Drying effect by infrared radiation on sensory quality in special coffees *(Coffea arabica)* cup

Efecto del secado por radiación infrarroja sobre la calidad sensorial en taza para cafés (*Coffea arabica*) especiales

Efeito da secagem por radiação infravermelha na qualidade sensorial em xícara para cafés (*Coffea arabica*) especiais

Maricely Guevara-Sánchez[1]
Karen Elizabet Guevara-Sánchez[1]
Neiser Quispe-Cubas[2]
Miguel Angel Valles-Coral[3*]
Jorge Raul Navarro-Cabrera[3]
Lloy Pinedo[3]

[1]Asociación de productores Selva Nor Oriental-Aproselvanor, Moyobamba, Perú.
[2]Programa Nacional de Desarrollo Tecnológico e Innovación – ProInnóvate, Perú.
[3]Universidad Nacional de San Martín, Tarapoto, Perú.

Rev. Fac. Agron. (LUZ). 2022, 39(3): e223936
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v39.n3.02

Received: 02-05-2022
Accepted: 10-06-2022
Published: 30-06-2022

Food Technology
Associate editor: Dra. Gretty R. Ettiene Rojas
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela

Keywords:
Cupping
Electromechanical
Heating
Organoleptic
SCAA

Abstract

The drying process of coffee (*Coffea arabica*) is important to achieve quality organoleptic characteristics. The objective of the study was to evaluate the effect of drying by means of an electromechanical system based on infrared on sensory quality in special coffees cup. For this, an electromechanical system was designed using infrared emitters that combines electromagnetic radiation with conventional convective heating. 75 coffee samples were collected at three (3) height levels. The samples underwent the traditional drying process and the electromechanical system, to later be evaluated by professional tasters under the SCAA (Specialty Coffee Association of America) scale. The samples dried with infrared at 12% humidity presented a cupping value of 82.93 for cup coffee with a smaller data dispersion than the traditional system that obtained 81.34, in addition the t-test of non-equivalent samples indicates that its value is significantly better ($p<0.05$). We concluded that the electromechanical system with infrared drying increased the sensory quality of coffee compared to traditional drying.

*Corresponding author: mavalles@unsm.edu.pe

Resumen

El proceso de secado del café (*Coffea arabica*), es importante para lograr características organolépticas de calidad. El objetivo del estudio fue evaluar el efecto del secado mediante un sistema electromecánico basado en infrarrojos sobre la calidad sensorial en taza para cafés especiales. Para ello se diseñó un sistema electromecánico utilizando emisores de infrarrojos que combina radiación electromagnética con calentamiento convencional convectivo. Se recolectaron 75 muestras de café en tres (3) niveles de altura. Las muestras se sometieron al proceso de secado tradicional y al sistema electromecánico, para luego ser evaluadas por catadores profesionales bajo la escala SCAA (Specialty Coffee Association of América). Las muestras secadas con infrarrojo al 12 % de humedad presentaron un valor de catación de 82,93 para café en taza con una dispersión de datos menor que el sistema tradicional que obtuvo 81,34, además la prueba *t* de muestras no equivalentes indica que su valor es significativamente mejor ($p<0,05$). Se concluye que el sistema electromecánico con secado infrarrojo aumentó la calidad sensorial del café con respecto al secado tradicional.

Palabras clave: Calentamiento, catación, electromecánico, organoléptica, SCAA.

Resumo

O processo de secagem do café (*Coffea arabica*) é importante para alcançar características organolépticas de qualidade. O objetivo do estudo foi avaliar o efeito da secagem por meio de um sistema eletromecânico baseado em infravermelho na qualidade sensorial da xícara para cafés especiais. Para isso, foi projetado um sistema eletromecânico utilizando emissores infravermelhos que combina radiação eletromagnética com aquecimento convectivo convencional. Foram coletadas 75 amostras de café em três (3) níveis de altura. As amostras passaram pelo processo de secagem tradicional e pelo sistema eletromecânico, para posteriormente serem avaliadas por provadores profissionais sob a escala SCAA (Specialty Coffee Association of America). As amostras secas com infravermelho a 12% de umidade apresentaram um valor de degustação de 82,93 para xícara de café com dispersão de dados menor que o sistema tradicional que obteve 81,34, além disso o teste t de amostras não equivalentes indica que seu valor é significativamente melhor ($p<0,05$). Conclui-se que o sistema eletromecânico com secagem por infravermelho aumentou a qualidade sensorial do café em relação à secagem tradicional.

