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MOISTURE CONTENT AND ITS POSSIBLE EFFECT ON TEXTURAL PROPERTIES AND COLOR OF GREEN COFFEA ARABICA

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ABSTRACT

Consumption of coffee is still high, and consumers demand high-quality coffee. Quality of coffee is a complex term. Moisture content (mc), water activity (aw), textural features, and the color of green coffee are one of the many attributes of the quality. In the research, we focused on these parameters and analyzed 21 samples of green *Coffea arabica* from different locations in Central America. Our results proved that moisture content did not exceed 14% in any samples. However, some samples had slightly lower values of moisture content. Water activity ranged from 0.391 to 0.582. Pearson's correlation was fairly positive at 0.70 between mc and aw.

Regarding textural analysis, we focused on hardness and fracturability. In this case, we observed a low negative correlation between water activity and fracturability. This might suggest that the higher the aw (to a certain point), the lower the fracturability. The color parameter shows no significant difference, which might be caused due to the same post-harvest processing (wet processing), which is crucial for obtaining relatively same color quality despite different harvesting locations. Since coffee is a hygroscopic matrix, the results might have great use regarding storage and minimalizing textural changes and color concerning further roasting and grinding.

Keywords: Coffea, physico-chemical properties, water activity, quality, sensory

INTRODUCTION

Green coffee is a valuable commodity exported worldwide **(Cheng et al., 2016).** Nowadays, coffee is the second most traded commodity after petroleum, with an annual production of 158.930 million 60-kg jute bags of green coffee at a value of over US $5 billion (**Kulapichitr *et al*., 2022**). The term coffee quality represents three main attributes: physical quality, sensory quality (i.e., cup quality), and chemical quality, or their combination, respectively **(Sunarharum *et al.*, 2014).** High quality (sensory properties, chemical composition, and health safety) caused high demand from the customers' point of view; vice versa, high demand emphasizes the high quality of the product **(Cheng *et al*., 2016; Upadhyay and Rao 2013).**

The moisture content is a crucial quality characteristic because it might alter the shelf life of green coffee beans **(Caporaso *et al*., 2018; Wintgens 2009)**. The determination of moisture content of green coffee is significant to maintaining safe and error-free transport, export, and storage process and avoiding fungal development and growth. **Caporaso *et al*., (2018)** also stated that too dry or too wet green coffee beans would not reach or maintain their quality **(Wintgens, 2009).** Green coffee contains more than 14% of moisture. Possible development of bacteria, mold, yeast, or enzymatic activity will cause a dramatic change in cupping score, thus quality. For further processing, parchment moisture must be decreased below 12% after the harvesting. **(Pitia *et al*., 2007)**. However, less than 8-9% of moisture can cause shrinking or distortion, and coffee might appear as a low-quality product.

Our previous study proved that green coffees are considered a rich source of phenolic compounds **(Demianová *et al*., 2022)**. The same was concluded by **Kulapichitr *et al*., (2022)**; **Cheng *et al*., (2019),** and **Somporn *et al*., (2011)**. The authors mentioned above added that mainly chlorogenic acids, known as esters, formed from hydroxycinnamic and quinic acid, represent approx. 12% of coffee beans dry matter basis. The major classes of CGAs in coffee are the caffeoylquinic acids (CQA), feruloylquinic acids (FQA), and dicaffeoylquinic acids (di-CQA). These comprise 56–62% of the total content of chlorogenic acids obtained from coffee beans. Furthermore, they are recognized as compounds for enzymatic browning via polyphenol oxidase, which induces dark color formation in green coffee. Thus, it can affect color and flavor development in green and roasted coffee **Kulapichitr *et al*., (2022)**.

