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OPENING MESSAGE

It is with great satisfaction that we present the proceedings of Vila Café – International Edition 2026, held in Patos de Minas, Minas Gerais, Brazil, from May 14 to 17, 2026.

Vila Café International – Patos de Minas Edition 2026 was conceived with the purpose of promoting the integration of science, technology, and culture within the context of coffee production, connecting high-quality scientific research with the dissemination of knowledge about specialty coffees. The event brought together researchers, undergraduate and graduate students, coffee producers, baristas, entrepreneurs, and members of the community to share innovative, sustainable, and high-value practices for the coffee sector.

This edition received 33 scientific papers from different national and international institutions, involving researchers from four Brazilian states and participants from several countries, further strengthening the interdisciplinary and international nature of the event. The papers were organized into five thematic areas: Coffee Quality, Coffee and Health, Coffee Postharvest, Coffee Plants and Crop Management, and Coffee Technology. These areas encompassed studies related to sensory analysis, processing, fermentation, drying, storage, sustainable management practices, crop science, artificial intelligence, remote sensing, health, and technological innovation applied to coffee production.

The scientific program included short courses, lectures, roundtable discussions, poster presentations, and oral presentations conducted through pitch sessions featuring the most outstanding works presented at the event. Among the highlights were international short courses focused on plant metabolomics, food science, and coffee quality, delivered by renowned researchers such as Monica Cala (Universidad de los Andes), Erica Liberto (University of Turin), and Alan César Pilon (São Paulo State University – UNESP).

In addition to its academic activities, the event promoted extension and community engagement initiatives, including guided coffee tastings with renowned producers and baristas, institutional presentations, discussion forums, and a technical visit along the Coffee Route, featuring Dom Parrillo Roastery and Fazenda Chuá. These activities provided participants with valuable opportunities to connect scientific knowledge with the practical and technological realities of coffee production.

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The event also counted on the participation of important educational, research, and innovation institutions, including the Federal University of Uberlândia, Federal University of Lavras, Federal University of Viçosa, Federal Rural University of Rio de Janeiro, São Paulo State University, and Centro Universitário de Patos de Minas, reinforcing scientific cooperation and knowledge exchange among universities, the productive sector, and society.

As a means of recognizing scientific excellence, awards were presented to the best works in both the poster and oral pitch categories, acknowledging the relevance and quality of the research conducted by the participants. The papers compiled in these proceedings reflect the commitment of the academic and professional communities to advancing science, innovation, and sustainability in coffee production. The contributions presented herein reinforce the importance of scientific research and interdisciplinary collaboration for strengthening the coffee sector and promoting the appreciation of specialty coffee value chains.

The Scientific Committee extends its sincere gratitude to all authors, reviewers, speakers, sponsors, partners, and participants whose dedication and support contributed to the success of this edition of the event.

We wish all readers an enjoyable and enriching reading experience.

Scientific Committee

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UNTARGETED METABOLOMICS OF GREEN COFFEE BEANS (COFFEA ARABICA): IDENTIFICATION OF CHEMICAL MARKERS FOR THE DISTINCTION OF SENSORY QUALITY CLASSES

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ABSTRACT: Distinguishing commodity from specialty coffees requires analytical methods that complement sensory evaluation by identifying objective chemical markers. The objective of this study was to investigate the metabolic profile of green Coffea arabica beans and identify discriminant metabolites across different beverage quality classes. A total of 20 samples (4 quality classes in quintuplicate) from the same cultivar were analyzed, all from the 2024 harvest (Patrocínio, Minas Gerais, Brazil), covering the Official Brazilian Classification (COB) categories: Riada (Rioy), Duro (Hard), Mole (Soft), and Estritamente Mole (Strictly Soft). Untargeted metabolomics was performed using gas chromatography-mass spectrometry (GC-MS) following silylation derivatization. Data were processed using MS-DIAL, followed by multivariate statistical analyses (PCA and PLS-DA) in MetaboAnalyst 6.0. The results revealed a clear chemical distinction between lower sensory quality samples (Riada) and the higher-quality classes (Hard, Soft, and Strictly Soft). Sucrose emerged as the primary biomarker candidate for higher-quality coffees (VIP = 1.8; PLS-DA: R^2=0.9438; Q^2=0.5546). Although sucrose is not a reducing sugar, its thermal hydrolysis during roasting releases glucose and fructose, which act as essential precursors for the Maillard reaction, directly influencing the sweetness and aroma of the beverage. In contrast, Riada samples showed higher levels of stearic and oleic acids. It is suggested that the accumulation of these fatty acids may be related to early degradative processes or changes in the cellular integrity of lower-quality beans, though the oxidative stability of these compounds warrants further study regarding the specific lipid degradation pathways involved. Overall, the metabolomic approach enabled the discrimination of coffee samples into two major quality groups and validated chemical markers that assist in the objective assessment of high sensory quality coffees.

Keywords: *Arabica coffee; Untageted metabolomics; GC-MS; Chemical marker.*

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THERMOKINETIC OPTIMIZATION OF BIOACTIVE EXTRACTION IN SPECIALTY GREEN COFFEE: EFFECT OF TIME AND TEMPERATURE

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ABSTRACT: Green coffee beans are recognized as a primary source of bioactive phenolic compounds, particularly chlorogenic acids, which possess antioxidant properties highly valued in the pharmaceutical and food industries. This study aimed to optimize the thermokinetic parameters for extracting these compounds from specialty green coffee produced in the Cerrado Mineiro region. Aqueous extractions were conducted using a fixed 1:10 (w:v) ratio under constant agitation (150 rpm). The experimental design evaluated the influence of temperature (40, 50, 60, and 70°C) and contact time (ranging from 10 to 120 minutes). Total phenolic content (TPC) was quantified via the Folin-Ciocalteu method, while antioxidant capacity was determined through ABTS and DPPH assays, all performed in triplicate. Statistical analysis revealed that both variables significantly impacted extraction yield ($p < 0.05$). The most efficient condition was identified at 70°C for 60 minutes, yielding a TPC of 153.55 mg GAE/g—a remarkable 210% increase compared to the initial 10-minute yield at the same temperature (49.82 mg GAE/g). Correspondingly, antioxidant activity reached its peak at 70°C/60 min, with 85.60 µmol TE/g for ABTS and a potent of 0.17 mg/mL for DPPH. Pearson correlations demonstrated a strong relationship between TPC and antioxidant power ($r = 0.94$ for ABTS; $r = -0.92$ for DPPH), confirming that phenolic concentration is a primary driver of the extract's biological activity. The kinetic data showed that the process reached a plateau at 60 minutes; extending the extraction to 120 minutes resulted in marginal gains of less than 3%, indicating mass transfer equilibrium. Furthermore, temperatures below 50°C were insufficient for optimal recovery, showing significant statistical differences ($p < 0.05$) when compared to higher temperatures. In conclusion, the extraction of bioactives in specialty green coffee is thermodynamically favored at 70°C, where higher kinetic energy enhances solute solubility and diffusion. The 70°C/60 min parameters provide an ideal balance between maximum antioxidant recovery and operational cost-effectiveness, preventing unnecessary energy consumption while ensuring high-quality extracts.

Keywords: *Antioxidants; Phenolic compounds; Yield.*

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SELF-INDUCED ANAEROBIC FERMENTATION (SIAF) AS A STRATEGY TO ENHANCE THE SENSORY QUALITY OF PARAÍSO MG2 COFFEE

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ABSTRACT: During the Self-Induced Anaerobic Fermentation (SIAF) process, coffee fruits are subjected to controlled conditions that favor the activity of naturally occurring endophytic microorganisms. These microorganisms play a fundamental role in the metabolic transformation of the substrate, promoting the production and accumulation of bioactive and volatile compounds. As a result, modifications occur in the chemical profile of the beans, directly reflecting changes in sensory attributes and contributing to a differentiated flavor profile in the final beverage. In this context, the present study aimed to evaluate the effect of fermentation on the sensory profile of coffee from the Paraíso MG2 variety, produced at Londrina Farm, located in Coromandel, Minas Gerais, Brazil. The evaluation was carried out by comparing a control sample (without fermentation) and a sample subjected to 72 hours of fermentation. The fruits were processed under controlled conditions using the SIAF method, conducted in a solid-state system, with temperature maintained at 27 °C throughout the fermentation period. Sensory analysis was performed according to the protocol of the Specialty Coffee Association (SCA), with the participation of five Q-graders. For each sample, three cups were prepared, as recommended by the protocol, and the evaluations were conducted independently in order to verify the consistency of sensory attributes across replicates. The results showed that the control coffee presented an average score of 82.60 ± 0.73 points, while the fermented sample reached 86.50 ± 0.97 points. These findings indicate that the fermentation process was effective in improving the sensory quality of the beverage. According to the literature, controlled fermentation enhances the metabolic activity of naturally occurring microorganisms in coffee, increasing the production of volatile compounds and aroma precursors. These compounds are directly associated with greater sensory complexity and overall beverage quality. Therefore, it can be concluded that controlled fermentation has the potential to improve the sensory quality of coffee, promoting enhancements in the final beverage. A coffee initially scoring 82.60 ± 0.73 points can achieve higher scores after fermentation, adding greater sensory complexity and value to the product. Thus, the application of appropriate fermentration techniques represets a promising strategy for the economic valorization of coffee.