Palavras-chave: Aquecimento, degustação, eletromecânico, organoléptico, SCAA.

Introduction

Worldwide, Peru is a benchmark in specialty coffees, producer and exporter of organic coffee, with up to 25 % of the United States market. In fact, its cultivation has become an important axis of the economic and social engine (Guevara-Sánchez *et al*., 2019).

According to Pérez-Escalante *et al*. (2021); Joy Cave. (2020) and Marquez Romero *et al*. (2016), coffee it is the livelihood of the highest percentage of agricultural producing families in the departments of Junín, San Martín and Amazonas, allowing them a decent living standard thanks to they receive the payment of a sustainable price for their cultivation. Coupled with the effect of farmer empowerment strategies based on fair trade certification (Sirdey and Lallau, 2020).

On the other hand, according to the International Coffee Organization (2021) after Brazil and Colombia, Peru is the third largest producer in Latin America with 2.32 % of world production; however, 85 % of coffee growers are small farmers with 1 to 5 ha of crops. In this regard, Díaz Vargas and Willems (2017), point out that small coffee growers have plots without technical or technological management and only 20 % are associated, affecting the productivity and homogeneity of the cup quality of specialty coffees. At the same time, the weak and scattered institutions of the sector mean that organic coffee is sold as conventional.

It should be noted that Aproselvanor (Asociación de Productores Selva Nororiental), has 478 associated producers, of which more than 90 % apply the traditional drying method based on sunlight (Devan *et al*., 2020; Vijayavenkataraman *et al*., 2012), which does not guarantee the physical conditions for the preservation of the optimal organoleptic characteristics and quality of the coffee bean (Tesfa *et al*., 2021), only reaching physical averages of 60 % and 81 points on the scale (Specialty Coffee Association, 2021). The consequences are seen in the decrease in production, due to the characteristics of the grain drying processes, due to loss due to rotting and mold due to poorly controlled humidity.

Aproselvanor exports coffee containers with organic certification and fair-trade seal; however, its capacity is limited by the need to ensure a homogeneous moisture content that ranges between 10 and 12 %, thus avoiding microbiological deterioration, physical damage and loss of coffee quality that is almost impossible to guarantee with the traditional method.

A stage of the drying process that needs to be controlled is that of grain filling, which is affected by the average temperature of the environment, a parameter that affects the acidity and fruity character of the drink (Bote and Jan, 2021).

The traditional drying system used by coffee farmers, documented by Devan *et al*. (2020) and Vijayavenkataraman *et al*. (2012), accompanied by hydrometeorological conditions with significant rainfall in the province, prevent standardizing the results of the process, causing losses due to uncontrolled fermentations when exposed to humidity and inadequate drying that changes the physical and sensory quality of the product due to the production of volatile compounds associated with the undesirable aroma of the grain (Leobet *et al*., 2019), having to be classified as conventional coffees with a low price in the market. According to Zartha Sossa *et al*. (2021) the damage in the nutritional and organoleptic characteristics to which the products are subjected are quite high.

For Aproselvanor, controlling the moisture present in the grains is a great challenge, how it is stored, the environmental humidity, the variety of the grain and the size of the particles, determine the humidity during the drying process, thus guaranteeing the increase in grain shelf life by reducing moisture and inactivating microorganisms (Meenu *et al*., 2017). For this, different drying methods were identified, some based on heating, infrared and intermittent microwaves (Castellanos *et al*., 2018; Kaveh *et al*., 2021), but the lack of facilities, techniques and technology for post-harvest activities affects in the quality of the coffee in the cup obtained (Lao *et al*., 2019).

Regarding infrared (IR) emitters, there are basically two types used in the industry, electric IR and gas IR (Pan and Atungulu, 2010). Electric IRs emit any wavelength from short to long wavelength, gas IRs emit medium or long wavelength offering advantages (Su *et al*., 2015). The device combines electromagnetic radiation with conventional convective heating (Aghbashlo, 2015), considered more efficient than both techniques separately (Zhang *et al*., 2019), with high efficiency and potential energy savings (Lao *et al*., 2019).