The textural characteristics of green and roasted coffee could be related to its quality **(Pitia *et al*., 2001)**. The same authors stated that overall mechanical properties depend on the cell structure, typical of various vegetables and fruits, or they may result from the physical state or porosity. On the other hand, one of the main factors that can fairly strong correlation with the mechanical properties of foods during processing and storage is the presence of plasticizers. In this case, water is the most significant. Some authors discovered the effect of moisture content and water activity on selected mechanical properties, such as certain foodstuff's hardness, toughness, and breaking force **(Pitia *et al*., 2001)**.

This study aimed to observe the textural properties and color of selected samples of *Coffea arabica* and their possible dependence on moisture content. Since coffee is known as a hygroscopic matrix, this information might have great use regarding storage and minimalizing textural changes and color concerning the roasting and grinding process, respectively.

MATERIAL AND METHODS

Material

Samples of green *Coffea arabica* were purchased from ORO Café Ltd. (Zvolen, Slovakia). The company focuses on importing and processing coffee from various well-known producers. To maintain an as homogenous group of samples as possible, we selected green coffee beans harvested in lowlands (<1200 mamsl), midlands (1200 – 1700 mamsl), and highlands (>1700 mamsl). Samples (n=21) originating from Central America (origin proved by the certificated), all samples were harvested during 2020, and next processed by ORO Café Ltd. and analyzed in 2022. Figure 1 shows the geographical distribution of analyzed samples and Table 1 describes the analyzed samples.

Methods

Moisture content determination and Water activity determination (aw)

Similarly, to **Caporaso *et al*. (2014)**, we used the standard oven method to determine moisture content. As in **Bobková *et al*., (2022)**. For the analysis, moisture analyzer KERN DAB 100-3 (KERN & SOHN GmbH, Balingen, Germany) was expressed in moisture percentage. The method is based on weight loss due to the heating process. Even-though that this loss might not represent only water, in coffee, the loss of other volatiles is insignificant if the internationally accepted method uses 105 °C for a maximum of 24 hours. Determination of water activity (aw) of coffee samples was performed using the Water Activity Meter Fast-Lab.

Table 1 Description of analyzed green coffee samples

Sample ID	Continent	Country	Post-harvest processing	Altitude location
1A	Central America	Costa Rica	washed	Midlands
2A	Central America	Costa Rica	washed	Highlands
3A	Central America	Guatemala	washed	Midlands
4A	Central America	Honduras	washed	Highlands
5A	Central America	Mexico	washed	Midlands
6A	Central America	Mexico	washed	Midlands
7A	Central America	Nicaragua	washed	Midlands
8A	Central America	Panama	washed	Midlands
9A	Central America	Guatemala	washed	Midlands
10A	Central America	Costa Rica	washed	Highlands
11A	Central America	Nicaragua	washed	Midlands
12A	Central America	Dominican Republic	washed	Lowlands
13A	Central America	Cuba	washed	Lowlands
14A	Central America	Guatemala	washed	Midlands
15A	Central America	Honduras	washed	Highlands
16A	Central America	Nicaragua	washed	Midlands
17A	Central America	Mexico	washed	Midlands
18A	Central America	Costa Rica	washed	Highlands
19A	Central America	Nicaragua	washed	Lowlands
20A	Central America	El Salvador	washed	Midlands
21A	Central America	Guatemala	washed	Highlands

Figure 1 Geographical distribution of analyzed samples

Textural analysis

As in **Bagheri *et al.*, 2019,** for textural analysis, we used TA.XT plus Texture Analyzer (Stable Micro Systems, Great Britain) and the Warner-Bratzler knife probe. We analyzed each sample in 10 repetitions to determine the average hardness and fracturability. During penetration, the probe completely cut through the sample, while the maximum developed weight necessary to destroy the sample was recorded. Conditions of textural analysis are shown in Table 2.

The principle evaluates textural properties by recording the strength, distance, and time of data at high speed, which is then evaluated with the help of the integrated Exponent system. The results were measured and processed using the software Exponent. The sample size influences the speed, so the products can be tested at a constant strain rate in tension or compression.