Keywords: *Sensorial; SCA; Q-Graders*

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LINKING CHEMISTRY AND FLAVOR IN FERMENTED SPECIALTY COFFEE

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ABSTRACT: Global consumption of specialty coffee has grown significantly in recent years, driven by demand for higher-quality beverages with distinctive sensory attributes. Fermentation processes have gained attention for their ability to enhance these characteristics, as the composition of sugars and organic acids is modified during fermentation, contributing to more complex aroma and flavor profiles. However, establishing clear relationships between these compounds and specific sensory descriptors is still challenging. So, this study aims to relate the compounds variations during fermentation to the sensory descriptors observed in fermented specialty coffee. Catucaí 2SL variety coffee was harvested and subjected to dry fermentation at 120 h under different fruit conditions (peeled cherry, cherry, or floaters) to investigate the influence of processing conditions on sugar and acid concentrations. These compounds were quantified using high performance liquid chromatography (HPLC), using Supelcogel C610H column, employing a mobile phase of phosphoric acid at 0.1% and a photodiode array detector (PDA) at 210 mn for organic acids and a refractive index detector (RID) for sugar and alcohols. For sensory evaluation, the specialty coffee samples were dried and roasted to a medium level, and five certified Q-graders tasted them following the cupping protocol established by the Specialty Coffee Association (SCA). The highest sensory scores (86.4 and 85.9, respectively) were observed for coffee produced from floaters and cherry fruit conditions, compared to peeled cherry (83.0). These higher-scoring samples showed elevated levels of lactic acid (18.0 and 29.3 mg/g fruit coffee) and fructose (43.8 and 42.1 mg/g fruit coffee), in contrast to peeled cherry coffees (5.6 mg/g lactic acid and 6.3 mg/g fructose). The superior sensory performance of floaters and cherry samples may be associated with these higher concentrations, as fructose has been linked in the literature to fruity, floral, and caramel descriptors, while lactic acid is commonly associated with caramel, fruity, and chocolate notes. These descriptors were clearly observed in the highest-scoring samples (floaters and cherry), whereas peeled cherry coffees presented less well-defined sensory attributes, although they still achieved scores above 80 and are therefore considered specialty coffee. In this way, well-controlled fermentation can result in high-scoring and distinctive specialty coffees, supported by compound transformations and clearly defined sensory descriptors. Notably, floaters typically considered defective fruits and usually removed to avoid negative impacts on beverage quality, especially in specialty coffee, may represent an opportunity for value addition when properly managed under controlled fermentation conditions.

Keywords: *Specialty coffee; Fermentation; Sensory attributes.*

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UNRAVELING METABOLIC PATHWAYS IN COFFEE FERMENTATION THROUGH MULTIVARIATE STATISTICAL ANALYSIS

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ABSTRACT: Coffee cultivation plays a strategic role in both global and regional economies, contributing significantly to income generation, employment, and socioeconomic development in producing regions. At the same time, consumer preferences have shifted toward higher sensory quality standards and greater transparency regarding origin and processing, driving the increasing importance of traceability within the coffee value chain. In this context, fermentation has emerged as a promising biotechnological tool for modulating sensory attributes through microbial activity and metabolic pathways. However, the integrated understanding of the biochemical routes involved, particularly those related to the conversion of sugars and organic acids, remains limited in complex fermentation systems. This study aimed to evaluate the dynamics of metabolic pathways associated with alcoholic fermentation and organic acid production in coffee subjected to self-induced anaerobic fermentation. Peeled cherry coffee beans (CD), cultivar Catuaí, harvest 2023, were fermented in 200 L bioreactors inoculated with Saccharomyces cerevisiae for 24, 48, and 72 hours. Metabolite characterization was performed using high-performance liquid chromatography (HPLC). Data were analyzed using Welch's ANOVA followed by Games-Howell ($p \leq 0.05$), as well as linear regression, Pearson correlation, and principal component analysis (PCA). Fermentation time was the primary factor modulating metabolic profiles, significantly influencing ethanol production ($p < 0.05$) and lactic acid accumulation ($p < 0.01$), reflecting the process's kinetic nature. The lack of a significant isolated effect of sugars in regression models is associated with high collinearity with time, a characteristic of dynamic systems in which substrate consumption and product formation occur interdependently. Correlation analysis showed no significant association between glucose and ethanol ($r = 0.025$; $p > 0.05$), while a positive correlation between malic and lactic acids ($r = 0.779$; $p < 0.01$) suggests that lactic acid production is not exclusively driven by malolactic fermentation, but also by parallel metabolic pathways. The positive association between ethanol and lactic acid ($r = 0.731$; $p < 0.01$) indicates the simultaneous occurrence of fermentative processes. PCA explained 86.3% of the total variance, with the first component associated with overall fermentation intensity and the second with glycolytic conversion, as evidenced by the opposing relationship between glucose and ethanol. The lack of a difference between malic and lactic acids indicates that malolactic fermentation is not predominant. These findings demonstrate that coffee fermentation is governed by an integrated metabolic network, highlighting the need for multivariate approaches to understand and optimize these processes.

Keywords: *Metabolic pathways; Multivariate analysis; Organic acids.*

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EFFECT OF COFFEE EXTRACT CONCENTRATION ON THE PHYSICOCHEMICAL PROPERTIES AND YIELD IN INSTANT COFFEE PROCESSING

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ABSTRACT: The growing interest in specialty coffees has spurred research aimed at understanding the factors that influence their sensory quality and processing efficiency. These coffees, prized for attributes such as aroma, acidity and complexity, require greater control over the production stages to ensure standardisation and industrial performance. In this context, the study of the variables involved in the production of instant coffee, particularly extract concentration, is relevant both for the industry and for the value of the final product. The objective of this study was to evaluate the influence of coffee extract concentration, as applied to the processing of instant coffee, on acidity and process yield. For this purpose, two extracts obtained from the same raw material were used: a non-concentrated extract (NC) (8 °Brix), obtained by immediate extraction, and a concentrated extract (C) (18 °Brix), produced in a rotary evaporator under reduced pressure. From these extracts, six formulations were prepared with different ratios of concentrated extract (C) to non-concentrated extract (NC): 20C/80NC, 40C/60NC, 50C/50NC, 60C/40NC, 80C/20NC, and 100C, with the latter adopted as the standard based on previous studies. Analyses of pH, titratable acidity, soluble solids (°Brix), moisture (%), and yield (%) were performed using conventional analytical methods. The data were subjected to one-way analysis of variance (ANOVA) to evaluate the effect of extract concentration on the measured parameters. Titratable acidity showed a continuous increase with the increase in the concentrated extract fraction, reaching a plateau in the 50C/50NC formulation, followed by a progressive decrease in formulations with higher proportions of concentrate. pH exhibited similar behavior, decreasing up to intermediate proportions and then increasing, indicating a nonlinear relationship between concentration and the acid-base equilibrium of the system. The soluble solids values varied according to the proportions used, ranging from 8 to 18 °Brix, as expected. Moisture content decreased steadily as the proportion of concentrated extract increased, due to the lower water content in the system. Process yield increased with higher extract concentration, but tended to stabilize at higher concentrate proportions, indicating reduced marginal gains under these conditions. The results show that increasing the concentration of coffee extract intensifies acidity only up to an intermediate level, beyond which this parameter decreases. At the same time, yield shows an increasing trend with a tendency toward stabilization. Thus, the 50C/50NC ratio stands out for promoting higher acidity combined with good yield performance, making it a promising condition for optimizing processes related to instant coffee.

Keywords: *Coffee extract; Titratable acidity; Yield.*

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TRIGONELLINE VARIATION IN IMMATURE COFFEE BEANS UNDER SUBMERGED ACID CONDITIONS

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ABSTRACT: Uneven fruit maturation in coffee crops is common in warm regions and results in the presence of immature fruits at harvest. The use of this material has been explored through processing strategies aimed at modifying its chemical profile. Trigonelline is an important coffee alkaloid and a precursor of aroma compounds formed during roasting, plays an important role as a precursor of aroma compounds formed during roasting and contributes to coffee aroma development. This study evaluated the concentration of trigonelline in immature coffee beans of the Bourbon Amarelo cultivar subjected to different post-processing conditions associated with acid immersion. Fruits were harvested at Fazenda São João DB (Varjão de Minas, MG, Brazil) and separated into mature and immature fractions. The immature fruits were subjected to a controlled immersion process in an acidic medium for 22 hours, reaching a final pH of 1.85. The process was conducted in a closed container to ensure complete submersion. Three experimental conditions were evaluated in triplicate: V3 (control – natural immature cherry, without treatment), VS3 (acid-immersed immature cherry without washing), and VL3 (acid immersed immature cherry followed by washing). Trigonelline was quantified by high-performance liquid chromatography (HPLC) using a Shimadzu diode array detector and a Promosil C18 column (5 µm, 150 mm × 4.6 mm). The mobile phase consisted of 5% acetic acid in water (A) and acetonitrile (B), with gradient elution (95:5 to 87:13, A:B), flow rate of 0.7 mL/min, injection volume of 20 µL, and column temperature of 35°C. Detection was performed at 262 nm. Data were analyzed using Tukey's test ($p < 0.05$). Significant differences were observed among treatments. The control (V3) showed higher trigonelline levels (~5.5 mg/g), while VS3 and VL3 showed lower values (~3.5 mg/g), with no significant difference between them, but both differing from the control. These results indicate that controlled acid immersion is associated with a reduction in trigonelline concentration, likely due to its water solubility and diffusion into the liquid medium. Although the mechanism was not directly investigated, the observed variation suggests changes in the pool of chemical precursors. In conclusion, acid immersion reduces trigonelline levels in immature coffee beans, indicating modifications in chemical composition and potential impacts on sensory quality. Further studies, including sensory and volatile analyses, are necessary to determine its practical implications.

Keywords: *Post-harvest processing; HPLC; Chemical composition.*

Acknowledgements

The authors acknowledge FAPESP, FAPEMIG, CNPq, MCTI, CAPES, EMBRAPA ConCafé, PROPP-UFU, and FINEP. The authors also thank Fazenda São João DB (Varjão de Minas, MG, Brazil) for providing the coffee samples and technical support.

