

Mapping the mountainous climate in the Matas de Minas region, Brazil which influences the top-quality coffee beverages

Mapeamento do clima de montanha na região de Matas de Minas, Brasil que influenciaram a alta qualidade das bebidas do café

Mapeo del clima de montaña em la región de Matas de Minas, Brasil que influyen en la alta calidad de las bebidas de café

Received: 08/05/2022 | Reviewed: 08/28/2022 | Accept: 09/06/2022 | Published: 09/13/2022

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Abstract

All the characteristics of the mountainous environment directly influence the coffee crops, and subsequently, on the final coffee note, that reflects the quality of the beverage produced in a region. Despite increasing coffee research, little is known about the influence of the water indices, factors, and the elements of climate on top-quality coffee production potential. Thus, the present study was carried out aiming to analyze the water indices, causes, and aspects of climate, to identify those that most contribute to the potential production of high-quality Arabica coffee beverages in a mountain environment. We considered harvesting the coffee fruits at the cherry stage in 26 municipalities in the Matas de Minas region in the Atlantic Forest Biome in the eastern state of Minas Gerais, and the International Cup of Excellence method was adopted for the sensory evaluation. The principal components analysis and the multiple linear regression (MLR) were used to relate the local environmental variables with the final grade of the coffee beverage. As a result, the Multiple Linear Regression model showed the value of 0.63 for R². This result means that the joint variability of all the variables considered explained 63% of the changes in coffee beverage quality. And the altitude impact on the grade achieved for the coffee beverage produced in the Matas de Minas region, represented by β , was 0.008068, meaning that for every 100 meters of increase in the altitude, there is an approximate increment of 0.8 points in the final note achieved for the coffee beverage. Among all the environmental characteristics studied, the climatic factor altitude was the main contributor to the coffee top-quality production potential in the Matas de Minas region.

Keywords: Coffee sensory evaluation; Arabica coffee; Specialty coffee; Environmental characteristics; Climate impact; Coffee beverage quality.

Resumo

Todas as características do ambiente montanhoso influenciam diretamente nas lavouras de café e, subsequentemente, na nota final do café, que reflete a qualidade da bebida produzida em determinada região. Apesar do aumento da pesquisa sobre café, sabe-se pouco sobre a influência dos índices hídricos, fatores e elementos do clima no potencial de produção de café de alta qualidade. Assim, o presente estudo foi realizado objetivando analisar os índices hídricos, causas e aspectos do clima, para identificar aqueles que mais contribuem para o potencial de produção de bebidas de café arábica de alta qualidade no ambiente montanhoso. Foram considerados os cafés no estágio de maturação de cereja, em 26 municípios da região de Matas de Minas, no Bioma Mata Atlântica, no leste de Minas Gerais, e adotados o método International Cup of Excellence para a avaliação sensorial. Utilizou-se a análise de componentes principais e a regressão linear múltipla (RMM) para relacionar as variáveis ambientais locais com a nota final da bebida de café. Como resultado, o modelo de Regressão Linear Múltipla apresentou o valor de 0,63 para R^2 . Esse resultado significa que a variabilidade conjunta de todas as variáveis consideradas explicou 63% das mudanças na qualidade da bebida de café. E o impacto da altitude na nota alcançada para a bebida de café produzida na região das Matas de Minas, representada por β , foi de 0,008068, ou seja, para cada 100 metros de aumento de altitude, há um incremento aproximado de 0,8 pontos na nota final alcançada para a bebida de café. Dentre todas as características ambientais estudadas, o fator climático altitude foi o principal contribuinte para o potencial de produção de café de alta qualidade na região das Matas de Minas.

Palavras-chave: Avaliação sensorial do café; Café arábica; Café especial; Características ambientais; Impacto climático; Qualidade da bebida de café.

Resumen

Todas las características del entorno montañoso influyen directamente en los cultivos de café y, posteriormente, en la nota final de la bebida de café, que refleja la calidad de la bebida producida en una determinada región.

A pesar de la creciente investigación sobre el café, se sabe poco sobre la influencia de los índices hídricos, factores y elementos del clima en el potencial de la producción de café de alta calidad. A pesar del aumento de la investigación sobre el café, se sabe poco sobre la influencia de los índices de agua, factores y elementos del clima en el potencial de la producción de café de alta calidad. Así, el presente estudio se realizó con el objetivo de analizar los índices hídricos, causas y aspectos del clima, para identificar aquellos que más contribuyen al potencial de producción de bebidas de café de alta calidad en el ambiente montañoso. Para lograr el objetivo, se evaluó el café arábica. Los cafés en la etapa de maduración de la cereza fueron considerados en 26 municipios de la región de Matas de Minas Gerais, en el Bioma de la Mata Atlántica, en el este de Minas Gerais, y se adoptó el método de la Taza Internacional Cup of Excellence para la evaluación sensorial. Se utilizó el análisis de componentes principales y la regresión lineal múltiple (MLR) para relacionar la variable ambiental local con la nota final de la bebida de café producida en la región. Como resultado, el modelo de Regresión Lineal Múltiple presentó un valor de 0.63 para R^2 . Este resultado significa que la variabilidad conjunta de todas las variables consideradas explicó el 63% de los cambios en la calidad de la bebida de café. Y el impacto de la altitud en la puntuación alcanzada por la bebida de café que se produce en la región de Matas de Minas, representada por β , fue de 0,008068, lo que significa que por cada 100 metros de aumento de altitud, hay un aumento aproximado de 0,8 puntos en la nota final lograda para la bebida de café. Entre todas las características ambientales estudiadas, el factor climático altitud fue el principal contribuyente al potencial de producción de café de alta calidad en la región de Matas de Minas.