The principal collected textural characteristics were hardness and fracturability. **Paula and DeSilva (2014)** defined hardness as "force applied by the molar teeth to compress the food" and fracturability as the "ability to break food into pieces when it is bitten using the incisors."

Table 2 Conditions used in the textural analysis

Condition	Preset
Speed of probe movement before penetration	5 mm.s^{-1}
Speed of probe movement during penetration	3 mm.s^{-1}
Speed of probe movement after penetration	10 mm.s^{-1}
Depth of penetration of the probe into the sample	20 mm
Capacity of strain gauge	50 kg

Color measurement

Analysis was performed according to **Jurčaga *et al.*, (2021)** and **Sudaryanto *et al.*, (2020)**. Before the analysis, samples were homogenized using Grindomix (GM 200; Retsch GmbH, Germany) for 120 s at 10 000 rpm. We measured color using a spectrophotometer (Konica Minolta CM-2600d, Osaka, Japan) with the setting Specular Component Included (SCI) and D65 light source and a 10° observer, with a port 8 mm in diameter. The white plate calibration was performed at 23 °C, according to the manufacturer's recommendation. The results represent coordinates in the color interface of CIELab. These values were used in various research, including **Bicho *et al.*, (2014)**, to assess the quality of Coffea arabica's green beans. **Sudaryanto *et al.*, (2020)** stated that these values describe qualities of visual sensation, i.e., tonality, luminosity, and chromatism. Tonality is defined as characteristics of the color (red, yellow, green, and blue). Coordinate L* represents the clarity (L=0 is black, and L*= 100 is colorless). Coordinate a* represents the shade of red and green, in which a*> 0 indicates the red color and a*< 0 means green. Coordinate b* represents the tone of blue and yellow, in which b*> 0 shows the intensity of yellow and b*< 0 indicates the hue of blue.

Statistical analysis

ANOVA, Duncan test, and REGWQ were used to identify significant differences within selected green coffee samples. Statistical analyses were performed using Microsoft Office Excel 365 for iOS and Addinsoft 2022, XLSTAT statistical and data analysis solution, New York, USA. Pearson's correlation was performed using RStudio for iOS from RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, Massachusetts.

RESULTS AND DISCUSSION

Moisture content and water activity (aw) determination

De Bruyn *et al.*, (2017) stated that post-harvest processing is crucial to maintain high quality and cupping scores. This chain contains linked steps focused on removing cherries' mucilage and drying to a moisture level of approximately 10 to 12% (mass/mass). **Waters *et al.*, (2015)** added that the essential quality of green coffee beans is affected by agricultural and farm practices, and vice-versa depending on plant cultivar, geography, weather conditions, and available infrastructure. **Caporaso *et al.*, (2018)** described that green coffee beans of *C. arabica* contain natural moisture, approx. 10.8%. The same authors added that beans must be stored in a proper environment, i.e., proper packaging, and humidity conditions, to reduce the risk of quality drop, or microbiological activity, which eventually can alter organoleptic properties or health. However, our samples of green coffee beans reached an average of 8.40% of moisture content. The highest abundance of moisture was obtained in sample from Mexico, 9.59%, Nicaragua 9.43%, Mexico 9.30, and Nicaragua 9.20%. On the contrary, the lowest in the sample from Costa Rica, 6.28%, and Dominican Republic coffee 7.34%. ANOVA Duncan and REGWQ test proved no significant difference ($p \leq 0.05$) regarding the moisture content of our samples, which might be caused due to same species, similarity in growing areas and altitudes (midlands), and the same post-harvest processing.