VALORIZATION OF COFFEE HUSK: EFFECT OF EXTRACTION METHODS ON THE RECOVERY OF BIOACTIVE ALKALOIDS

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ABSTRACT: Coffee is the most consumed beverage worldwide, and its production chain generates large volumes of residues, with coffee husk standing out as the main by-product. The accumulation of this material can lead to environmental, social, and economic impacts, including pollution and resource depletion. In this context, the valorization of coffee husk from a biotechnological perspective is promising. This study aimed to evaluate the influence of different extraction methodologies on the recovery of bioactive compounds, focusing on trigonelline and caffeine from Coffea arabica cv. MGS Paraíso 2 husk, as well as to characterize the kinetic relationship between these compounds. Samples were freeze-dried for 24 hours and ground to obtain a homogeneous particle size. Extraction was carried out at a solid-to-liquid ratio of 1:100 (w/v) using three methods: infusion (80 °C for 7 min), decoction (95–100 °C for 20–30 min), and cold extraction (25 °C for 24 h with agitation at 150 rpm). After extraction, samples were filtered, centrifuged at 5000 rpm for 15 minutes, and stored at −20 °C until analysis. Quantification was performed by high-performance liquid chromatography (HPLC) on a C18 column with a mobile phase of acetonitrile and acetic acid (5:95), with detection at 264 nm (trigonelline) and 273 nm (caffeine). Results indicated that the extraction method significantly affects compound recovery. Normality and homogeneity of variance assumptions were confirmed by Shapiro–Wilk and Levene tests ($p > 0.05$). One-way ANOVA (with Welch correction) showed significant effects for trigonelline ($F = 8.35$; $p = 0.040$) and caffeine ($F = 62.40$; $p = 0.002$). Tukey's test revealed significant differences between cold extraction and decoction for trigonelline and between cold extraction and the other methods for caffeine. Pearson correlation analysis showed a strong positive linear association between trigonelline and caffeine ($r \approx 0.91$), indicating co-extraction. These results suggest that both compounds respond similarly to operational conditions due to their polar nature and high solubility in aqueous media, being governed by diffusive and mass equilibrium mechanisms. Cold extraction was the most efficient method, contributing to sustainable strategies for the valorization of agroindustrial residues.

Keywords: *Coffee husk; Trigonelline; Caffeine.*

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IMPACT OF CINNAMON (CINNAMOMUM VERUM) ENRICHMENT ON THE ANTIOXIDANT CAPACITY OF FERMENTED SPECIALTY COFFEE

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ABSTRACT: Coffee is a complex matrix rich in bioactive compounds, such as chlorogenic acids, caffeine, and melanoidins, which are associated with important antioxidant effects and potential health benefits. In addition, post-harvest processes such as fermentation can modulate the chemical composition of coffee, potentially enhancing its functional properties. The incorporation of natural ingredients rich in phenolic compounds, such as cinnamon, represents a promising strategy to further improve the antioxidant capacity and nutritional value of coffee beverages. This study aimed to evaluate the antioxidant capacity of fermented Coffea arabica beverages enriched with cinnamon (Cinnamomum verum) at different concentrations using the Ferric Reducing Antioxidant Power (FRAP) assay. Fermented coffee beans (cv. Arara), previously classified as specialty grade (>80 SCA points), were used to prepare beverages with cinnamon added at 2%, 4%, and 6% (w/w). A control beverage without addition was also evaluated. The samples were prepared under standardized conditions (1:10 m/v, 80 °C), filtered, and analyzed in triplicate. Antioxidant capacity was determined according to the FRAP method, with results expressed as µmol Trolox equivalents per gram of coffee (µmol TE·g^{-1}). Data were subjected to ANOVA, followed by Tukey's test ($p < 0.05$), after verification of normality and homoscedasticity. The addition of cinnamon influenced the antioxidant capacity of the beverages. The control sample presented a FRAP value of 662.1794^{b} µmol TE·g^{-1}. The formulations with 2% (667.3740^{b} µmol TE·g^{-1}) and 4% cinnamon (719.1658^{ab} µmol TE·g^{-1}) did not differ significantly from each other or from the control, indicating that these concentrations were not sufficient to promote a statistically significant increase. In contrast, the 6% formulation showed a significantly higher value (808.6915^{a} µmol TE·g^{-1}), evidencing a pronounced enhancement. These results indicate that the antioxidant capacity increases with cinnamon concentration, although a significant effect is only observed at higher levels. This effect may be associated with specific phenolic compounds from cinnamon, such as cinnamaldehyde, eugenol, and procyanidins, which can act synergistically with chlorogenic acids and melanoidins from coffee through redox interactions and regeneration of antioxidant capacity. Additionally, these compounds present moderate thermal stability under the extraction conditions applied (80 °C), which may contribute to the preservation of their bioactivity in the beverage. In conclusion, the incorporation of cinnamon at 6% significantly enhances the antioxidant capacity of fermented coffee beverages, highlighting its potential as a functional ingredient in the development of value-added coffee products.

Keywords: *Fermented coffee; Functional coffee; FRAP assay.*

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EXHAUSTIVE EXTRACTION OF ROASTED COFFEE USING DIFFERENT SOLVENTS: OPTIMIZATION BASED ON PHYSICAL PARAMETER

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ABSTRACT: Coffee is a beverage consumed worldwide and a source of bioactive compounds, with applicable use as dry extracts, which recovery depends on the extraction conditions employed. This work aimed to compare water, ethanol and ethyl acetate as solvents in exhaustive extraction to obtain a dry coffee extract, using a mixture experimental design to determine the best solvent composition based on physical extraction parameters. Roasted arabica specialty coffee beans (83 points, with notes of caramel, nuts and ripe fruits) were grounded and sieved between 150 and 500 µm. The samples were portioned into cartridges with an amount of 20 g each (moisture w.b. of 4.22% ±0.11), and then subjected to exhaustive extraction in a Soxhlet system (around 5 reflux/h, during 8 h, with a fixed solid/solvent ratio of 1:10 m/v). The study was developed through a mixture experimental design, totaling 11 experiments; different volumetric fractions of solvent (water, ethanol and ethyl acetate) were adopted as independent variables. Solid extract yield (SEY) was measured by oven-drying at 105°C, meanwhile total soluble solids (TSS) content was evaluated through overnight ressolubilization of the dry extract in 100 mL of deionized water. SEY results varied from 14.27 to 30.34%, while TSS content varied from 0.4 to 4.4°Brix. The prediction full cubic models had a good fit for both responses, with determination coefficients (R^2) of 0.924 and 0.974, respectively for SEY and TSS. In the model adjusted for SEY, linear effects of the volumes of water (A), ethanol (B) and ethyl acetate (C), in addition to the AB interaction, were statistically significant (p-value ≤ 0.10); the ternary diagram indicated that high values of SEY are associated with low volumetric contents of ethyl acetate and higher water fraction. Similar results were obtained for TSS. Aiming to simultaneously maximize the SEY and TSS responses, a desirability function analysis was carried out; the optimal volumetric composition of solvents was obtained (75% A and 25% C), achieving 100% desirability under this condition, predicting SEY of 33.87% and TSS content of 4.5°Brix. Based on the physical parameters analyzed, it indicates that the binary mixture of water and ethyl acetate (3:1) could be further studied to ensure extraction quality, regarding bioactive compounds and solvent-residue toxicity after drying. With the confirmation of good chemical screening behavior and security for food applications, this extract could be compared to water and ethanol-water extracts efficiency and, finally, employed in products such as beer and others beverages.

Keywords: A*rabica specialty coffee; Soxhlet extraction method; mixture experimental design.*

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TURNING COFFEE WASTE INTO NEUROPROTECTIVE AGENTS: ANTI-ACHE ACTIVITY OF SPENT COFFEE GROUNDS

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ABSTRACT: In recent years, the increasing generation of agro-industrial waste and inefficient recovery processes have raised global environmental concerns. The coffee industry produces over 10 million tons of waste annually, with spent coffee grounds (SCG) as a major byproduct rich in carbohydrates, proteins, lipids, and phenolic compounds. These phenolics are associated with several health benefits, including neuroprotective effects. Acetylcholinesterase (AChE) inhibitors play a key role in Alzheimer's disease management; however, current drugs present limitations. Natural products have emerged as promising alternatives, and coffee-derived compounds have shown moderate AChE inhibitory activity. Therefore, this study aims to evaluate SCG as a sustainable source of neuroprotective agents. Extracts were obtained by supercritical CO_2 extraction (SFE) at 40 °C and 350 bar, using a CO_2 flow rate of 6 mL/min and ethanol (1.8 mL/min) as co-solvent for 90 min (SPE-ED SFE Helix system). A comparison was performed using pressurized liquid extraction (PLE) with a betaine:triethylene glycol NADES (60%) at 150 °C, 1500 psi, and 20 min (ASE 200, Dionex). Prior to PLE, SCG were defatted by SFE under the same conditions without co-solvent. AChE inhibitory activity was determined by a fluorescence-based kinetic assay. Reaction mixtures containing extract solutions (83–830 µg/mL), Tris–HCl buffer (pH 8), and AChE were incubated, and the reaction was initiated by substrate addition. Fluorescence was monitored for 10 min at 37 °C, and inhibition percentages were calculated relative to galantamine (GE). A NADES blank was included to assess solvent interference. AChE inhibitory activity, expressed as galantamine equivalents, showed significant differences depending on extraction method and solvent. The PLE extract with BET:TEG (60%) exhibited the highest inhibitory potential (2583 ± 287 µg GE/g SCG), significantly higher than other extracts ($p \leq 0.05$), while the NADES blank showed no interference. In contrast, the SFE extract with 30% ethanol showed much lower activity (220 ± 23 µg GE/g SCG). These results suggest that NADES-based PLE enhances the recovery of polar bioactive compounds, likely due to solvent polarity and elevated temperatures, which may promote compound release and stabilization. This study demonstrates that SCG can be transformed into high-value neuroprotective agents, reinforcing their role in sustainable circular bioeconomy approaches.