Palabras clave: Evaluación sensorial del café; Café arábica; Café Especial; Características ambientales; Impacto climático; Calidad de bebida de café.

1. Introduction

Among the four main coffee production areas in the Minas Gerais state, the Matas de Minas region stands out as the second largest in production volume and, above all, in quality beverages (Silveira et al., 2016). The morphoclimatic zones of “Mares de Morros” profit the quality of the coffees produced in this region, with the mild temperatures, high altitudes, and rugged relief the most prominent environmental characteristics, thus characterizing the Matas de Minas region as an area of a mountain coffee.

The search for coffees with a top-quality beverage and environmental sustainability, called differentiated coffees, boosts international trade and scientific research focused on this segment, such as the studies that sought to make associations between the environmental variables of the place of the coffee production and the quality of the beverage (Ferreira et al., 2016; Silva et al., 2016; Silveira et al., 2016).

Brazil will only achieve coffee production able to withstand the higher demands of consumption and exports from the practice of more technically qualified plantations (Ferreira et al. 2019). The adoption of new technologies has also contributed

to the differentiated coffees segment (Barra et al., 2020) that has been showing constant expansion in the last decades; from January to September 2018, this sector represented, according to the report of the Brazilian Coffee Exporters Council round about 17% of the volume of coffee exports, totaling 3,949,656 bags (of 60 kg). Also, some specialty coffees have shown an increase in the market value of approximately 30% compared to conventional coffee production (Cecafe, 2018).

To get differentiated coffees (Fernandez et al., 2020), particularly coffees produced in mountainous areas, the research conducted by Camargo and Camargo (2001), Ferreira et al. (2016), Silveira et al. (2016), and Zaidan et al. (2017) have emphasized the importance of the influence of climatic factors such as “altitude and the mountain slope towards the sun” and the climatic elements “precipitation and minimum temperatures”, and the existence of a period with water deficit, with the influence of these last two variables (climatic elements and water deficit) associated mainly to the Bean-set phase and Fruit ripening. However, there is no consensus about the environmental characteristic (Ahmed et al., 2120) that most contributes to the high quality of the coffee produced in the Matas de Minas region.

Thus, this study was carried out to analyze the water indices, factors, and elements of climate, aiming to identify those that most contribute to the coffee production with the top-quality beverage in the Matas de Minas region. It also aims to identify the phase of the phenological cycle in which these environmental variables can exert more influence on the quality of coffee produced in this region.

2. Methodology

Samples were composed by 3,0 kg of Arabica coffee, red and yellow berries of the coffee variety group ‘Catuaí’, harvested in the cherry phase, at 367 georeferenced points in different coffee plants of 26 properties in the Matas de Minas region that present an altitude ranging from 150 to 2,830 m in the Atlantic Forest Biome, eastern Minas Gerais State (40° 50’ and 43° 36’ South, and 18° 35’ to 21° 26’ West). The samples were labeled with all information concerning the altitude, variety, and orientation that the mountain slope presents, towards the incident solar radiation (FACE) (Ferreira et al., 2012).

Based on the FACE the aspect of the terrain was classified as follow: colder southeast-facing slopes (CSEFS); hotter southwest-facing slopes (HSWFS), hotter northwest-facing slopes (HNWFS), and colder northeast-facing slopes (CNEFS).

After harvesting, the fruits were washed, and selected only the ripe grains that were pulped (wet process), and evenly dried in an artificial dryer.

Coffees that were benefited, and stored were selected for the sensory analysis and tests of the physical quality of the beverage (Moreira et al., 2021). The light-medium roasting was adopted and performed with Agtron disc number 65, based on the Agtron/SCAA Roast Classification Color Disk System (Staub, 1995) and the international rules for sensory evaluation of coffee beverages, through the method of the Cup of Excellence (COE) that had to be changed aiming to meet the national standards established by the Brazilian Association of Specialty Coffees (BSCA, 2021).

Three Q-grader evaluators classified the coffee beverage grades produced in the Mata de Minas region and considered eight nuances for the final classification, namely: “clean cup”; “balance”; “aftertaste”; “body”; “sweetness”; “flavor”; “acidity” and global perception of beverage. The BSCA (2021) characterize these nuances as the organoleptic standards of coffee beverage.

Climatic variables

The “TerraClimate” reanalysis database was used, which is available for the period 1958 to 2017 (Abatzoglou et al., 2018) in the matrix format with a Ground Sample Distance (GSD) of approximately four square kilometers (1/24°). For the present study, the water indices and elements of climate (Table 1) were considered, referring to the second year of the coffee crop from September 2014 to September 2015 (Table 2).

We also considered the average distance among the collection points of the coffee sample in the coffee plantation (using the Global Navigation Satellite System - GNSS with an approximate margin of error of up to 10 meters) and the centroid of the pixels adopted in the process of obtainment climate data available in the TerraClimate site. ArcGIS 10.3 and SNAP 6.3 were used for data geoprocessing.

Table 1. Description of the considered elements of climate (PRP, RAD, TMAX, and TMIN) and water indices (DEF and PAL).