The objective of this study was to evaluate the effect of drying by means of an electromechanical system based on infrared on sensory quality in the cup for special coffees, for which infrared radiation was used, which directly heats the product, with little heat loss in the surrounding air, leading to high energy efficiency and reduced drying time due to high heating rates. In addition, with the convection heated drying air, the evaporated water is removed in the form of saturated air, achieving efficient drying.

In this sense, an electromechanical drying system based on far infrared technology was designed and built, which according to Chunshan *et al*. (2016), is a method to save energy and obtain effective drying, to control the process indicators that include temperature and relative humidity of the drying environment, time used, resulting humidity, allowing the standardization and homogenization of the process.

Materials and methods

Construction of electromechanical drying system with far infrared (FIR) technology

The prototype was designed, acquiring structural materials, equipment, accessories with far infrared technology for its assembly, motors, movement transmission elements and heat transfer elements such as infrared panels.

Sample Collection

The collection of the coffee bean was carried out in 30 plots of the provinces of Moyobamba and Rioja, which are at an altitude of between 850 and 1,600 m.a.s.l. These were grouped and classified by low zone, middle zone and high zone. Thirty samples of 300 g of clean green coffee (without defects) dried in the traditional way were collected: 10 with an average of 12.96 % humidity from the lower area; 10 with an average of 13.13 % humidity in the middle area and 10 with 14.83 % humidity in the high area. Also included were 45 samples of 300 g of clean green coffee (without defects) dried with the electromechanical system based on far infrared (IR) technology with 12 % humidity: 15 samples from the lower area, 15 from the middle area and 15 from the high area.

The collected samples received in bags with hermetic closures were subjected to organoleptic analysis (fragrance, flavor, residual taste, acidity, body, uniformity, balance, clean cup, sweetness and taster score), through tasting sessions, in which forms endorsed by the SCAA (Specialty Coffee Association of America) were applied, in order to assess the organoleptic characteristics with scores ranging between 6 and 10 per attribute (being 6 - 6.75 good, 7 - 7.75 very good, 8 - 8.75 excellent and 9 - 9.75 extraordinary), resulting in the average sensory quality classification based on the total score of the sum of the qualified attributes (less than 80 below specialty quality; 80 - 84.99 very good; 85 - 89.99 excellent; 90 - 100 extraordinary). The tastings were carried out on homogeneous samples of coffee, with the same levels of roasting, quantity and conditions.

Coffee cupping procedure

The samples were dried, stacked, without defects, exportable gold coffee variety were roasted from 8 to 12 minutes, from 63 to 58 on the Agtron roasting scale in grain and ground, from 8 to 24 hours prior to cupping. They were stored in a cool, dry and dark place for nine (9) hours of rest. Subsequently, 10 g of coffee were ground at 70 - 75 %, 15 minutes before infusion with 200 mL of water. The "dry" tasting was carried out to determine fragrance, smelling and assessing in the file.

"In a cup", water at 93 °C was added homogeneously. For the analysis, the nose is brought closer to the cup and with a deep inhalation the aromas are transmitted and identified, forming foam or crust, the taster smells the aroma that he values. After three (3) to five (5) minutes of rest, with three gentle movements with a spoon, the crust was broken, which developed the aromas for evaluation.

For the taste, acidity and body test, the crust was removed and only coffee with liquid was left at 71 °C. The parameters were determined by absorbing the coffee with the testing spoon covering the mouth, tongue and upper palate and spitting out the drink.

The final analysis was uniformity, sweetness and clean cup. It was obtained by testing each cup, no more than five per sample. The process was based, in the same way, on the absorption and determination by the sense of taste.

The peculiarities were scored and noted. Tastings with characteristics that were not favorable to the quality of the product throughout the process were punished and valued as defects, lowering the final evaluation.

Results and discussion

Construction of the electromechanical drying system with far infrared technology

System design

For the design, AutoCAD was used for the 2D structural plans, and Autodesk Inventor Professional for the modeling of 3D views, resulting in the designs shown in figures 1 and 2, in which, geometrically, a cylindrical shape positioned horizontally whose rotation it is achieved thanks to a system of driving force multiplied by gear and pinion transmission.