Keywords: *Neuroprotective potential; Green extraction; Bioactive compounds.*

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VILA CAFÉ
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THE FERMENTATION METHOD AND MICROBIAL INOCULATION DIRECTLY INFLUENCE THE SYSTEM TEMPERATURE

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ABSTRACT: Controlled fermentation has been widely used in the processing of specialty coffees because it influences microbial activity and the formation of metabolites associated with the sensory profile of the beverage, with temperature being an important indicator of metabolic intensity during the process. In this context, the objective of this work was to evaluate the thermal dynamics during the fermentation of pulped natural coffee subjected to different processing methods and fermentation times. The experiment was conducted at Fazenda Sementes Gaúcha, located at 990 m altitude, in the municipality of Presidente Olegário (MG), using pulped natural fruits of the MGS Paraíso 2 cultivar, mechanically harvested in the 2024/2025 crop season. The experimental design consisted of 17 treatments with pulped natural coffee subjected to two fermentation methods: solid-state fermentation (SSF) and submerged fermentation (SF), conducted with and without the addition of commercial Saccharomyces cerevisiae inoculum (CIMA Lallemand®), with fermentation times of 24, 48, 72, and 96 hours. The temperature of the fermenting mass and the ambient temperature were continuously monitored using electronic sensors with automatic data recording throughout the process. During the experimental period, the ambient temperature varied approximately between 12 °C and 29 °C, while the temperature of the fermenting mass remained between 18 °C and 26 °C. In the first 24 hours, thermal peaks close to 25–26 °C were observed, indicating a higher intensity of microbial metabolic activity in this initial stage. After 48 hours, a tendency towards stabilization and a slight reduction in temperature was observed, with average values close to 20–22 °C at the end of 96 hours of fermentation. The inoculated treatments showed a more pronounced initial thermal increase compared to the treatments without inoculation. Furthermore, the submerged fermentation systems showed a smaller thermal amplitude throughout the process, while the solid-state treatments showed slightly greater variations. The results demonstrate that the fermentation method and microbial inoculation directly influence the thermal dynamics of the fermentation process, contributing to the understanding and control of fermentation processes applied to the post-harvest processing of specialty coffees.

Keywords: *Coffee fermentation; fermentation temperature; post-harvest processing.*

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REALIZATION:
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EFFECT OF DIFFERENT FERMENTATION CONDITIONS ON THE GRAIN TEXTURE OF COFFEA ARABICA CULTIVAR ACAUÃ

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ABSTRACT: Fermentation is an important step in post-harvest coffee processing, promoting physicochemical changes in the beans and influencing structural parameters relevant to beverage quality. In this context, the present study aimed to evaluate the effect of different fermentation conditions on the texture of coffee beans. Fruits of the species Coffea arabica L., cultivar Acauã, produced at Fazenda Chuá (DB), located in Patos de Minas, Minas Gerais, Brazil, were used. After mechanized harvesting, fruits were washed, subjected to density separation, and processed by self-induced anaerobic fermentation (SIAF) for 48 hours in 200 L polyethylene bioreactors. Two fermentation systems were evaluated: solid-state fermentation (SSF) and submerged fermentation (SMF), using 30% water by volume. In both treatments, conditions with and without inoculation of the yeast Saccharomyces cerevisiae (RX60—LAFFORT) and the bacterium Bacillus amyloliquefaciens were applied, allowing comparison between spontaneous and induced fermentation. The texture profile of green coffee beans was analyzed using a TA-XT2i texture analyzer (Stable Micro Systems) to determine mechanical resistance after fermentation treatments. For the tests, a 25 mm cylindrical aluminum probe (model TPA macro – AIBCAKE 2) was used, with data acquisition via Texture Expert software (version 1.20). Individual green beans were analyzed, with five measurements per sample in four samples per treatment. During tests, the probe was positioned 40 mm above the sample, with return velocity of 30 mm/s^{-1} and initial contact force of 30 g. The control sample showed an average of 449.48 ± 0.47 N, while solid-state without inoculum, submerged without inoculum, submerged with inoculum, and solid-state with inoculum showed averages of 427.99 ± 0.83 N, 417.48 ± 0.00 N, 404.77 ± 0.63 N, and 398.35 ± 0.05 N, respectively. No statistically significant differences were observed between treatments ($p>0.05$). These results indicate that fermentation methods and presence or absence of inoculum did not influence the strength of green coffee beans after 48 h. Thus, fermentation conditions did not interfere with grain structural integrity, maintaining characteristics for subsequent processing such as drying, beneficiation, roasting, and milling.

Keywords: *Post-harvest; Controlled fermentation; Grain texture.*

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REALIZATION:

SEBRAE

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VILA CAFÉ Internacional

INNOVATION IN COFFEE PROCESSING: AUTOMATED PROTOTYPE FOR NATURAL DRYING AND LABOR REDUCTION IN POST-HARVEST

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ABSTRACT: In Brazil, the Cerrado Mineiro is a region with great agricultural potential, especially in coffee production; however, it faces significant challenges in post-harvest stages, particularly during the natural drying of coffee on patios, carried out after harvesting and before processing and roasting. In this stage, the fruits are spread on sun-exposed surfaces and must be constantly turned using rakes to ensure uniform drying, prevent undesirable fermentation, and preserve product quality, making the process manual, labor intensive, and physically demanding. In this context, the present study aimed to develop an automated prototype to assist in the natural drying of coffee, promoting continuous turning of the fruits and contributing to process standardization. The experiment was conducted in June 2025 at the Centro Universitário de Patos de Minas (UNIPAM), based on the construction of a mechanical system inspired by raised drying beds, adapted at a reduced scale in a metallic container approximately 25 cm in diameter, equipped with rotating toothed blades designed to move the coffee continuously and in a controlled manner, simulating the action of manual rakes. The system was integrated with a capacitive moisture sensor, responsible for monitoring the material and automatically activating the system when moisture was equal to or above 14%, a value above the ideal drying range (10% to 12%), as well as a DHT22 sensor used to measure ambient temperature and relative humidity. As results, two experimental trials were conducted using 200 g samples of post-harvest coffee cherries, in which the drying time was 12 days in the first trial and 11 days in the second, resulting in an average of approximately 11.5 days, representing a reduction of up to about 30% compared to the traditional patio method, which typically ranges from 15 to 20 days, in addition to showing performance equivalent or slightly superior to raised drying beds with manual turning (12 to 17 days). It was also observed that the need for frequent manual turning traditionally performed every 3 hours was eliminated, indicating a significant potential reduction in labor demand, as well as greater uniformity in drying due to automatic activation based on the material's moisture. It is concluded that the prototype shows potential for application in the natural drying of coffee, contributing to process modernization and reduction of labor, especially in small- and medium-sized farms.

Keywords: *Automation; Coffee; Drying.*

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VILA CAFÉ
Internacional

SUGAR CONSUMPTION DURING COFFEE FERMENTATION IN DRY AND SUBMERGED SYSTEMS

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ABSTRACT: Coffee fermentation is an important step to improve the sensory quality of the beverage, as it involves the consumption of sugars present in coffee fruits, such as sucrose, fructose and glucose. During the mucilage degradation process, microorganisms use these compounds as an energy source, converting them into metabolites such as organic acids, glycerol and ethanol, resulting in a gradual reduction of sugars over time. Therefore, understanding sugar consumption is essential to monitor fermentative activity. In the production of specialty coffees, a segment that has gained increasing importance in Brazil, monitoring sugar consumption contributes to process standardization, improvement of final product quality and value addition to coffee. In this study, the consumption of sugars present in coffee fruits of Catuaí variety was analyzed during the fermentation process conducted in dry and submerged systems using cherry samples at fermentation times of 96 hours. The analyzed sugars were sucrose, glucose and fructose, determined by high-performance liquid chromatography (HPLC). A reduction in sugar concentration was observed after 96h, compared to the zero time (above 63% of reduction), indicating their consumption by microorganisms. Submerged fermentation showed higher sugar consumption compared to dry fermentation,with fructose being the most consumed sugar, followed by glucose and sucrose in wet fermentation in all fermentation periods analyzed. This behavior occurs because glucose and fructose are monosaccharides, simpler molecules that are more easily assimilated by microorganisms, while sucrose, as a disaccharide, must first be hydrolyzed into glucose and fructose before being metabolized. The wet condition showed in general the highest sugar consumption (sucrose: 7.3; fructose: 5.4; glucose: 1.5 mg/g fruit coffee), comparing to the dry fermentation (sucrose: 4.8; fructose: 26.7; glucose: 7.6 mg/g fruit coffee), indicating greater fermentative activity in wet condition. Overall, long submerged fermentation results in higher sugar consumption, reflecting the intensification of microbial activity. It is concluded that monitoring sugar consumption is an important tool to understand fermentative dynamics and contribute to process standardization and quality improvement of specialty coffees.

Keywords: *Coffee fermentation; Sugars consumption; Specialty coffee.*

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LOW-COST IOT-ASSISTED FERMENTATION FOR IMPROVING COFFEE QUALITY CONSISTENCY AT FARM LEVEL

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ABSTRACT: For smallholder farmers and producers of regional coffees (Varieties that often lack the inherent genetic attributes associated with specialty markets) post-harvest processing represents one of the few controllable levers available to elevate cup quality and access premium price tiers. Coffee fermentation holds significant and largely untapped potential for these producers, yet it is still managed through empirical practices with little process visibility, resulting in inconsistent outcomes and unrealized value at origin. This study evaluates the practical impact of low-cost IoT-based monitoring on fermentation control and sensory outcomes at farm level, with direct application to producers whose path to the specialty market runs through process excellence rather than varietal distinction. Five fermentation trials were conducted using coffee from a single harvest (spontaneous, extended, inoculated, and pre-oxidized fermentations of 60 to 90 hours) alongside washed controls. Sensors captured substrate and headspace temperature, pH, TDS, and headspace CO_2 continuously. Manual pH, ORP, and °Brix readings served as calibration references. The contrast between controlled and uncontrolled fermentations was most evident in two variables. Substrate temperature in uncontrolled trials fluctuated between 12°C and 33°C tracking ambient oscillations (11–30°C day/night range), while controlled fermentations maintained stable ranges of 20–25°C throughout. pH evolution diverged sharply: uncontrolled fermentations dropped from ~5.7 to ~3.6 within 48 hours, while controlled profiles descended gradually to ~3.8–4.0 at 48 hours and ~3.2–3.8 at 72 hours, indicating a more structured acidification curve. Headspace CO_2 accumulation in uncontrolled trials mirrored ambient temperature cycles, whereas controlled fermentations displayed progressively larger peaks over time, suggesting sustained and organized microbial activity. Controlled fermentations scored 86–87 SCA points, spontaneous trials reached 82–86, and washed controls ranged from 81–83, confirming that temperature stability and pH management are the primary drivers of consistent differentiation. For smallholders and regional producers, this gap is not marginal: it represents the threshold between commodity and specialty classification, with direct consequences for farmgate price and market access. The system enables adaptive, data-driven decisions rather than rigid protocols, making it scalable across diverse farm realities. Future work should focus on standardized protocols and predictive models linking sensor profiles to sensory outcomes.