Code	Variable	Description
DEF	Water deficit (mm)	It designates the occurrence in which precipitations exhibit values lower than those of evaporation and transpiration of plants.
PRP	Precipitation (mm)	Amount of water accumulated at the monthly level for the crop year at different phases of the coffee crop.
RAD	Short-wave radiation ($W.m^{-2}$)	Amount of water accumulated at the monthly level for the crop year at different phases of the coffee crop.
TMAX	Maximum temperature ($^{\circ}C$)	Average monthly maximum air temperatures registered for the crop year at different phases of the coffee crop.
TMIN	Minimum temperature ($^{\circ}C$)	Average monthly minimum air temperatures registered for the crop year at different phases of the coffee crop.
PAL	Palmer's index (dimensionless)	It quantifies the "meteorological drought" phenomenon that occurs when the precipitation of one region decreases considerably concerning the amount climatologically expected.

Source: Williams P. M. Ferreira (Elaboration).

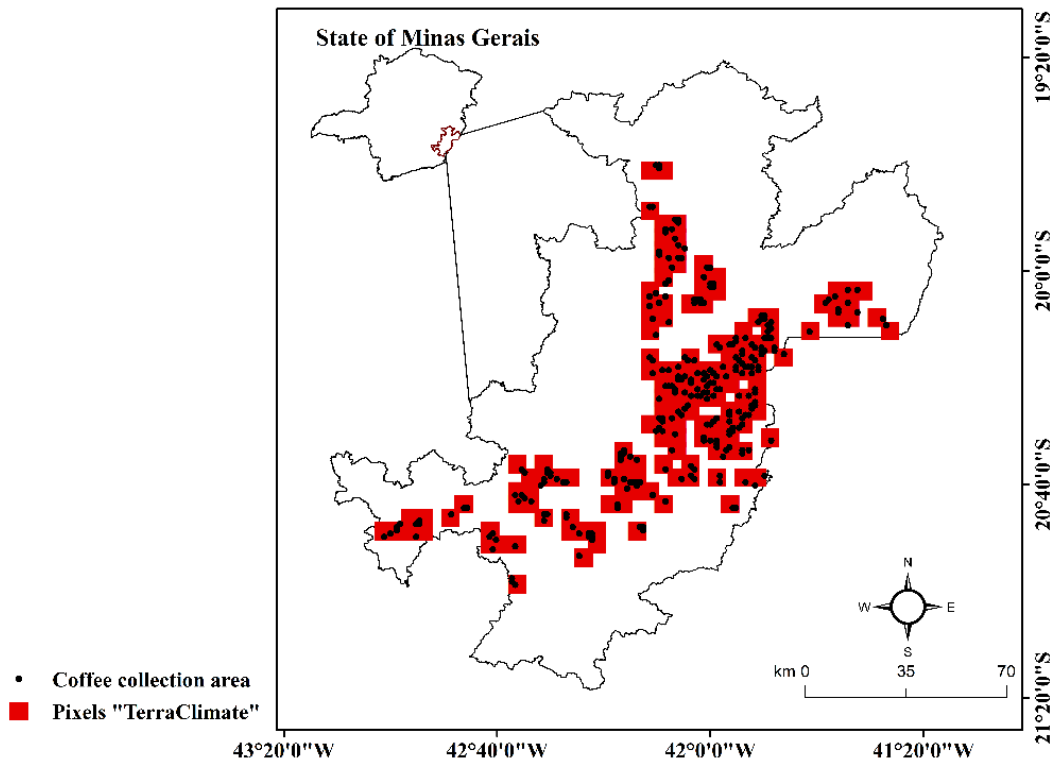
Table 2. Phases that occurred in the second phenological year of the coffee plant considered in the present study

Code	Phenological Phase	Description
F3	Flowering	The period from birth to flowers fall.
F4	Bean-set	When the internal liquids solidify, giving form to the coffee beans. It usually happens in the middle of summer, from January to March.
F5	Fruit ripening	The potential evapotranspiration decreases significantly, and the moderate water deficiencies benefit the final quality of the fruits.

Source: Camargo and Camargo (2001).

The actual location of the coffee plantations' collection points and the centroids of the pixels of the TerraClimate reanalysis database representative of the elements of climate is shown in Figure 1. The distance between the collection points of the coffee samples in the field and the centroids of the TerraClimate pixels was 0.05 km on average. The standard deviation was 0.006 km, which validates the use of such data in the present study.

Figure 1. The distribution of the pixels with centroids refers to the location of the collection points of the coffee samples.



Source: Williams P. M. Ferreira (Coordinator); Humberto Paiva Fonseca (Elaboration).

Statistical analysis

First, the influence of water indices, factors, and elements of climate and the phenological phases on the final grade achieved for the top-quality coffee-produced beverage in the Matas de Minas region were analyzed. Following, the correlation matrix of the nuances and the final grade of the beverage to visualize the potential correlations among all these variables was elaborated. Finally, the influence of the climatic factor altitude, latitude, and the mountain slope towards the sun were tested; the interaction of the elements of climate and the water indices (Table 1) with the phenological cycle of coffee (Table 2), and at the end, the influence of the joint performance of this group of environmental variables in the coffee beverage with top-quality produced in the Matas de Minas region.

We also used for the Multiple Linear Regression (MLR) model the Stepwise Method (with backward), from the prediction models elaborated by the Stepwise Method. The MLR (equation 1) using the Stepwise method was used aiming to correlate the climatic factors, the elements of climate, and water indices with the coffee beverage grade produced in the study region. The MLR method (stepwise) removes the non-representative variables in the model and maintains those (independent variables) that exert a strong influence on the grade (dependent variable).