Another essential parameter connected with the moisture content is water activity (aw). Aw is defined as the amount of free water, i.e., unbound and thus available to microorganisms for growing and spreading. Therefore, it is vital for food safety and health. According to **Maneffa *et al.*, (2017)**, "the water activity (aw) of a food is the ratio between the vapor pressure of the food itself, when in a completely undisturbed balance with the surrounding air media, and the vapor pressure of distilled water under identical conditions". **Pittia *et al.*, (2007)** stated that unroasted coffee reached an average of 0.523. Our samples reached an almost identical value, 0.508. The lowest aw was detected within coffee from Costa Rica, 0.39. However, the highest in another sample is from Costa Rica, 0.582, and Honduras, 0.572. The same origin proved that post-harvest handling and farm processing is crucial for further steps in processing green beans. Even in this case, ANOVA did not prove any significant difference between samples ($p \leq 0.05$).

Based on Figure 2 and the main definitions of previously mentioned characteristics, it is possible to assume a linear correlation between aw and moisture content. The correlation test estimated Pearson's correlation coefficient at 0.70, representing a fairly strong positive correlation among selected characteristics. Samples from Nicaragua, Mexico, Guatemala, Costa Rica, and Honduras showed the highest correlation.

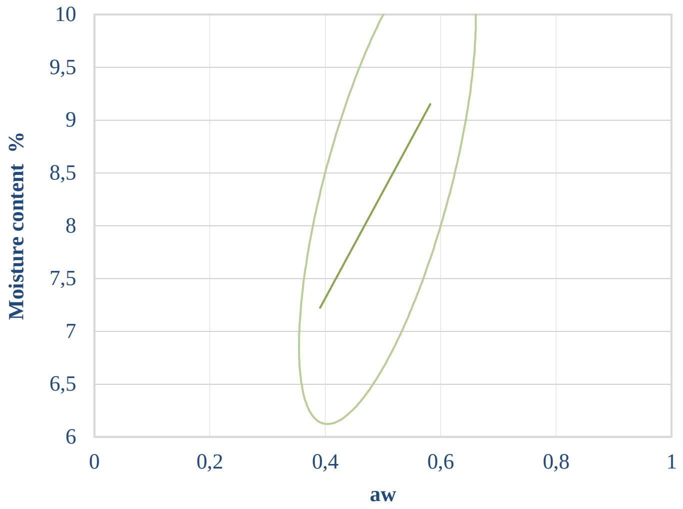


Figure 2 Distribution of samples in 2D space representing the correlation of moisture and water activity in green coffee beans

Textural Analysis

Textural profiling is an objective method of coffee assessment. We focused mainly on two parameters - hardness and fracturability of green beans. The former represents the force the molar teeth apply to compress the food and later the ability to break food into pieces using incisors. Samples were tested in 10 deformation cycles, and present values represent the average.

Only a few studies deal with the textural properties of green beans. However, green coffee is known for its dense structure. On the other hand-roasted beans are considered more fragile. The process of roasting is a crucial point in coffee processing. Heat treatments usually reach temperatures roughly around 200–250 °C. The reaction causes changes in green beans' chemical, chemical-physical, physical, and structural properties. These changes determine different organoleptic and textural properties of roasted beans and thus beverages **(Pitia *et al*., 2007). Sudaryanto *et al*., (2020)** proved that the hardness of the green bean could alter further processing, i.e., roasting, given that the higher hardness of the green bean, the longer time and the more energy for the process is required.

The average hardness of our green beans from Central America reached 106848.32 g. The highest values were measured in Costa Rica (10A), harvested in 1200 mamsl. The highest hardness was observed in the Nicaragua (19A) sample harvested in 1300 mamsl. Relatively high hardness was observed in samples from Nicaragua (16A), on average, 130587.39 g and Guatemala (21A) harvested from 1500 to 2000 mamsl. Among our samples, we observed a trend that the lower the altitude of harvesting was, the lower values of bean hardness were measured. Sample 10A from Cuba, harvested in 1000 mamsl reached the hardness averagely of 89615.25g, or sample 2A from Costa Rica, harvested in around 1100 mamsl, reached only 83178.60g. However, a few exceptions did not follow this trend, such as sample 20A from El Salvador, harvested in only 1250 mamsl with the hardness of 114718.10g, or sample 4A from Honduras, harvested in approx. 1400 mamsl reached 95325.11g. These values might suggest a trend between environmental factors – altitude and beans' hardness. However, more samples with detailed altitude descriptions suitable for the textural analysis are required to prove this statement.