Rotating cylindrical drying chamber

The cylinder was perforated 1.2 m x 2.4 m, for the coffee beans, this perforated surface served to transfer far infrared rays and facilitate vapor evacuation. Technically, the rate of heat transfer is in equilibrium with the latent heat consumed by evaporation. During this condition, most of the water evaporates including moisture on the surface of the product; the rate of heat transfer is greater than the latent heat consumed by evaporation and the temperature of the product increases, in this sense, the rate of drying decreases and is controlled by the rate of diffusion of water on the surface of the product (Adonis and Khan, 2004).

Preheated air blower or fan and heater unit

They are responsible for heating and injecting the heated air flow into the rotary dryer, which is distributed by the interior air diffuser that is attached to the rotary cylinder chamber. The heating system delivers heat from two infrared burners whose fuel used It was liquefied petroleum gas (LPG) and coffee husks.

The emitters are distributed on both sides of the drying chamber, internally and externally, a panel holder and a displacement mechanism have been conditioned for their handling. They are responsible for the emission of far infrared waves from the center of the prototype to the receptors that are the wet coffee beans subjected to drying. In Figure 2 it appears unfolded thanks to the mounting system attached to it.

Assembly and installation of the drying prototype and its components

The joint assembly was carried out for function tests and calibration, provision of adequate electricity supply to its drives and emitters of far infrared waves. Knowing the elements that are part of the electrical circuit, the control system required to carry out the start-up and start-up of the actuator that is part of the prototype was designed.

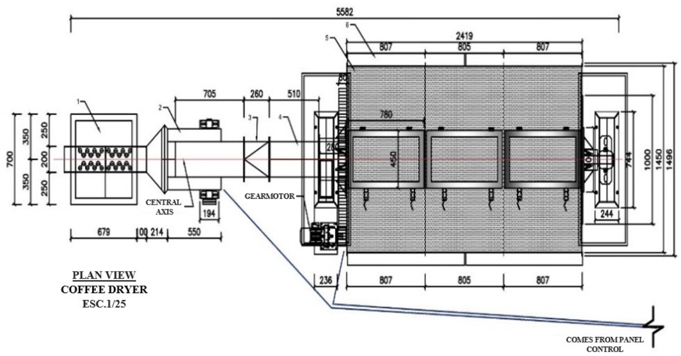

Figure 1. 2D design of the far infrared rotary dryer.

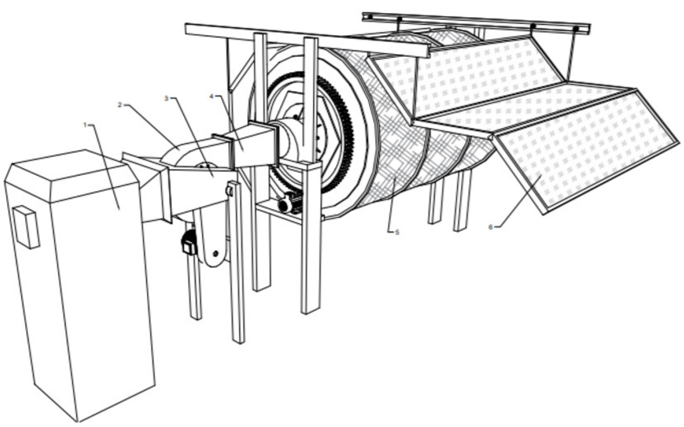

Figure 2. 3D design of the far infrared rotary dryer.

Sensor mounting

For humidity measurement, a microwave sensor was used whose operating characteristics have been carefully evaluated and selected. For the temperature measurement of the heated air flow, a J-type temperature sensor was used. For the loading and unloading positioning of the equipment, inductive sensors were used.

Drying time

Figure 3 presents the values of the drying speed and temperature inside the cylindrical chamber used in the IR system, the results of the middle zone (1271 m.a.s.l.) were used as a reference.

It is observed in figure 3, that the drying time with IR was approximately 12 hours, reducing the humidity of the coffee bean from 34.62 to 13.13 %, during the drying process the temperature of the cylindrical chamber worked in the range from 35.20 to 87.20 °C, likewise, the physical temperature of the coffee beans ranged between 23.96 °C minimum and 44.62 °C maximum. It should be considered as the altitude of the collected grain samples increases, that the incident radiation decreases, so the heat transfer is less, which affects the increase in the drying time of the coffee beans (Guevara-Sánchez *et al*., 2019). Therefore, the statement applies, in this case, if the height is less, the time used for the drying process will be less.