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 [\dots] + \beta_{21}x_{21} + \varepsilon \quad (1)$$

in which: Y = coffee beverage grade; x_1 = the mountain slope towards the sun; x_2 = latitude; x_3 = altitude; x_4 = radiation in flowering phase; x_5 = water deficit in flowering phase; x_6 = Palmer index in flowering phase; x_7 = precipitation in flowering phase; x_8 = maximum temperature in flowering phase; x_9 = minimum temperature in flowering phase; x_{10} = radiation in the bean-set phase; x_{11} = water deficit in the bean-set phase; x_{12} = Palmer index in the bean-set phase; x_{13} = precipitation in the bean-set

phase; x_{14} = maximum temperature in the bean-set phase; x_{15} = minimum temperature in the bean-set phase; x_{16} = radiation at fruit ripening phase; x_{17} = water deficit in the fruit ripening phase; x_{18} = Palmer index in the fruit ripening phase; x_{19} = precipitation in the fruit ripening phase; x_{20} = maximum temperature in the fruit ripening phase; x_{21} = minimum temperature in the fruit ripening phase; $\sim N(0; \tau\epsilon^2)$.

For the stepwise procedure, we maintained in the multiple linear regression model the water indices, factors, and elements of climate with statistically significant coefficients ($PVALUE \leq 0.10$). The free software “R” (R Core Team, 2021) was used to made the statistical analyzes.

To visualize the association of the variables, we used the Biplot Exploratory Chart, elaborated from the Principal Components Analysis (PCA), which comprises a statistical method of multivariate analysis that aims to select the main variables considered in this research as the most influential variables (factors and elements of climate) in the coffee production potential with the top-quality beverage in the Matas de Minas region.

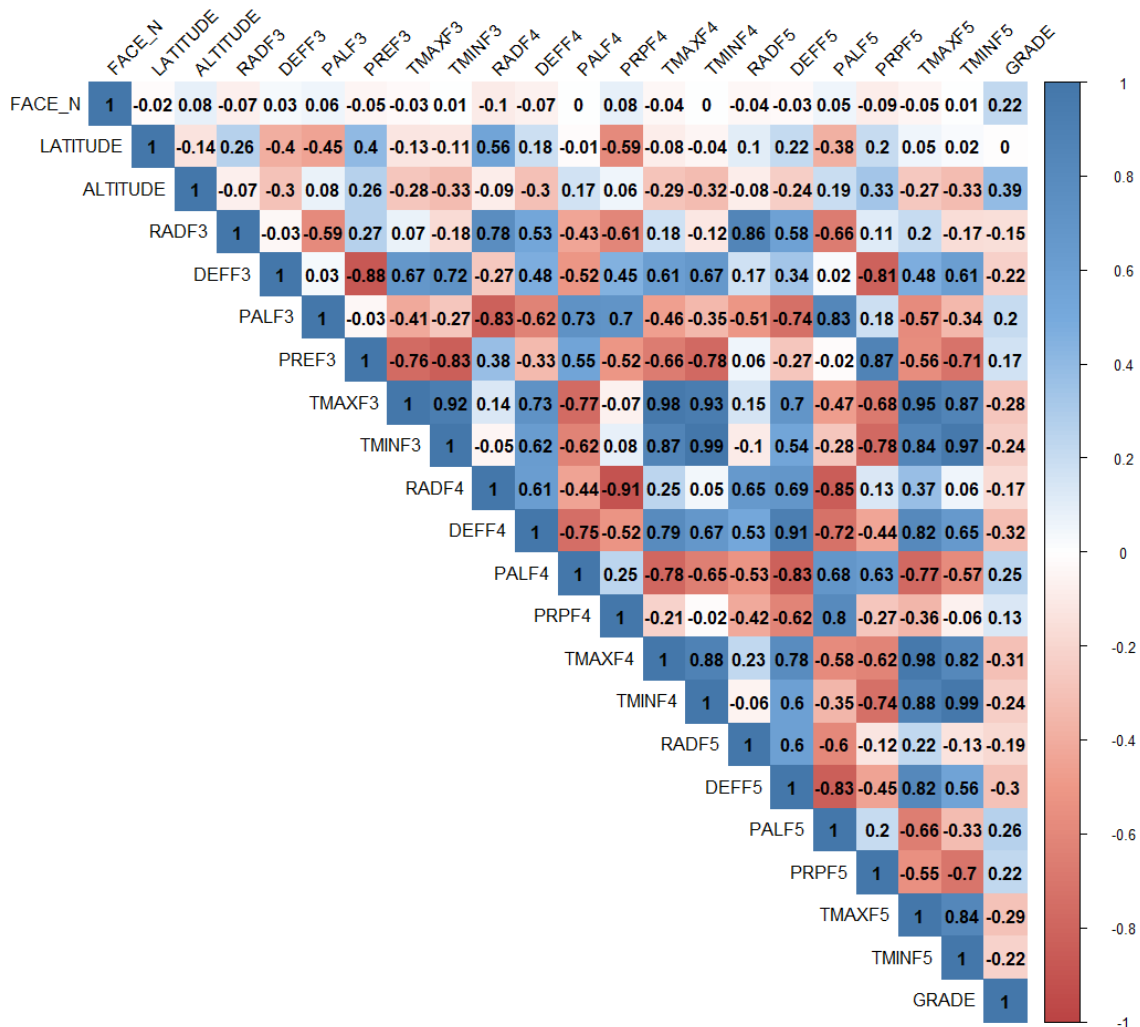
Each Main Component linearly combines the original variables, constructed to explain the maximum total variability of these initial variables that do not correlate. However, one of the most common problems in using multivariate statistical models is that they depend on the units and scales in which we gauged the variables (Morrison, 1976; Nathan and McMahon, 1990). Thus, the standard solution for this problem is the normalization of the data, i.e., the standardization with a mean equal to zero ($M = 0$) and variance equal to 1 ($s = 1$). Based on the normalized data, we constructed the correlation matrix [R] ($p \times p$) for “P” equal to 81 (maximum number of combinations). This matrix represents the basis for the transformation of orthogonal variables observed in factors, and this procedure was carried out automatically in the R software.