Keywords: *IoT; Fermentation; Specialty Coffee.*

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INFLUENCE OF SOLAR RADIATION AND TEMPERATURE ON THE DRYING PROCESS OF COFFEA ARABICA IN A SOLAR TRAY DRYER

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ABSTRACT: The use of non-renewable and high-cost energy sources in coffee drying increases the final product cost. In this context, solar energy emerges as a sustainable, low-cost, and widely available alternative, especially in the Triângulo Mineiro region. The most consumed variety worldwide and widely produced in Brazil (Coffea arabica) is traditionally dried on patios, a method susceptible to contamination by dust and pathogens, in addition to being highly dependent on climatic conditions. Thus, drying in a tray solar dryer stands out as a more efficient solution, as it harnesses solar energy while providing greater protection against external agents. Therefore, the objective of this study was to evaluate the influence of solar radiation and convective air temperature during the drying process of Arabica coffee. The coffee used was the cherry stage of the Novo Mundo variety, already semi-dry, donated by the Regional Cooperative of Coffee Growers of Guaxupé. The initial moisture content of the beans was 32.17±1.07% (w.b.). The solar dryer used consists of an indirect exposure system operating under forced convection (airflow rate of 202 m³/h), composed of a solar collector (2 m × 1 m), a drying chamber, and a wind-driven exhaust fan. Local solar radiation during the experiments was measured using a solarimeter (INSTRUTHERM MES 200). In addition, four PT100 temperature sensors were used. The drying process was conducted for 6 hours. Statistical analysis of the data was performed using STATISTICA® software. The results indicated that, under solar radiation of 846±1 W/m², the drying air temperature reached 56±1 °C, resulting in a final moisture content of 12.4% (w.b.). For 823±1 W/m², the observed temperature was 53±1 °C, with a final moisture content of 15.3% (w.b.), while for 749±1 W/m², the temperature recorded was 53±1 °C, with a final moisture content of 16.0% (w.b.). Thus, a consistent trend was observed: the greater the solar radiation incident on the collector, the higher the drying air temperature and the lower the final moisture content of the fruit at the end of the process. Conversely, reduced radiation led to slightly lower temperatures and, consequently, higher final moisture levels. Therefore, in addition to temperature, exposure time and energy availability throughout the process influenced water removal. These results highlight the importance of higher solar radiation conditions to optimize drying and achieve more suitable moisture levels for coffee storage.

Keywords: *Coffee drying; Solar Energy; Operating conditions.*

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VILA CAFÉ Internacional

INFLUENCE OF FERMENTATION TIME AND PROCESSING CONDITIONS ON THE METABOLIC PROFILE OF COFFEA ARABICA CV. ACAIÁ

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ABSTRACT: Fermentation has emerged as an important strategy for improving the chemical and sensory qualities of specialty coffee by modulating microbial activity and metabolite production. However, the influence of fermentation time and processing conditions on these metabolic transformations remains poorly understood, particularly when these factors are integrated in multivariate analyses. This study aimed to evaluate the effects of fermentation time and processing conditions (dry and submerged) on the metabolic profile of Coffea arabica cv. Acaiá focuses on the dynamics of organic acids, sugars, and ethanol during controlled fermentation using a starter culture. Coffee cherries from the 2023 harvest were processed using the natural pulping method and subjected to self-induced anaerobic fermentation (SIAF) in 200 L bioreactors inoculated with Saccharomyces cerevisiae. Fermentation was conducted for 24, 48, and 72 h under dry and submerged conditions, respectively. Chemical characterization was performed using HPLC. Data were analyzed using Welch's ANOVA, followed by the Games-Howell test ($p \leq 0.05$). Significant differences were observed in citric acid, acetic acid, glucose, fructose, and ethanol levels ($p \leq 0.01$), while malic acid levels remained unchanged ($p > 0.05$), indicating metabolic stability. Citric acid increased in all treatments compared to the control (2.79 ± 0.23 mg/g), reaching up to 4.50 ± 0.26 mg/g (submerged, 48 h), suggesting early formation and stabilization of citric acid. Fructose decreased sharply from 9.85 ± 0.69 mg/g to 2.27 ± 0.63 mg/g (submerged, 72 h), confirming its role as the main fermentable substrate for yeast fermentation. Glucose showed a transient increase at 24 h in dry fermentation (5.90 ± 1.15 mg/g), followed by a decline, indicating initial carbohydrate degradation and subsequent microbial consumption. The ethanol content increased over the course of fermentation, reaching 4.86 ± 0.84 mg/g after 72 h, indicating intensified microbial activity. The acetic acid content varied over time and throughout the process, indicating progressive metabolic transformation. Principal component analysis (PCA) explained 67.9% of the total variance and separated the samples based on their metabolic changes. The results indicate that fermentation time and processing conditions significantly modulated metabolic pathways, promoting sugar consumption and the accumulation of fermentation-derived compounds, with distinct dynamics between dry and submerged systems.

Keywords: *Coffee fermentation; Metabolic profile; Principal component analysis.*

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EVALUATION OF THE PERFORMANCE OF COMMERCIAL YEASTS IN ETHANOL PRODUCTION FROM COFFEE PULPING RESIDUES

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ABSTRACT: Coffee processing generates between 10 and 15 million tons of by-products annually, with pulp and wet husk standing out as solid residues produced in proportions similar to coffee bean production. Due to their high carbohydrate content, these residues show great potential as raw material for bioethanol production. In this context, the present study aimed to evaluate the ethanol concentration obtained from the fermentation process of fresh coffee pulp residues (husk and pulp), comparing the use of different commercial yeasts (FX10, RX60, and PhibroAdy) with a control sample (C), at 6, 12, 24, and 48 hours. Husks of Coffea arabica, Topázio variety, cultivated in Patos de Minas, were used. The fermentation systems were prepared in triplicate containing 125g of substrate, 37.5mL of inoculum, and 50mL of sterile water. For the control samples, 37.5mL of sterile water was added in place of the inoculum. The flasks were sealed with cotton plugs and maintained under constant agitation at 180 rpm and 32 °C. Samples were collected at 6, 12, 24, and 48 hours. Ethanol concentrations were determined by high-performance liquid chromatography, and the data obtained were subjected to ANOVA followed by Tukey's test ($p \leq 0.05$). The results indicated that the highest ethanol concentrations occurred after 24 hours of fermentation, with values of C-24h (0.39±0.06 g/L)B, RX60-24h (23.83±2.32 g/L)A, PhibroAdy-24h (25.10±3.53 g/L)A, and FX10-24h (26.89±1.21 g/L)A. This increase is consistent with the literature, as the rise in ethanol concentration over the course of fermentation is associated with the metabolic activity of microorganisms, which convert sugars into ethanol and other metabolites through catabolic pathways. However, a significant decrease was observed at 48 hours, with values of C-48h (1.94±0.68 g/L)B, RX60-48h (4.66±1.60 g/L)AB, PhibroAdy-48h (7.20±1.24 g/L)A, and FX10-48h (7.39±1.56 g/L)A. This behavior can be explained by factors such as depletion of fermentable sugars, accumulation of inhibitory compounds, and cellular stress, since even though Saccharomyces cerevisiae yeast exhibits moderate ethanol tolerance, high concentrations can reduce cell viability and consequently ethanol production itself. In addition, the decrease observed at 48 hours may be related to ethanol consumption and/or partial oxidation, favored by passive gas exchange conditions. Furthermore, ethanol production from coffee pulp and wet husk was comparable to that of other agro industrial residues, which generally require supplementation or hydrolysis, although lower than that of sugarcane (approximately 80 to 120 g/L). This demonstrates potential for valorization and can be improved through pretreatments, representing a viable alternative to add value to these residues.

Keywords: *Fermentation; metabolites; bioprocess.*

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MONITORING DASHBOARD FOR DECISION SUPPORT IN COFFEE DRYING FOCUSED ON QUALITY AND PRODUCTIVITY

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ABSTRACT: In the context of coffee production, drying represents one of the most critical stages for determining final beverage quality and production efficiency, with the increasing use of mechanical dryers as an alternative to traditional terrace drying methods. In this context, the present study focused on the development of a monitoring dashboard applied to coffee drying, structured from experimental data obtained with Arabica coffees subjected to different drying conditions in fixed-bed dryers and on cement terraces, considering variations in volume and fruit maturation stage. The experimental results indicated drying time reductions of 30% for cherry coffees and 57% for overripe coffees when compared to terrace drying. In terms of decision-making, the 12 m³ volume was associated with higher sensory quality for both maturation stages. Also, for overripe coffees, the 18 m³ volume allowed gains in processing capacity while maintaining satisfactory sensory quality, whereas for cherry coffees it resulted in a higher incidence of undesirable sensory attributes, indicating limitations for this condition when quality is the main objective. The dashboard integrates operational, physicochemical, and sensory information, allowing users to visualize and correlate indicators such as drying time, processing time reduction between methods, sensory scores, composition, fresh fruit characteristics like moisture content, density, soluble solids, percentage of immature fruits, color and texture of dried beans. Additionally, it enables the analysis of drying rate, temperature and the distribution of sensory descriptors, including the proportion of desirable and undesirable attributes, as well as the exploration of an interactive coffee taster's flavor wheel with dynamic filters. The dashboard structure allows filtering by drying method, operating volume and maturation stage, enabling direct comparisons between different scenarios. In this way, producers can evaluate the relationship between increasing volume and its impact on sensory quality, or quantify operational gains in terms of time and efficiency. Based on these insights, it becomes possible to guide the selection of drying parameters according to specific production goals. Although developed based on drying data, the dashboard has broader application potential in coffee production, as it can be adapted to other post-harvest stages or even to monitor agronomic and quality indicators throughout the production chain. Thus, the main outcome of this study is not limited to the analysis of drying conditions, but rather the delivery of a technological tool that transforms experimental data into strategic information, contributing to more efficient, data driven management aligned with the quality and productivity demands of the coffee sector.