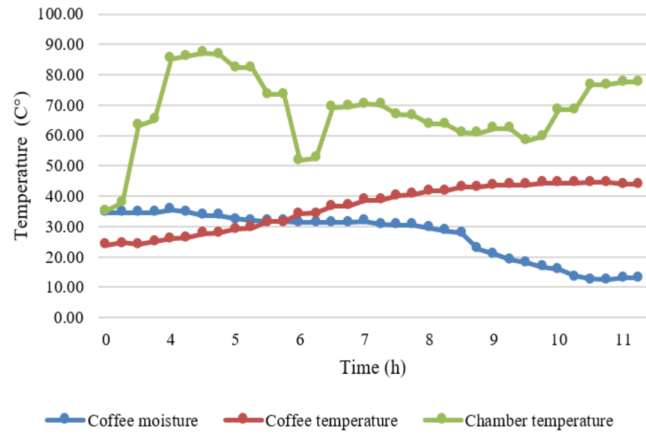

Figure 3. Time and temperature used for infrared drying.

Harvest height, cupping and moisture percentage

The results obtained from the cupping according to the Specialty Coffee Association (2021), the harvest height and the percentage of humidity of the samples obtained by the traditional method are presented in table 1. Thus, on average the samples from the lower area presented 80.15 in tasting, 814 m.a.s.l. and 12.96 %; in the middle area, 81.22 in tasting, 1271 m.a.s.l. and 13.13 %; in the upper area 82.65 in tasting; 1460 m.a.s.l. and 14.83 %, respectively. The result of the cupping according to the Specialty Coffee Association (2021), harvest height and moisture percentage obtained by the infrared-based electromechanical system is shown in table 2. On average, the samples from the lower area presented 82.05 in cupping, 818.3 m.a.s.l. and 12.96% humidity; in the middle area they reached 83.05 in tasting and 1,270 m.a.s.l.; in the high area 83.70 and 1 460 m.a.s.l., respectively. Due to the infrared-based electromechanical drying system, the samples reached a relative humidity of 12%.

Analysis of the results of coffee cupping

Based on the data obtained in the organoleptic evaluation forms of the coffee beans, a comparative descriptive statistical analysis was carried out (table 3) of the two types of drying.

The descriptive results obtained show better values in the organoleptic characteristics evaluated for the case of the IR system, which were like those reported by Guevara-Sánchez *et al*. (2019), in which the flavor, fragrance, acidity and body attributes of the coffee tasted by specialists, made with mechanical drying, obtained higher values compared to the traditional method, favoring the cup score with up to 2 % more than performance. Likewise, in the study carried out by Lao *et al*. (2019), in which they used the IR-based electromechanical system, achieved the objective of producing high-quality food efficiently.

Subsequently, different inferential statistical tests were carried out (table 4) that allowed the analysis of the results and gave greater support to the process.

The mean with the traditional method was 81.34, with standard deviation and mean standard error higher than the mean of 82.93 for the electromechanical system. This indicates that the cupping value with the electromechanical system is higher and the data is less dispersed. To validate this statement, the data normality test was carried out (table 5).

Table 1. Tasting value, harvest height and moisture percentage obtained by the traditional method.

Low area				Middle area				High area			
Sample	SCAA	Height	% Humidity	Sample	SCAA	Height	% Humidity	Sample	SCAA	Height	% Humidity
A-01	80.25	850	12.0	A-11	81.75	1200	13.0	A-21	82.50	1400	14.0
A-02	79.75	900	12.5	A-12	81.50	1250	13.0	A-22	82.50	1430	15.3
A-03	82.00	920	13.5	A-13	81.50	1100	13.8	A-23	82.00	1500	16.0
A-04	81.50	880	14.0	A-14	80.50	1300	14.0	A-24	82.50	1550	13.0
A-05	80.78	780	12.0	A-15	81.25	1350	13.0	A-25	82.75	1600	12.0
A-06	81.00	700	12.0	A-16	81.75	1400	12.5	A-26	83.25	1300	17.0
A-07	80.00	720	12.5	A-17	80.25	1380	12.0	A-27	82.75	1460	13.5
A-08	72.00	800	13.6	A-18	81.75	1250	13.0	A-28	82.25	1600	17.5
A-09	82.25	790	14.0	A-19	80.50	1200	14.0	A-29	82.50	1360	12.0
A-10	82.00	800	13.5	A-20	81.50	1280	13.0	A-30	83.50	1400	18.0
Mean	80.15	814	12.96	Mean	81.22	1271	13.13	Mean	82.65	1460	14.83

