general, when at altitude, coffee plantations are affected by specific microclimatic factors, such as low average annual temperature, shorter periods of water deficit and greater leaf wetness associated with lower light intensities [39,40]. This result reinforces the need for a broader discussion regarding the implementation of process control for precision coffee farming.

Another factor that may have been determinant for this specific response is that normally at high altitudes and with less intensity of solar radiation, coffee beans undergo a very slow maturation [30–34]. Although the fruits were harvested at the cherry stage, it is assumed that these fruits at an altitude of 1150mamsl in the morning sun did not reach the accumulation and full development of sugars and aromatic compounds, which add quality to the coffee. Chemical analyses may provide this answer in future studies, indicating which metabolite reserves are or are not forming, depending on the plant's condition in this microclimatic environment.

It is also noteworthy that although light is an essential resource for the plant, its intensity and durability can affect the patterns of biochemical and physiological responses of plants, with emphasis on the synthesis of secondary metabolites, chlorophyll, nitrogen allocation and cellular respiration [41–44]. These changes at biochemical and physiological levels associated with the plant's genetic response may have been decisive for the sensory quality of the coffee.

Thus, for higher altitude regions, when the production of specialty coffees is recommended, there is a tendency for the exposed face of the plant that receives the afternoon sun to present a greater quality potential when compared to the face that receives the morning sun. For the other altitudes studied, based on the multivariate behavior of the treatments, greater familiarity with sensory quality tends to be observed in the region exposed to the morning sun.

Based on the correlation estimates, it is possible to observe greater correlations between sensory attributes for dry post-harvest processing compared to wet post-harvest processing (Figure 4). This answer may be related to the greater capacity of natural coffees (dry) to express their sensory characteristics. In a study aiming to observe the sensory analysis of the beverage in rust-resistant Arabica coffee cultivars according to post-harvest processing, Pereira [45] highlights that the studied genotypes presented different sensory behavior among themselves and between different post-harvest models, harvest, highlighting, as in this study, the gain in aroma, flavor and acidity of coffees that were subjected to post-harvest processing by the dry route in relation to the wet process [46,47].

Such behavior possibly occurred as a result of the consumption of sucrose levels that normally occur in the wet phase. Thus, the invertase enzyme may have acted by breaking the sucrose molecule into glucose or fructose, which was consumed by microorganisms during wet processing [48–50].

It is also observed that the attribute body had a significant correlation with the attribute global score for natural coffees (91% of correlation), although for peeled cherry coffees this correlation was lower (82%). Such behavior was already expected, since dry processed coffees are usually thicker than wet processed ones [25]. This behavior occurs due to the drying of the beans together with the exocarp and mucilage, which tends to lead to gains in aroma, flavor, acidity and body [7,17].

In Figure 4B, it is possible to observe that the post-harvest processing of wet coffee in the afternoon sun of 950mamsl showed an opposite correlation with the quality parameters. According to Jesus Junior et al. [51] low altitude regions tend to have greater water restrictions and higher temperatures for the coffee tree when compared to higher regions. This water restriction associated with strong insolation favors faster fruit maturation, preventing the proper formation of compounds related to coffee quality [30,34].

It can also be seen from the analysis of Figure 5 that the treatment at 1150mamsl in the afternoon sun was the one that best related to the quality parameters and that at lower altitudes, the coffees that received predominantly the morning sun had a greater association with the quality of those that received the afternoon sun. Such behavior leads to the interpretation that factors such as slower maturation of the coffee tree at higher altitudes [34], as well as coffee cultivation and the exposure face allow the plant to be less stressed when at low altitudes [6,7,18]. This can be advantageous when seeking the production of specialty coffees.

It is also noteworthy that the processing that gives rise to the hulled cherry coffee is advantageous because this method helps to reduce the drying time [52]. This speed of drying the beans provides more security in the quality of the coffee, as this technique has been attributed to a reduction in the risk of unwanted fermentation and attack by fungi and bacteria [7,53].

Due to the physical characteristics (granulometry) and grain defects, it can be observed that the altitude of 950mamsl in the morning sun showed a good correlation with cuttlefish grains and the afternoon sun with the brocade grain variable (Figure 6B), in addition to the good correlation between the grains retained in sieve 16 and the perforated grains (Figure 6A,B).

This behavior may have occurred because in regions with a hotter and drier climate there is more likelihood of attack by the coffee borer (*Hypothenemus hampei* Ferrari), since the warmer and often drier climate shortens the insect's life cycle and increases its number of generations in the same productive year [54]. In addition, uneven blooms also favor the maintenance of the insect in the field. Thus, possibly the drier and hotter climate found at lower altitudes, followed by the uneven flowering observed in the 2018/2019 crop for the region [55], may have favored the development of the pest and, consequently, increased the percentage of defects, brocade in beans by coffees at altitude of 950mamslin the morning sun.

Based on Figure 6, it was possible to observe the different responses to treatment for different grain sizes (P12, P13, P14, P15, P16, P17, P18 and P19). Such behavior can be justified, as highlighted by Pimenta et al. [56] and Ferreira et al. [5] because the size of the coffee beans depends, in a determinant way, on the edaphoclimatic conditions of the area that occur during the plant's reproductive period, mainly from 10 to 17 weeks after flowering. This period corresponds to the phenological phase called rapid fruit expansion, which is marked by cellular expansion that delimits the grain size, considered quite sensitive to climatic variations, especially thermal and water [57–60]. This could possibly explain the variations found in this work.

5. Conclusions

There is variation in the physical and sensory characteristics of coffee as a function of the interactions between different altitudes and solar radiation in the coffee tree.

Coffees at altitudes of 950mamsl and 1050mamsl on the face of the plant exposed to the morning sun had a positive relationship with the physical and sensory quality characteristics, compared to coffee grown on the face of the afternoon sun at these same altitudes. However, when at the highest altitude studied (1150mamsl), there was a positive interaction with the face of plant exposure to the afternoon sun, with favorable responses to coffee quality.

Dry processed coffee showed higher correlations between sensory attributes than wet processed coffee.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy12081885/s1, The search database.

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