Keywords: *Coffee drying; Monitoring dashboard; Technical product.*

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HEADSPACE SPME-GC-MS ANALYSIS OF COFFEE VOLATILE PROFILE

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ABSTRACT: The objective of this study was to characterize the volatile profile of roasted Coffea arabica cv. Arara coffee and evaluate the influence of different post-harvest fermentation conditions on the relative abundance of volatile compounds. Coffee samples were obtained from Chuá Farm, located in Patos de Minas, Minas Gerais, Brazil. Five treatments were evaluated in triplicate: non-fermented control (0 h); 96 h solid-state fermentation without inoculum; 72 h solid-state fermentation with inoculum; 96 h submerged fermentation with inoculum; and 48 h submerged fermentation without inoculum, all conducted under controlled temperature conditions. For analysis, roasted coffee samples (medium roast) were ground for 2 minutes, and 2.0 g were transferred to headspace vials under controlled preparation conditions to ensure analytical reproducibility. Volatile compounds were analyzed by headspace solid-phase microextraction coupled with gas chromatography–mass spectrometry (HS-SPME/GC-MS). Compound identification was performed by comparison with NIST spectral libraries, combined with linear retention index (LRI) calculation, increasing confidence in compound assignment. The chromatograms showed consistent retention time alignment across runs, indicating adequate analytical stability. A higher density of well resolved peaks was observed between 8 and 25 minutes, consistent with the typical distribution of coffee volatiles, while increased baseline and noise at longer retention times limited compound identification, leading to an analytical cutoff at approximately 30 minutes. The volatile profile was dominated by compound classes typically associated with roasted coffee, including pyrazines, furanic compounds, aldehydes, ketones, and nitrogen-containing species. Quantitative differences were observed in relative peak area (%RPA), with furanic compounds presenting the highest abundance (approximately 14–25%), while pyrazines remained relatively stable (~8%). Aldehydes such as 2-methylpropanal showed increased intensity in fermented samples compared to the control, indicating that processing conditions influenced ompound abundance. Overall, the samples showed high qualitative similarity, with differences primarily associated with variations in compound abundance rather than the formation of new chemical classes. These results demonstrate that HS-SPME/GC-MS is suitable for generating reproducible chromatographic fingerprints and for evaluating the impact of fermentation conditions on coffee volatile profiles.

Keywords: *Coffee processing; Chemical characterization; Flavor profile.*

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EXPERIMENTAL STRATEGY FOR HYDRATION AND FERMENTATION OF PROCESSED COFFEE WITH EVALUATION OF THE CHEMICAL PROFILE

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ABSTRACT: Fermentation has emerged as a promising strategy for modulating the chemical and sensory profile of coffee. However, most studies have focused on freshly harvested beans, leaving gaps regarding the application of this process to already processed (green) coffee beans. In this context, the present study aimed to develop and evaluate an experimental protocol for the hydration, solid-state fermentation, and drying of processed coffee beans, with a focus on investigating the chemical transformations induced by the fermentative process. Initially, rehydration experiments were conducted using different vaporization systems and exposure times (10 to 210 minutes), with water uptake monitored by gravimetric analysis. Subsequently, the beans were subjected to solid-state fermentation for 72, 96, and 120 hours. After fermentation, the samples were dried in a forced-air oven until reaching a moisture content close to the initial level (~11%), ensuring the interruption of microbial activity and material stability. The hydration kinetics exhibited an approximately linear behavior as a function of vapor exposure time, indicating efficient control of water absorption. Similarly, the drying stage showed progressive and reproducible mass loss across samples, demonstrating the robustness of the developed protocol. Spectroscopic analyses by FTIR and solid-state ^{13}C NMR indicated that the hydration and drying processes did not promote significant structural changes in the overall chemical profile of the beans, suggesting preservation of the plant matrix. The application of multivariate statistical tools, such as PCA, revealed a clear separation between fermented and non-fermented samples, confirming that the fermentative process induces detectable modifications in the metabolite profile. Furthermore, the 96-hour fermentation time showed greater consistency among replicates, indicating improved reproducibility of the chemical profile. Overall, the results demonstrate that the proposed protocol is capable of inducing and controlling chemical transformations in processed coffee beans, contributing to the advancement of fermentation-based strategies for improving coffee quality and enhancing the understanding of metabolomic changes associated with these processes.

Keywords: *Fermentation; Hydration; Green coffee.*

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RESULT OF A MULTIFUNCTIONAL BIOSTIMULANT ANALYZED BY GCMS AND RESULT IN THE FIELD

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ABSTRACT: The biostimulant has a diversified chemical composition, with emphasis on nitrogenous compounds, organic acids, phenolics, terpenes and lipids. Nitrogenous compounds, such as dipeptides, lactams, amines, and heterocyclics, are related to signaling and inducing systemic resistance, as well as stimulating root growth and nitrogen metabolism. Fatty and carboxylic acids contribute to plant nutrition, acting on nutrient solubilization and stress tolerance. Phenolic and aromatic compounds exert an antioxidant function and participate in the formation of lignin, reinforcing the structural defense of plants. Terpenes and alcohols, on the other hand, have antimicrobial action and can act to protect against insects, in addition to improving the absorption of substances. Finally, lipids, hydrocarbons and fatty acid esters favor the efficiency of applications, acting as spreading agents and facilitating the penetration of active compounds into plant tissues. For the chemical characterization of the biostimulant, a gas chromatography system coupled to a mass spectrometer (GCMS-QP2020, Shimadzu) was used. The identification of the compounds present in the sample was carried out by comparing the mass spectra obtained with the data from the spectral library (such as the NIST database), allowing the confirmation of specific chemical classes. In the field, the work was carried out in the coffee plantation of the Gaucha farm, located in the municipality of Presidente Olegário – MG. The biostimulant was applied together with the biological Bacillus amyloliquefaciens, which was the diagnostic treatment and only the biological treatment, the control treatment. After 14 days of application, the soil was collected and sent to the Celasa laboratory, to prove the multiplication of the biological in the soil. Microbiological analysis revealed the presence of Bacillus amyloliquefaciens at a concentration of 1.7 x 10.7 CFU x mL-1 in the treatment associated with the biostimulant and 1.0 x 107 CFU x mL-1 in the control treatment. It is concluded that the results obtained show that the biostimulant has high chemical complexity, containing 136 molecules distributed in different classes, such as nitrogenous, phenolic, heterocyclic, organophosphate, lipid and hydrocarbon compounds, which suggests a potential multifunctional action in the soil-plant system. The field application, associated with Bacillus amyloliquefaciens, showed an increase in the microbial population compared to the control treatment, indicating a positive effect of the biostimulant on the multiplication and maintenance of the microorganism. Thus, the data indicate that the biostimulant can act as a biological modulator of the soil, favoring microbial dynamics and potentially contributing to the improvement of fertility and sustainability of coffee cultivation.

Keywords: *Biostimulant; Plant defense; Multiplication of biological.*

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ESP-NOW AND LORA COMMUNICATION ARCHITECTURE FOR COLLECTING THERMAL DATA IN COFFEE FERMENTATION

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ABSTRACT: The coffee fermentation process is crucial for the formation of biochemical compounds responsible for the sensory characteristics of the final product. Temperature monitoring at this stage is essential, as thermal variations can compromise the quality of entire batches. To address this challenge, a technological solution was developed for thermal monitoring in rural properties with low connectivity and difficult access. The system uses pairs of Heltec ESP-32 LoRa V2 microcontrollers, configured as a controller and gateway. The controller collects data from temperature sensors connected to Arduino Nano and ESP 01 based devices using the ESP-NOW protocol. During the experiments, the distance between the devices and the controller was approximately 10 m. According to the manufacturer, it is possible to reach up to 100 m with moderate obstacles. In the experiments, each device used five temperature sensors, and each controller monitored up to six devices, resulting in 30 temperature samples per minute. After data collection, the controller uses the LoRa protocol to send the data to the gateway. During the data collection, the greatest distance used was 0.7 km. It is important to highlight that the LoRa protocol can reach up to 10km under ideal conditions, and 2km under obstacle-prone conditions. From the gateway, the data is transmitted via Wi-Fi to the online server. The server then saves the samples in a database and displays the temperature variation in real time on a dashboard. The web system allows exporting the data to spreadsheets, which can be used for later analysis. The system operated from April 14th to May 28th, 2024 in 22 experiments and from April 14th to June 28th, 2025 in 9 experiments. The amount of data collected is proportional to the fermentation time. The system was designed to collect one temperature sample per minute, resulting in approximately 1440 samples per day for each sensor. The system may experience signal drops, and therefore there is a backup system to save data on SD cards. Based on this data, researchers can perform calculations, make predictions about product quality, and publish reliable data.

Keywords: *ESP; LoRa; Embedded Systems.*

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The authors thank the Federal University of Uberlândia (UFU) for the infrastructural support, the "Da Semente à Xícara" project and the Cerrado Mineiro coffee producers for providing the field environment, and our supervisors, M.Sc. Daniel de Oliveira Ferreira and Dr. Pedro Luiz Lima Bertarini, for their continuous guidance.