Table 2. Tasting value, harvest height and humidity percentage obtained by the infrared-based electromechanical system.

Low area			Middle area			High area		
Sample	Taste	Height	Sample	Taste	Height	Sample	Taste	Height
SEC-001	82.50	890	SEC-016	82.75	1183	SEC-031	83.00	1443
SEC-002	82.25	890	SEC017	83.50	1183	SEC032	83.50	1443
SEC-003	81.50	890	SEC-018	83.25	1183	SEC-033	83.25	1443
SEC-004	82.00	890	SEC-019	82.50	1183	SEC-034	84.00	1443
SEC-005	82.25	890	SEC-020	83.00	1183	SEC-035	82.50	1443
SEC-006	82.50	787	SEC-021	83.75	1350	SEC-036	83.50	1483
SEC-007	82.50	787	SEC-022	83.25	1350	SEC-037	84.00	1483
SEC-008	82.00	787	SEC-023	82.50	1350	SEC-038	84.20	1483
SEC-009	82.25	787	SEC-024	82.75	1350	SEC-039	83.00	1483
SEC-010	81.00	787	SEC-025	83.25	1350	SEC-040	84.00	1483
SEC-011	82.00	778	SEC-026	83.50	1278	SEC-041	83.75	1455
SEC-012	82.50	778	SEC-027	82.50	1278	SEC-042	84.00	1455
SEC-013	81.75	778	SEC-028	82.50	1278	SEC-043	84.25	1455
SEC-014	81.50	778	SEC-029	83.50	1278	SEC-044	84.50	1455
SEC-015	82.25	778	SEC-030	83.25	1278	SEC-045	84.00	1455
Mean	82.05	818.3	Mean	83.05	1270	Mean	83.70	1460

Note: The humidity percentage obtained with the electromechanical system was 12 %.

Table 3. Effect of the type of drying on the SCAA value.

	Traditional drying			Drying with IR technology		
Analysis	Low	Middle	High	Low	Middle	High
Fragrance	7.25	7.50	7.50	7.50	7.75	7.75
Taste	7.25	7.50	7.50	7.50	7.75	7.75
Residual taste	7.00	7.00	7.50	7.50	7.50	7.50
Acidity	7.25	7.25	7.50	7.50	7.50	7.75
Body	7.00	7.25	7.50	7.50	7.50	7.75
Uniformity	10.00	10.00	10.00	10.00	10.00	10.00
Balance	7.25	7.50	7.50	7.50	7.50	7.75
clean cup	10.00	10.00	10.00	10.00	10.00	10.00
Sweetness	10.00	10.00	10.00	10.00	10.00	10.00
Taster score	7.00	7.25	7.50	7.25	7.50	7.50
Total score	80.00	81.25	8.5	82.00	83.00	83.75

Table 4. Main statistics of the tasting process by type of drying.

Item	drying	N	Mean	Standard deviation	Mean standard error
Taste	Traditional	30	81.34	2.01	0.37
	Electromechanical system	45	82.93	0.83	0.12

Table 5. Normality tests.

Item	Drying type	Kolmogorov-Smirnova >30			Shapiro-Wilk <= 30		
		Statistical	DF	Sig.	Statistical	DF	Sig.
Tasting	Electromechanical	0.14	45	0.02	0.97	45	0.34
	Traditional	0.20	30	0.00	0.64	30	0.00
a. Lilliefors significance correction							

The results of the cupping in both treatments presented a normal distribution (tables 4 and 5). The t-test for independent samples was applied (table 6).

Table 6. Independent samples test.