For the principal components analysis, the Jolliffe’s criterion (Jolliffe, 1972) was used, which discards the components whose variance is less than 0.7 ($\lambda \geq 0.7$).

3. Results

Through Figure 2, it is possible to observe the correlation matrix of all the variables considered in the present study.

Figure 2. Correlation matrix of variables (Pearson Correlation): FACE—the mountain slope towards the sun; LAT—latitude; ALT—altitude; RAD—radiation; DEF—deficit; PAL—Palmer index; PRP—precipitation; TMAX—maximum temperature; TMIN—minimum temperature; F3—flowering phase; F4—bean-set phase, and F5—phase of fruit ripening.



Source: Williams P. M. Ferreira (Elaboration).

No variable studied showed a high correlation with the “GRADE” (sensory quality of coffee) (Figure 2), thus validating the use of the multiple linear regression model and the principal components analysis. Because of the high collinearity among some variables, we excluded, for the best statistical adaptation of the models, those ones with the lowest Pearson correlation coefficient (r) concerning the “GRADE” achieved.

Table 3 presents the standardized coefficients (β) of the variables present in the construction of the multiple linear regression model.

Table 3. Statistics of the variables concerning the coffee quality we used on the multiple linear regression model.

Variables	β	Standard error	Tvalue	PVALUE
ALTITUDE	0.007	0.001	5.732	$2.19 \times 10^{-8}^{**}$
FACE	0.462	0.124	3.724	0.0002**
PALF3	3.260	1.277	2.553	0.0111*
DEFF4	-0.117	0.057	-2.035	0.0426*
PALF4	-4.382	2.161	-2.028	0.0433*
LATITUDE	1.060	0.798	1.328	0.1851
PRPF3	-0.144	0.113	-1.266	0.2063
PRPF5	0.064	0.051	1.259	0.2088
PRPF4	-0.053	0.043	-1.224	0.2216
TMINF5	3.705	3.088	1.200	0.2310
TMINF3	-4.356	3.747	-1.163	0.2457
TMAXF4	-2.616	2.344	-1.116	0.2651
RADF3	0.036	0.038	0.956	0.3397
TMAXF3	2.911	3.578	0.814	0.4163
PALF5	0.783	0.973	0.805	0.4216
DEFF3	0.063	0.090	0.701	0.4836
TMAXF5	-1.208	3.039	-0.397	0.6913
DEFF5	-0.024	0.091	-0.267	0.7896
TMINF4	0.973	4.171	0.233	0.8155
RADF4	0.011	0.054	0.220	0.8260
RADF5	0.001	0.049	0.021	0.9833
INTERCEPT	151.032	91.824	1.645	0.1009

* Statistical significance at 5%; ** Significant at 1% by Student's t-test; β –is the standardized regression coefficients (beta weight); FACE–the mountain slope towards the sun; RAD–radiation; DEF–deficit; PAL–Palmer index; PRP–precipitation; TMAX–maximum temperature; TMIN–minimum temperature; F3–Flowering phase; F4–Bean-set phase; F5– Fruit ripening phase; PVALUE–is the conditional probability or probability value of t-test for the significance of the coefficient and INTERCEPT–is the constant value of the linear regression equation or the expected mean value of Y when all X=0. Source: Authors.

Among all variables analyzed, those referring to temperature (TMIN F5, TMINF3, TMAXF4, TMAXF3, TMAXF5, and TMINF4) presented the highest standard error values, highlighting this element of the climate as the one that least contributes to the change of the model.

It was also observed that was low the PVALUE of the following variables: altitude; the mountain slope towards the sun - FACE; Palmer index during the Flowering phase - PALF3; water deficit on the Bean set phase - DEFF4 and the Palmer index during the Bean-set phase - PALF4. In this way, these variables have considerable impacts on the general regression model and are statistically significant, i.e., the regression coefficients were statistically different from zero at a significance level of values $\geq 5\%$, according to the Student test (t-test); therefore, the first five β coefficients were considered as the most important. It is also noticeable, though, that the climatic factors (statistically significant at the level of 0.1%) mountain slope towards the sun and altitude positively affect the quality of coffee, as observed by the values of β (0.462 and 0.007, respectively).

The Palmer index in the coffee Flowering phase (F3) had a positive relationship with the final grade of the beverage, being this the tested variable that presented the highest value of β (3.260) among those with the significance level above 5%. The water deficit and the Palmer index showed an inverse relation to coffee quality according to the β values (-0.117 and -4.382, respectively) in the Bean-set phase with values of β for variables with a significance level higher than 5%.

Results of the MLR model (Stepwise method) are presented in Table 4.