VILA CAFÉ
Internacional

AGRICULTURAL REMOTE SENSING

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ABSTRACT: Remote sensing has emerged as a strategic tool in modern agriculture, enabling efficient monitoring of crop conditions and supporting data-driven decision-making. This study evaluated the integration of Sentinel-2 satellite imagery, multispectral sensing, and QGIS-based geospatial analysis for assessing spatial variability in coffee crops. Vegetation indices, including NDVI (Normalized Difference Vegetation Index) and NDRE (Normalized Difference Red Edge), were combined with georeferenced soil and leaf data. The study was conducted at the experimental field of Escola Estadual Agrotécnica Afonso Queiroz, in Patos de Minas – MG, Brazil. A completely randomized polygon design (CRPD), structured in a 2×2 + 1 vector scheme with two analytical replicates, was adopted. Four sampling areas were evaluated, integrating multispectral leaf data and georeferenced soil sampling at 20 cm depth. Multispectral imagery (10 m spatial resolution) was processed in QGIS to generate vegetation index maps, enabling the identification of spatial variability in plant health and nutritional status. Data were analyzed using descriptive statistics and comparison of means to identify differences among areas. Significant variability was observed: Area 1 showed the highest performance (NDVI = 0.81; NDRE = 0.55), associated with favorable soil conditions (pH 6.8, 4.2% organic matter, and balanced nutrient levels), whereas Area 2 exhibited stress conditions (NDVI = 0.54; NDRE = 0.38), correlated with soil acidity (pH 5.6) and nutrient deficiencies. Areas 3 and 4 presented intermediate responses, confirming field heterogeneity. The integration of remote sensing and georeferenced soil data enabled accurate identification of spatial patterns, supporting targeted agronomic interventions. These findings demonstrate that combining spectral indices with soil analysis enhances precision strategies, optimizing input management and improving the sustainability of coffee production systems.

Keywords: *Precision agriculture; NDVI; Satellites.*

ECONOMIC ANALYSIS OF LIMESTONE APPLICATION AT VARIABLE RATE AND FIXED RATE IN COFFEE CULTIVATION

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ABSTRACT: Among the limiting factors for coffee productivity, the presence of acidic soils can be highlighted. As a solution, lime application can be carried out either at a fixed rate or through the use of precision agriculture (variable rate). This study aimed to evaluate the economic feasibility of lime application at fixed and variable rates. The study was conducted in a pivot-irrigated area located in the municipality of Patos de Minas, MG, covering 32.62 hectares, with soil sampling carried out in January 2024. For the variable-rate lime recommendation, a three-hectare sampling grid was established, and the sampling points were imported into a navigation GPS, which was used to locate each point in the field. Each sampling point consisted of five subsamples. Conventional sampling was performed using a zigzag path, with subsamples collected along the route. Soil samples were collected at a depth of 0–20 cm. After collection, the samples were sent to the Brazilian Laboratory of Environmental and Agricultural Analysis, located in Monte Carmelo, MG, for analysis of pH, calcium, magnesium, aluminum, potential acidity, cation exchange capacity, and base saturation. The results were tabulated and subjected to geostatistical analysis, followed by the creation of recommendation maps. Lime recommendations were based on the base saturation method for coffee crops. Finally, an economic analysis comparing variable-rate and fixed-rate lime application was conducted. Variable-rate application was divided into three application ranges: 870, 1200, and 1542 kg ha^{-1}, totaling 42.78 tons of lime. Fixed-rate application was 1,010 kg ha^{-1}, totaling 32.94 tons; however, it did not meet any of the recommendation ranges used in the variable-rate approach. Cost analysis showed that fixed-rate applications amounted to R$ 3,318.89, while variable-rate applications reached R$ 4,737.61. The total difference was R$ 1,418.72, making variable-rate application more expensive compared to fixed-rate application. It can be concluded that fixed-rate lime application proved to be more economically viable for the producer; however, further studies are needed to evaluate the coffee crop's response to both application methods.

Keywords: *Geostatistics; Precision agriculture; Sampling grid.*

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FRONT-END ARCHITECTURE FOR REAL-TIME MONITORING OF CONTROLLED COFFEE FERMENTATION IN LOW-CONNECTIVITY RURAL ENVIRONMENTS

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ABSTRACT: Coffee fermentation at rural farms demands continuous temperature tracking because thermal deviations during this stage can degrade entire batches. Most rural properties lack reliable internet, which makes conventional cloud dashboards impractical. This study describes the design, implementation, and field evaluation of FrontCafe's web interface, a single-page application built to display fermentation data collected by Heltec ESP-32 LoRa V2 microcontrollers and routed through MQTT to a MongoDB backend. The objective is to deliver a responsive monitoring tool that works under intermittent connectivity and allows producers to spot thermal anomalies quickly. The frontend was developed with React 19, TypeScript, and Vite. It has 9 routes, role-based access for two profiles (operator and administrator), and two monitoring modes: a tabular view for operational tracking and a dashboard with time-series charts for historical analysis. Data reaches the browser through two complementary channels. HTTP requests retrieve paginated experiment lists and historical readings on demand. Socket.IO keeps a persistent bidirectional connection and pushes live temperature updates as they arrive, rather than forcing the browser to poll the server repeatedly. In our field measurements this cut average update latency from several seconds down to under 200 milliseconds. The interface subscribes only to experiments visible on screen, so bandwidth stays proportional to what the user is actually watching. To handle multiple experiments without slowing down scrolling, chart components load only when they enter the viewport (triggered at 10 percent visibility), and tables pre-load 250 pixels ahead. Invalid sensor readings, especially the -127 °C error typical of DS18B20 hardware faults, are filtered before computing per box arithmetic means on each chart. Experiment state is tracked in three categories — Ativado, Desativado, and Sincronizando — so operators can tell whether a box is fermenting, finished, or waiting for the gateway to reconnect. When connectivity returns after a gap, the interface merges server-retrieved history with locally buffered socket updates, deduplicating by timestamp, so the chart stays continuous. In practice, the producer sees a phone screen showing which fermentation boxes are active, the current reading of each sensor, and whether any box is drifting outside the target range. There is no need to interpret raw numbers or call a technician. FrontCafe turns sensor telemetry into something a farmer can check between tasks and act on immediately.

Keywords: *Coffee fermentation; Frontend; ESP-32.*

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EVALUATION OF THE ADDITION OF COFFEE HUSKS AND ZINC TAILINGS TO TRADITIONAL MORTAR

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ABSTRACT: The use of agroindustrial waste as a substitute or additive to cementitious processes in the civil construction sector has been gaining consideration. This study aimed to evaluate the inclusion of dried and crushed coffee husks, as well as the inclusion of zinc tailings in conventional mortar. For this analysis, a standard mixture (T1) was established (cement/sand ratio of 1:3, with the addition of 60% water relative to the cement). From this, other varied mixtures were generated, with percentages of coffee husks (CC), zinc tailings (RN), and a mixture of both (sieved between 150-600 µm), always performing this addition in relation to the amount of binder (cement). The variations adopted were as follows: standard mixture with 6% CC (T2), standard mixture with 6% RN (T3), standard mixture with 6% CC and 6% RN (T4), and standard mixture with 3% of each addition (T5). To evaluate the compositions in the fresh state, a slump test was performed, in which thirty blows were applied to a consistency table using the fresh sample; after this process, the spread was measured with a caliper. A compression spread test was also performed, which consists of applying force by a press on the fresh mortar to evaluate the stress-strain relationship, generating graphs that show the behavior of the sample when subjected to stresses at different speeds, 3.0 and 0.1 mm/s. As a result, it was observed that the spread of all mixes was satisfactory (ranging from 18.0 to 25.8 mm), highlighting that the sample with 6% CH obtained a lower value than the others (T2 = 18.00 mm; T4 = 18.3 mm), which can be explained by the porosity of the material and may be related to water loss due to contact with the CH. Regarding the stress-strain test, it was observed that tests performed at a speed of 3.0 mm/s (maximum deformation ranging from 2.8 to 4.9 mm) did not show a significant difference in the regression analysis. However, for tests performed at 0.1 mm/s (maximum deformation ranging from 2.5 to 3.6 mm), a higher initial stress (up to 2 mm of compression) was observed in samples with interaction between CH and ZT (T4 showed 105.1 N at 1 mm and 373.7 N at 2 mm, with lower maximum deformation). This research topic demonstrates potential for the use of agro-industrial waste in civil construction, especially for permeable mortars, where a considerable initial stress and less fluid mixing conditions are required.

Keywords: *Reology; Stress-strain behavior; Fresh mortar spread.*

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VILA CAFÉ Internacional

HARDWARE OPTIMIZATION AND IOT SENSING FOR THE "DA SEMENTE À XÍCARA" PROJECT

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ABSTRACT: The present work details the development and architectural optimization of a custom Printed Circuit Board (PCB) applied to real-time data acquisition for the "Da Semente à Xícara" research project. The primary objective of this project is to develop a robust and reliable hardware platform to perform the uninterrupted monitoring of thermal and biogas data during coffee fermentation experiments on farms in the Cerrado Mineiro region. Given that fermentation dynamics are highly sensitive to environmental variations, the precise collection of these metrics is of utmost importance for quality control and batch standardization. To meet these demands, the primary hardware evolution consisted of migrating the platform from an Arduino Nano base to the ESP32 microcontroller. This transition significantly expanded the system's memory capacity, enabling the implementation of more complex and robust firmwares. From a telecommunications perspective, adopting the ESP32 eliminated the reliance on the legacy peripheral module (ESP-01), centralizing processing and native Wi-Fi connectivity within a single System on a Chip (SoC), thereby granting greater reliability to data transmission to the cloud. Within the scope of instrumentation, the reading capacity was expanded. In addition to the temperature measurement sensor array, the circuit updated its analog interface to integrate new sensors dedicated to extracting data regarding the gases released during the fermentative process. Regarding the physical infrastructure, the new layout design resolved chronic maintenance vulnerabilities present in the previous version. The connections formerly based on jumpers (susceptible to oxidation and accidental disconnections) were replaced by connectors soldered directly onto the PCB, comprehensively mitigating mechanical contact failures. The current board features electrically exclusive buses for each sensor, establishing a plug-and-play architecture. Consequently, the physical insertion order of the connectors on the board does not interfere with the addressing and integrity of the logical data. It is concluded that the PCB restructuring and processing migration were successful, eliminating recurrent mechanical failures and establishing a highly stable IoT system fully prepared for the operational rigors of rural properties.