		Levene test for equality of variances		*t* test for equality of means						
		F	Sig.	T	DF	Sig. (bilateral)	Mean difference	Standard error difference	95% CI of the difference	
									Lower	Higher
Tasting	Equal variances	2.99	0.09	4.74	73	0.00	1.59	0.34	0.92	2.26
	Non-equal variances			4.11	35.70	0.00	1.59	0.39	0.80	2.37

In tables 4 and 6, it is observed that the cupping value of samples dried with the IR system was different from the traditional system (P<0.05), so it is inferred that with the electromechanical prototype a greater effectiveness in sensory quality of coffee was obtained. Similar results were reported in different studies, in which the highest cupping values were obtained through artificial drying, using drying tunnels based on heated air (Tesfa et al., 2021), by far infrared convection (Chunshan et al., 2016; Lao et al., 2019), and by mechanical drying (Guevara-Sánchez et al., 2019).

Conclusions

The built electromechanical drying system works safely. The function tests, temperature and heat transfer tests of the heating unit, as well as the correct displacement of the external emitters in its bearing structure were successful. Humidity, temperature and positioning sensors have been installed by specialists in instrumentation, connectivity and programming.

The results indicate that the infrared-based electromechanical system increased the sensory quality of the coffee compared to traditional drying, since the sensory quality of the beans at the evaluated altitudes was higher. Likewise, the values of the applied tasting and statistical tests showed that the sensory quality obtained is due to the type of drying used that preserves the attributes of the coffee. Determining that electromechanical drying is an efficient and effective alternative for the drying processing of coffee beans for the agricultural sector, which seeks to ensure the appropriate organoleptic characteristics for the commercialization of specialty coffees.

Acnowledgements

To the Programa Nacional de Desarrollo Tecnológico e Innovación - ProInnóvate for the financing of the project "Incremento de la calidad en taza para cafés especiales con la aplicación y validación de un sistema electro-mecánico de secado, con tecnología de infrarrojos lejanos (IR) en Aproselvanor, Provincia Moyobamba - Región San Martín", Contract No. 293-INNOVATEPERU-PIEC1-2019.

Literature cited

Adonis, M. and Khan, M. T. E. (2004). Combined convective and infrared drying model for food applications. *2004 IEEE Africon. 7th Africon Conference in Africa (IEEE Cat. No.04CH37590)*, *2*, 1049–1052. https://doi.org/10.1109/AFRICON.2004.1406850

Aghbashlo, M. (2015). A proposed mathematical model for exergy analysis of an infrared (IR) drying process. *International Journal of Exergy*, *18*(4), 480–500. https://doi.org/10.1504/IJEX.2015.072912

Bote, A. D. and Jan, V. (2021). Tree management and environmental conditions affect coffee (*Coffea arabica* L.) bean quality. *NJAS: Wageningen Journal of Life Sciences*, *83*(1), 39–46. https://doi.org/10.1016/J.NJAS.2017.09.002

Castellanos, J. M., Quintero, C. S. and Carreno, R. (2018). Changes on chemical composition of cocoa beans due to combined convection and infrared radiation on a rotary dryer. *3rd International Congress of Mechanical Engineering and Agricultural Science (CIIMCA 2017)*, *437*(1), 012011. https://doi.org/10.1088/1757-899X/437/1/012011

Chunshan, L., Siyu, C., Wenfu, W., Rui, W. and Hao, Z. (2016). Experimental study on Heat Transfer Effect of Far Infrared Convection Combined Drying. *2016 International Conference on Intelligent Transportation, Big Data and Smart City, ICITBS 2016*, 505–508. https://doi.org/10.1109/ICITBS.2016.38

Cueva Alegría, D. (2020). Branding of an Ethical Development Narrative: Fair Trade, Gender, and Peru's Café Femenino. In *Handbook of the Changing World Language Map* (Vol. 1, pp. 4001–4015). Springer, Cham. https://doi.org/10.1007/978-3-030-02438-3_163

Devan, P. K., Bibin, C., Asburris Shabrin, I., Gokulnath, R. and Karthick, D. (2020). Solar drying of fruits – A comprehensive review. *International Conference on Future Generation Functional Materials and Research 2020, 33*, 253–260. https://doi.org/10.1016/J.MATPR.2020.04.041