Table 4. Statistics values of the multiple linear regression model considering the Stepwise (backward) method of the variables associated with coffee quality.

Variables	β	Standard error	Tvalue	PVALUE
ALTITUDE	0.0080	0.0013	6.157	2×10^{-9} ***
FACE	0.4515	0.1217	3.708	0.00024***
TMINF5	60.312	16.528	3.649	0.00030***
TMINF3	-64.159	20.379	-3.148	0.00178***
DEFF4	-0.0808	0.0298	-2.709	0.00708***
PALF3	2.0319	0.8723	2.329	0.02041**
PRPF5	0.055	0.0263	2.091	0.03724**
LATITUDE	13.856	0.7504	1.847	0.06565*
PRPF3	-0.1322	0.0764	-1.729	0.08460*
PALF4	-2.3090	13.534	-1.706	0.08888*
RADF3	0.0523	0.0307	1.704	0.08920*
INTERCEPT	131.799	239.934	9.65	0.00040***

* Statistical significance at 10%; ** Significant at 5% and *** Significant to values $\leq 1\%$ by Student's t-test; β – is the standardized regression coefficients (beta weight); P_{VALUE} – is the conditional probability or probability value of t-test for significance of the coefficient; FACE - the mountain slope towards to the sun; RAD = radiation; DEF = deficit; PAL = Palmer index; PRP = precipitation; TMIN = minimum temperature; F3 = flowering phase; F4 = bean-set phase; F5 = phase of fruits ripening, and INTERCEPT – is the constant value of the linear regression equation, or the expected mean value of Y when all X=0. Source: Authors.

Precipitation in the Flowering phase (PRPF3), the minimum (TMINF3) temperature in the Flowering phase, the Water Deficit (DEFF4) in the Bean-set phase, and Palmer index (PALF4) in the Bean-set phase presented negative values of β , that means, statistically, considering the MLR model with the stepwise method, an inverse association to the coffee production potential with the top-quality beverage in the Matas de Minas region.

In the present study, the Principal Components Analysis (PCA) was also carried out to confirm, or refute, the results observed through the Multiple Linear Regression. In this way, we can see in Table 5 the two main components, PC1, and PC2.

Table 5. Result of the factorial and statistical loads of the principal component analysis (PCA).

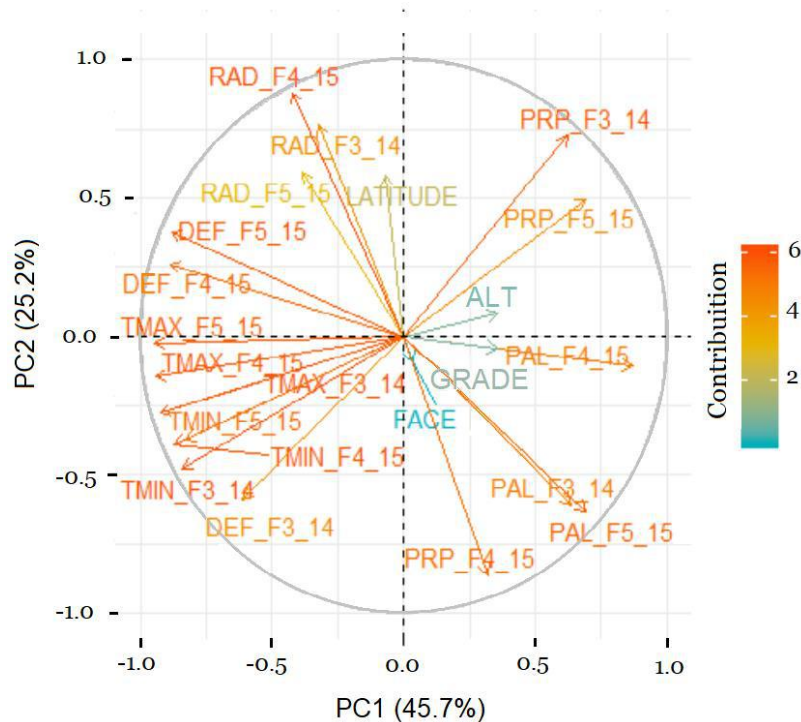
Variable	PC1	PC2
Standard deviation	3.17	2.35
Variation ratio	0.46	0.25
Cumulative ratio	0.46	0.71

PC1 - first principal component, and PC2 - second principal component. Source: Authors.

The first two Principal Components explained 71% of the total variation of the grade achieved for coffee produced in the Mata de Minas region. Thus, according to Jolliffe criterion, we deleted the other main components.

The relationship among all the variables considered in the present study (phenological periods, factors and elements of climate, and water indices) that are more associated with the grade achieved for the coffee beverage produced in the Mata de Minas region are showed in Figure 3.

Figure 3. Exploratory chart Biplot that shows environmental variables that contribute more to the potential for coffee production with the top-quality beverage in the Matas de Minas region.