Fracturability ranged from 30784.24 to 51322.48 g. The highest reached sample was from Nicaragua (16A), and the lowest sample was from Honduras (4A). **Sudaryanto *et al*., (2020)** proved that the fracturability of beans can be affected by the post-harvest processing, but not significantly. Authors further stated that wet post-harvest processing tends to reach higher fracturability than natural (dry) or honey beans. Results of the textural analysis are shown in the following table (Table 2)

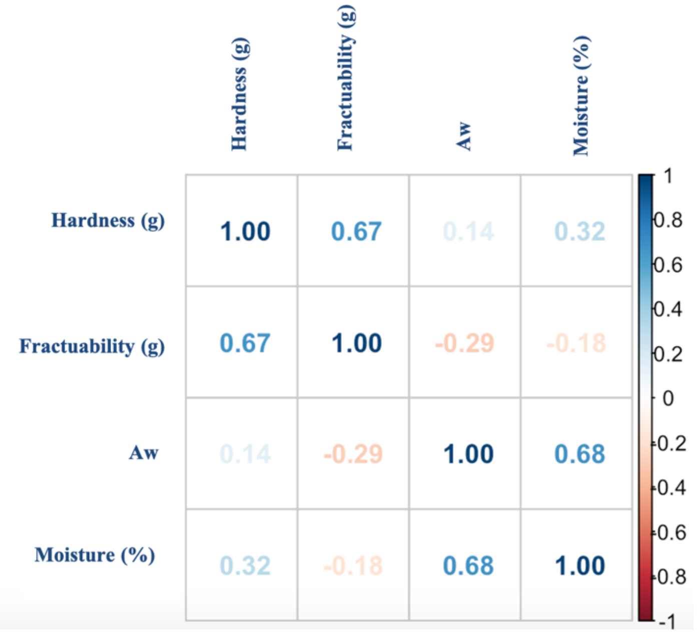
Table 2 Average values of hardness and fracturability of green beans from Central America

Batch ID	Hardness (g)	Fracturability (g)	Batch ID	Hardness (g)	Fracturability (g)	Batch ID	Hardness (g)	Fracturability (g)
1A	119942.81	40530.74	**8A**	102502.0	49759.97	**15A**	99023.99	36608.36
2A	83178.6	38619.91	**9A**	109694.8	49160.26	**16A**	130587.39	51322.48
3A	103088.2	42356.16	**10A**	77324.8	39046.83	**17A**	111027.7	40608.12
4A	95325.11	30784.24	**11A**	117581.81	39411.85	**18A**	105102.57	41471.64
5A	103838.31	39365.81	**12A**	104640.83	42408.43	**19A**	138284.78	48863.41
6A	113747.42	43941.61	**13A**	81528.91	35790.11	**20A**	114718.1	48235.35
7A	112594.48	38823.11	**14A**	89615.25	36989.8	**21A**	130466.86	44450.64

Estrada-Bahena et al., (2021) stated that the value of water activity could significantly affect the color and texture of the green beans due to fungal growth. In coffee beans, water acts as both an anti-plasticizer and plasticizer, depending on the hydration state **(Pitia *et al*., 2007).** The same authors stated that green coffee's textural characteristic strictly depends on water activity. Above the value of 0.538 to 0.760, water acts as a plasticizer, meaning that fracture force, energy, and strain decrease. Thus, it is possible to presume decreasing fracturability with increasing aw. Our results proved a slightly negative correlation between these characteristics (Figure 3). Within our analyzed beans, samples 1A, 2A, 3A, 4A, 5A, 6A, 7A, 11A, 17A, and 18A reached higher water activity than 0.538. These samples reached lower values of fracturability, 39591.32g on average. On the other hand, samples with lower water activity than 0.538 tend to reach higher fracturability, 43875.97 g on average.