Keywords: *Internet of Things; Embedded Systems; Precision Agriculture.*

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VILA CAFÉ Internacional

NDVI DYNAMICS REVEAL SOIL AND BIENNIALLY EFFECTS ON COFFEE VIGOR

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ABSTRACT: Coffee yield and vegetative vigor are directly related to soil physical–hydric properties, which modulate distinct physiological responses, particularly under abiotic stress, making remotely sensed vegetation indices an effective and scalable tool for monitoring. This study aimed to evaluate the temporal dynamics of the Normalized Difference Vegetation Index (NDVI) in a commercial coffee farm (Coffea arabica cv. Catuaí, 20 years old) established on contrasting soils (stony Haplic Cambisols – CX, Haplic Organosols – OX, and Red-Yellow Argisols – PVA) in the municipality of Santo Antônio do Amparo, Campos das Vertentes region, MG. Google Earth Engine was used to process Sentinel-2 (MSI) imagery, with 10 m spatial and 5-day temporal resolution, integrated with monthly precipitation data from the Rainfall Estimates from Rain Gauge and Satellite Observations (CHIRPS) dataset. NDVI time series were extracted for 2024 (negative biennially) and 2025 (positive biennially), applying cloud masking and monthly median filtering. The monthly median of NDVI values were calculated and a linear interpolation model was fitted to generate curves throughout the time series (R software, packages tidyverse and lubridate). The function geom_line were applied to preserve peaks and drops of NDVI values to better reveal contrasts. Overall, plants in negative biennially presented lower NDVI values (0.55 ± 0.16, expressed as mean ± standard deviation) than positive biennially (0.72 ± 0.13). Plants growing on CX showed the greatest variability in NDVI values over time (mean NDVI of 0.58 ± 0.17), with pronounced declines during months of low precipitation (minimum NDVI of 0.30 in September), likely due to reduced effective soil depth and the presence of coarse fragments limiting water storage capacity. In contrast, plants on OX maintained higher and more stable NDVI values throughout the time series (mean NDVI of 0.68 ± 0.16), indicating greater hydric and nutritional resilience associated with higher soil organic matter content until 1.30 m depth, which enhances water retention even under lower clay content. Plants on PVA exhibited intermediate behavior (mean NDVI of 0.67 ± 0.14), but with higher NDVI peaks following rainy periods (maximum NDVI of 0.87) when compared to CX (0.86) and OX (0.91), likely due to increasing content of clay particles in depth increasing water retention after rainy season period. The temporal dynamics of NDVI showed strong potential for supporting the delineation of management zones, as it was sensitive to differences among soil classes, highlighting the key role of soil physical–hydric properties in controlling coffee plant vigor.

Keywords: *Remote Sensing; Precision Agriculture; Soil-Water Relations.*

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VILA CAFÉ
Internacional

ANALYSIS OF THE ULTRAVIOLET INDEX IN THE COFFEE CANOPY AND ITS RELATIONSHIP WITH PROTECTION AGAINST OXIDATIVE STRESS

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ABSTRACT: Leaf canopy architecture in coffee cultivation (Coffea arabica) plays a fundamental role in regulating the internal microclimate, directly influencing radiation interception and the protection of lower layers. This study aimed to evaluate the ultraviolet (UV) radiation interception efficiency between the top and the base of the plants, correlating radiative variability with protection against oxidative stress. For data acquisition, the UVM-30A sensor was used, integrated into a processing system developed in Python. UV radiation was measured in terms of UV Irradiance (µW/cm2), and the radiative stress was quantified through three processed data levels: the Raw Value (digital conversion from 0 to 1023), the Voltage (mV) representing the physical electrical signal, and the UV Index (UVI), a standardized dimensionless unit that weights radiation intensity by its potential for biological tissue damage. The experiment was conducted in Patos de Minas–MG, at the Alfonso Queiroz Agricultural School, where 38 samples per plant were collected, divided between the upper stratum (Top) and lower stratum (Base). Collections occurred on different days due to natural variations in solar radiation, ensuring the robustness of the analysis under different radiant flux intensities. The collected data were subjected to linear regression analysis and stochastic modeling via Poisson Distribution. After analysis, it was observed that the results demonstrated a systematic and significant attenuation (p-value < 0.001), with reduction rates ranging from 64.3% to 100%. The low average coefficient of determination (R2 < 0.26) evidenced the independence of the basal microclimate in relation to external oscillations, while the adherence of the basal data to the Poisson Distribution (wavelength = 0.11; variance = 0.10) confirmed that UV entry at the base occurs in a random and discrete manner. It is concluded that the canopy acts as a high-efficiency biological filter, promoting interception that mitigates the incidence of excessive radiation in the lower strata. This average attenuation of 95.1%—calculated as the mean relative difference between the radiant flux at the top and the base—is decisive in minimizing oxidative stress, highlighting that plant architecture management is a key variable for protecting plant tissues and maintaining physiological homeostasis in precision agriculture systems.

Keywords: *Coffea arabica; Radiation Sensing; Oxidative Stress.*

VILA CAFÉ
Internacional

ANALYSIS OF THE ULTRAVIOLET INDEX IN THE COFFEE CANOPY AND ITS RELATIONSHIP WITH PROTECTION AGAINST OXIDATIVE STRESS

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ABSTRACT: Leaf canopy architecture in coffee cultivation (Coffea arabica) plays a fundamental role in regulating the internal microclimate, directly influencing radiation interception and the protection of lower layers. This study aimed to evaluate the ultraviolet (UV) radiation interception efficiency between the top and the base of the plants, correlating radiative variability with protection against oxidative stress. For data acquisition, the UVM-30A sensor was used, integrated into a processing system developed in Python. UV radiation was measured in terms of UV Irradiance (µW/cm2), and the radiative stress was quantified through three processed data levels: the Raw Value (digital conversion from 0 to 1023), the Voltage (mV) representing the physical electrical signal, and the UV Index (UVI), a standardized dimensionless unit that weights radiation intensity by its potential for biological tissue damage. The experiment was conducted in Patos de Minas–MG, at the Alfonso Queiroz Agricultural School, where 38 samples per plant were collected, divided between the upper stratum (Top) and lower stratum (Base). Collections occurred on different days due to natural variations in solar radiation, ensuring the robustness of the analysis under different radiant flux intensities. The collected data were subjected to linear regression analysis and stochastic modeling via Poisson Distribution. After analysis, it was observed that the results demonstrated a systematic and significant attenuation (p-value < 0.001), with reduction rates ranging from 64.3% to 100%. The low average coefficient of determination (R2 < 0.26) evidenced the independence of the basal microclimate in relation to external oscillations, while the adherence of the basal data to the Poisson Distribution (wavelength = 0.11; variance = 0.10) confirmed that UV entry at the base occurs in a random and discrete manner. It is concluded that the canopy acts as a high-efficiency biological filter, promoting interception that mitigates the incidence of excessive radiation in the lower strata. This average attenuation of 95.1%—calculated as the mean relative difference between the radiant flux at the top and the base—is decisive in minimizing oxidative stress, highlighting that plant architecture management is a key variable for protecting plant tissues and maintaining physiological homeostasis in precision agriculture systems.

Keywords: *Coffea arabica; Radiation Sensing; Oxidative Stress.*

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SMARTPHONE-BASED RGB IMAGING AND DATA FUSION FOR DEFECT CLASSIFICATION IN SPECIALTY ROASTED COFFEE BEANS

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ABSTRACT: Digital image analysis is a low-cost and accessible tool for food quality assessment. In coffee, RGB (Red Green Blue) imaging shows potential for defect detection; however, discrimination at the roasted stage remains challenging due to visual homogenization induced by the process. This study evaluated RGB imaging combined with chemometric modeling and data fusion for classifying defective and sound roasted specialty coffee beans A dataset of 288 Coffea arabica beans (144 sound and 144 defective) from 12 specialty coffee samples was analyzed. Twelve beans per sample were used, corresponding to the maximum number accommodated by the imaging device, ensuring standardized conditions. The coffee samples were equally divided between natural and washed post-harvest processing. All coffees were roasted to a medium level using a Probat TP2 (initial temperature 150 °C, maximum time 12 min). All Images were acquired in the same day of analysis using a Xiaomi Redmi Note 8 (48 MP) with fixed settings (f/1.89, 1/30 s, ISO 200) under controlled illumination in a closed device, ensuring consistent resolution and acquisition conditions. Segmentation was performed using a relative green index. Shape, color, and texture descriptors were extracted, including geometric features, soft color–texture descriptors (SCTD), colourgram descriptors, and GLCM-based texture features at multiple spatial distances. Seven data blocks were obtained, representing shape, color, and texture information. Supervised classification was performed using PLS-DA (Partial Least Squares Discriminant Analysis), with cross-validation and external test sets. Low and mid-level data fusion strategies were applied to integrate complementary information. Among single block models, shape descriptors showed the best performance, consistent with defects linked to geometric alterations (e.g., broken, chipped, or shell beans). Color-based features, particularly colourgram descriptors, captured complementary variability associated with defect-related color heterogeneity (e.g., quakers), whereas texture descriptors showed limited discriminative power. Data fusion significantly improved classification results by enhancing sensitivity toward defective beans and reducing the imbalance in single-block models. Mid-level fusion achieved the best balance between sensitivity and specificity, with cross-validation efficiency of ~94%, confirmed by external validation. Pairwise fusion combining shape with color or texture achieved comparable performance to full multi-block models with reduced dimensionality, supporting more parsimonious approaches. RGB analysis combined with chemometric modeling represents a viable approach for defect classification in roasted coffee beans. Mid-level data fusion enhances model robustness by integrating complementary morphological, color, and texture information. These findings support the use of integrated and parsimonious feature-based strategies for quality control in specialty coffee.

Keywords: *Digital image analysis; Coffee quality; Computer vision.*

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