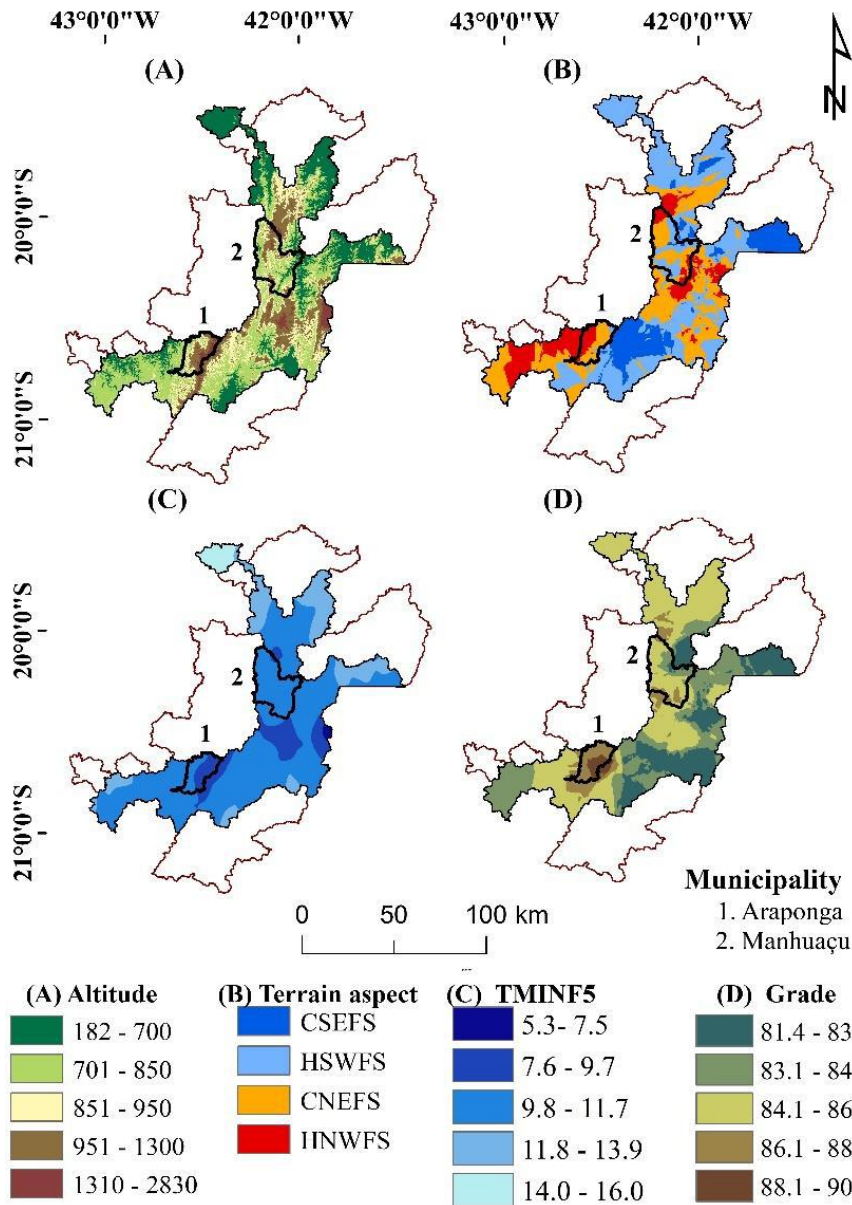
Source: Williams Pinto Marques Ferreira (Elaboration).

The first principal component (PC1), represented by the positive values of the ordinates and abscissae axes, is the main responsible for the high grades achieved for the coffees produced in the Matas de Minas region with the altitude (ALT) and the precipitation in the flowering phase (F3) in the year 2014, and Fruit ripening (F5) in 2015, representing, according to Camargo and Camargo (2001), the second phenological year of a coffee crop.

In the second quadrant (PC1=positive; PC2=negative) is the FACE climatic factor, the PAL water index in the three phenological phases tested (F3 in the year 2014, and F4 and F5 in 2015), and the PRP climatic element in the Bean-set phase in the year 2015 (PRPF4_15).

Based on Table 4, we constructed thematic maps (Figure 4) to define the grades of coffee quality produced at all 367 sampling points. Therefore, we considered only the three environmental variables with the highest significance ($PVALUE \geq 0.001$), which are: coffee quality values for the different altitudes, the mountain slope toward the sun (terrain aspect), and minimum temperature in the phase of fruit ripening.

Figure 4. Thematic maps of coffee quality produced at different altitudes (A), the mountain slope towards the sun (B) (*terrain aspects*: Colder southeast-facing slopes–CSEFS, Hotter southwest-facing slopes–HSWFS, Colder northeast-facing slopes–CNEFS and Hotter northwest-facing slopes–HNWFS), the minimum temperature in the phase of fruits ripening–TMINF5 (C) and the final grades of coffee beverage produced in the Matas de Minas region.



Source: Williams P. Marques Ferreira (Coordinator) Humberto Paiva Fonseca (Elaboration).

In Araçonga, the altitude varies between 701 and 1,300 meters (Figure 4A), with the predominant terrain aspect being the CNEFS and HNWFS (Figure 4B). In this municipality, when the minimum temperatures in the fruit ripening phase (Figure 4C) range from 7.6 to 9.7°C, coffee scores above 88 points were obtained.

At higher altitudes (Figure 4A), on the exposed faces of the CNEFS (Figure 4B) the highest coffee scores were obtained at lower temperatures (Figure 4C) for the municipality of Araçonga (Figure 4D).

4. Discussion

Considering that the calculated R^2 value in the model was 0.69, it means that the MLR model can explain 69% of the data variability.

We also used the MLR model with the Stepwise (backward) method, with an approximate R^2 result of 0.63, i.e., the group variation of all variables considered explained 63% of the coffee beverage quality. Except TMIN F5 (16.528), TMINF3 (20.379), and PALF4 (13.534), all other variables presented a standard error close to zero, a fact that, when associated with the other parameters, reveals that the fitting of the model had a good accuracy (Table 4).