Color Analysis

Color is the quality factor for drying process optimization **(Dong *et al*., 2017; Kulapichitr *et al*., 2022)**. Therefore, CIE-LAB parameters might be a helpful tool for observing coffee color quality regarding the drying process or moisture content. We observed no significant differences in our samples regarding L, a*, and b* ($p \leq 0.05$). However, performed dendrogram showed groups of samples similar to each other based on these tree parameters (Figure 4). According to the statistical analysis, samples were from Guatemala (3A), Honduras (4A), Nicaragua (7A), Panama (8A), and Guatemala (9A). Costa Rica (10A), Dominica Republic (12A), Honduras (15A), Nicaragua (16A), El Salvador (20A), and Guatemala (21) created one group and samples. Costa Rica (1A), Costa Rica (2A), Mexico (5A), Nicaragua (11A), Cuba (13A), Guatemala (14A), Costa Rica (18A), and Nicaragua (19A) created another group different from the rest of the sample set. These results suggest that despite different geographical origins, the color parameter shows no significant difference, which might be caused due to the same post-harvest processing (wet processing), which is crucial for obtaining relatively same color quality despite the different locations of harvesting.



	Hardness (g)	Fractuability (g)	Aw	Moisture (%)
Hardness (g)	1.00	0.67	0.14	0.32
Fractuability (g)	0.67	1.00	-0.29	-0.18
Aw	0.14	-0.29	1.00	0.68
Moisture (%)	0.32	-0.18	0.68	1.00

Figure 3 Pearson's correlation between analyzed parameters

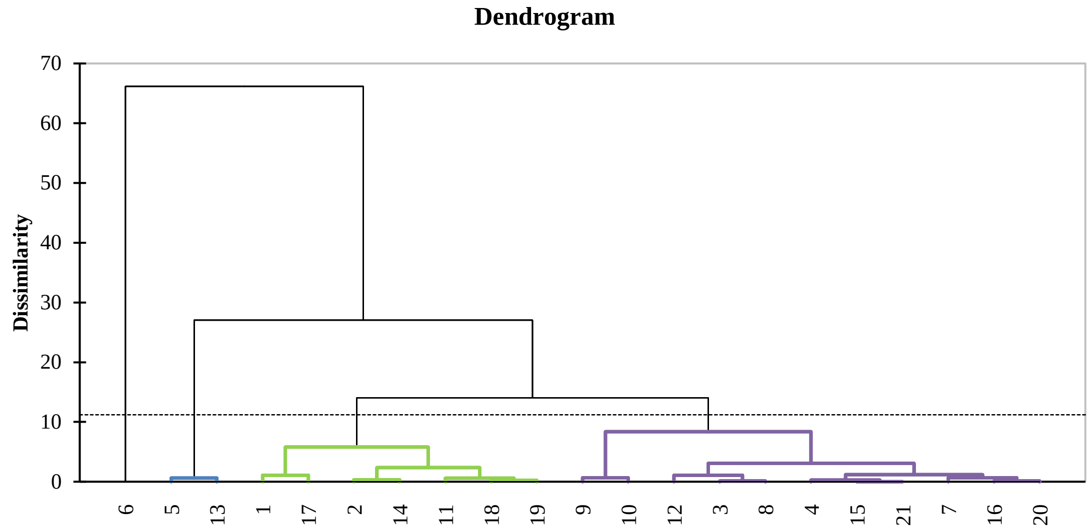


Figure 4 Dendrogram of dissimilarities between samples based on color analysis

Sudaryanto *et al*., (2020) stated that specific changes in luminosity depend on post-harvest processing. However, not significant. They measured the average luminosity in wet-processed coffee at 46.44. Our samples are not in accordance with these values due to our average value being 70.14. Results are shown in Table 3.