Ferreira et al. (2016) observed, in a previously performed study, considering 14 municipalities in the same mountain region, that the simultaneous variation of climatic factors influenced the quality of the coffees of the northern portion of the Mata de Minas region. It was observed (Table 4) results similar to those of this author for the 26 municipalities studied, i.e., for all environmental variables analyzed, only those that reached significance degrees higher than 10% remain in the MLR model with the stepwise method. Thus, all variables not shown in Table 4 did not directly influence the final quality of the coffee beverages produced in the Matas de Minas region. However, among all variables analyzed, the climatic factor altitude stood out as one that most contributed to the final quality of beverages produced in the Matas de Minas region ($PVALUE \leq 0.0001$), a fact not observed by Ferreira et al. (2016).

Another aspect to consider for the altitude climate factor is that the value of β for this variable was 0.00807; so, for each increase of 100 meters at the altitude of the coffee plantation, there is an approximated increasing of 0.8 points in the final grade achieved for the coffee beverage, being this variation observed in the altitude range between 600 and 1,300 meters.

Mild temperatures increase the cycle between the phases of Flowering and Bean-set, increasing the potential for coffee production with a top-quality beverage (Ortolani et al., 2000). Considering the MLR model with the stepwise method, for every 0.1°C of minimum temperature that increases (which becomes more negative) in the Flowering phase (TMINF3), there is a decrease of 6.4 points in the final grade of the beverage ($\beta = -64,159$) (Table 4). Thus, it is desirable in phase F3 to have not-so-low average values of the minimum air temperature.

During the Bean-set phase (F4), both water indices analyzed (Water Deficit and Palmer index) were statistically significant for the MLR model ($PVALUE \leq 0.01$ and ≤ 0.1), presenting negative β values. This result means that the lower the water stress (becomes smaller the value) in this phenological phase of the coffee plant, the greater the potential for quality coffee production in the Mata de Minas region. Camargo and Camargo (2001) and Ortolani et al. (2000) got similar results, in which the authors related the lowest water stress with the increase in quality of the coffee fruits.

Also, it could be observed that, depending on the phenological phase, the Palmer index (PAL) presented different statistical associations with the final grade of coffee beverage (Table 4), which can be shown, through the values of β , that when in the flowering phase (F3) β is 2.0319 and, the bean-set phase (F4) β is -2.3090. We can relate the demand of the coffee plant with this since during the phenological cycle of the plant to start the flowering phase, there is a need to water shock (Camargo and Camargo, 2001), represented in the present study by β positive. To start the Bean-set phase, the constant precipitation rates are necessary (Meireles et al., 2004), represented here by the negative value of β .

The maturation of the coffee fruits and the quality of the coffee beverages have a high correlation with moderate precipitations indices (Oliveira Aparecido et al., 2018). This was also observed in the present study (Table 4), in which PRPF5 was significant in the MLR model ($PVALUE < 0.05$). In this way, there is a strong correlation between the moderate precipitation and the potential for coffee production with the top-quality beverage in the Matas de Minas region.

Concerning PCA (Figure 3), based on the biplot chart, we considered that all the variables correlated positively with the final coffee score (GRADE). We emphasize that among all considered, FACE was the one, based on the analysis of the PCA,

with the lowest contribution factor. Thus, these are the main variables associated with the grade of the beverage, being also observed in MLR (Table 4) that the altitude variable was the one that stood out in the production potential of top-quality coffee beverages in the Matas de Minas region. The other variables, especially those observed in the fourth quadrant (PC1 = negative; PC2 = positive), showed a negative correlation to the GRADE, thus negatively influencing the production potential of top-quality coffee beverages in the Matas de Minas region.

As seen in the MLR model, we can see in the third quadrant (PC1 = negative; PC2 = negative) that the water deficit in the flowering phase occurred in the year 2014 was negative for the production potential of top-quality coffee beverage in the Matas de Minas region. This result agrees with Ortolani et al. (2000) and Camargo and Camargo (2001), who found that a prolonged water deficit in the flowering is harmful to the plant and the coffee production potential with the top-quality beverage in the Matas de Minas region.

Araponga was the only municipality with scores above 88 points, that is, the highest scores for coffee beverages. All the municipalities analyzed showed a high coffee production potential with the top-quality beverage in the Matas de Minas region (grade higher than 81) (Figure 4D).

Colder southeast-facing slopes are the least recommended for achieving coffee scores above 80 points, and the best coffee scores in the region were obtained above 950m of altitude.

5. Conclusion

In the Bean-set phase, both water indices analyzed (Water Deficit and the Palmer Index) had a higher influence contributing to the potential for top-quality coffee beverage production in the Mata de Minas region.

The main climate factor that contributed to the coffee production potential with the top-quality beverage in the Matas de Minas region were the precipitation and the altitude associated with the mountain slope toward the sun.

The precipitation and the minimum temperature in the Flowering phase, as well as the water deficit and Palmer index during the Bean-set phase, all show inversely correlated with the production potential of coffee beverages with superior quality in the Matas de Minas region.

Acknowledgments

We performed this work in partnership with the Federal University of Vicosa (UFV) and the Agricultural Research Service of the Government of Minas Gerais State (EPAMIG). The authors wish to acknowledge the Embrapa Brazilian Coffee Research Consortium, National Coffee Research Center, and Brazilian Support Service for Micro and Small Businesses (SEBRAE/MG) for their support in performing this study.

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