Table 3 Results of color analysis of green coffee beans

Batch ID	L*	a*	b*	Batch ID	L*	a*	b*	Batch ID	L*	a*	b*
1	69,94	4,23	24,28	**8**	70,22	0,66	21,85	**15**	70,97	1,88	22,68
2	70,29	1,34	24,04	**9**	72,25	1,38	21,93	**16**	70,1	1,5	22,54
3	70,7	0,71	21,97	**10**	72,92	2,05	21,28	**17**	70,15	3,16	23,29
4	70,63	2,33	22,63	**11**	71,24	2,47	23,96	**18**	71,59	2,11	23,44
5	67,49	2,44	23,23	**12**	69,95	1,58	21,17	**19**	72,16	2,34	23,11
6	63,7	0,83	18,09	**13**	66,74	2,81	23,96	**20**	70,52	1,36	22,43
7	69,67	2,15	22,26	**14**	70,66	1,95	23,64	**21**	71,03	1,78	22,69

To better understand the relationship between moisture content, water activity, and color, we subjected the dataset to Pearson's correlation (Figure 5). Results suggest a small negative correlation between moisture and water activity and luminosity (L*) of analyzed samples.

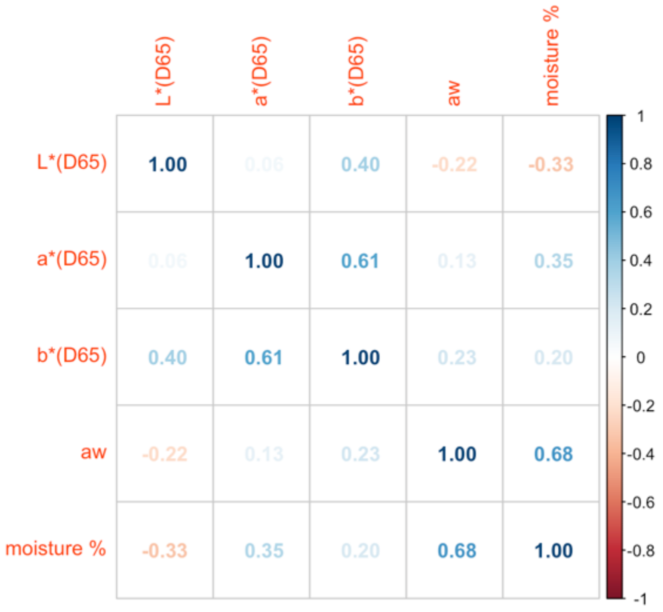


Figure 5 Pearson's correlation of measured color parameters

CONCLUSION

Performed analyses suggest a fairly strong positive relationship between water activity and moisture content of green *Coffea arabica*. Pearson's coefficient reached the value of 0.68. The texture of coffee is the essential quality factor that might affect further processing (e.g., roasting and grinding). Our results suggest that the beans' hardness might depend on the harvesting sites' altitude. We observed that samples harvested in higher altitudes tend to reach higher hardness values. However, more samples with the accurate altitude and longitude coordinates are needed to prove this statement.

Nevertheless, we observed a relationship between moisture content and water activity, which is vital regarding both hardness and fracturability. Previous research from other authors suggests that water behave as both anti-plasticizer and plasticizer, depending on the water activity value, where the critical value is between 0.538 to 0.760 for green coffee. After reaching this interval, water behaves as a plasticizer. Thus, a small negative correlation between aw and fracturability was observed within samples with aw in this interval. These results suggest that despite different geographical origins, the color parameter shows no significant difference, which might be caused due to the same post-harvest processing (wet processing), which is crucial for obtaining relatively same color quality despite the different locations of harvesting. Pearson's correlation suggests only a small negative correlation between moisture, water activity, and luminosity (L*).

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