Díaz Vargas, C. and Willems, M. C. (2017). Línea de Base del Sector Café en el Perú. https://www.midagri.gob.pe/portal/pncafe-publicaciones/20118-linea-de-base-del-sector-cafe-en-el-peru

Guevara-Sánchez, M., Bernales del Águila, C. I., Saavedra-Ramírez, J. and Owaki-López, J. J. (2019). Efecto de la altitud en la calidad del café (*Coffea arabica* L.): comparación entre secado mecánico y tradicional. *Scientia Agropecuaria*, *10*(4), 505–510. https://doi.org/10.17268/SCI.AGROPECU.2019.04.07

International Coffee Organization. (2021). Historical Data on the Global Coffee Trade. https://www.ico.org/new_historical.asp?section=Statistics

Kaveh, M., Abbaspour-Gilandeh, Y., Fatemi, H. and Chen, G. (2021). Impact of different drying methods on the drying time, energy, and quality of green peas. *Journal of Food Processing and Preservation*, *45*(6), e15503. https://doi.org/10.1111/JFPP.15503

Lao, Y., Zhang, M., Chitrakar, B., Bhandari, B. and Fan, D. (2019). Efficient Plant Foods Processing Based on Infrared Heating. *Food Reviews International*, *35*(7), 640–663. https://doi.org/10.1080/87559129.2019.1600537

Leobet, E. L., Perin, E. C., Fontanini, J. I. C., Prado, N. V., Oro, S. R., Burgardt, V. C. F., Alfaro, A. T. and Machado-Lunkes, A. (2019). Effect of the drying process on the volatile compounds and sensory quality of agglomerated instant coffee. *Drying Technology , 38*(11), 1421–1432. https://doi.org/10.1080/07373937.2019.1644347

Márquez Romero, F., Julca Otiniano, A., Canto Saenz, M., Soplín Villacorta, H., Vargas Winstanley, S. and Huerta Fernández, P. (2016). Environmental sustainability in coffee farms after an organic certification process at la convencion (Cusco, Perú). *Ecología Aplicada, 15*(2), ág. 125-132. https://doi.org/10.21704/REA.V15I2.752

Meenu, M., Guha, P. and Mishra, S. (2017). Coupled heat and moisture transfer of a single mung bean grain based on IR heating. *International Journal of Modeling, Simulation, and Scientific Computing, 8*(2). https://doi.org/10.1142/S1793962317400013

Pan, Z. and Atungulu, G. G. (2010). Infrared Heating for Food and Agricultural Processing (1st ed.). CRC Press. https://doi.org/10.1201/9781420090994

Pérez-Escalante, J. J., Gómez-Chávez, I. A. and Estela-Escalante, W. D. (2021). Isolation of microorganisms from the feces of ring-tailed coati related to the production of "misha coffee" in the central forest of Peru and evaluation of some features of technological importance. *Microbiological Research, 245*, 126670. https://doi.org/10.1016/J.MICRES.2020.126670

Sirdey, N. and Lallau, B. (2020). How do producer organisations enhance farmers' empowerment in the context of fair trade certification? *Oxford Development Studies, 48*(2), 166–180. https://doi.org/10.1080/13600818.2020.1725962

Specialty Coffee Association. (2021). Protocols *and* Best Practices. https://sca.coffee/research/protocols-best-practices

Su, Y., Zhang, M. and Mujumdar, A. S. (2015). Recent Developments in Smart Drying Technology. *Drying Technology, 33*(3), 260–276. https://doi.org/10.1080/07373937.2014.985382

Tesfa, M., Sualeh, A. and Mekonen, N. (2021). Assessment of the Effectiveness of Coffee De-mucilager and Driers for Physical and Sensorial Coffee Quality. *World Journal of Food Science and Technology, 5*(2), 36. https://doi.org/10.11648/J.WJFST.20210502.13

Vijayavenkataraman, S., Iniyan, S. and Goic, R. (2012). A review of solar drying technologies. *Renewable and Sustainable Energy Reviews, 16*(5), 2652–2670. https://doi.org/10.1016/J.RSER.2012.01.007

Zartha Sossa, J. W., Orozco, G. L., García Murillo, L. M., Peña Osorio, M. and Sánchez Suarez, N. (2021). Infrared Drying Trends Applied to Fruit. *Frontiers in Sustainable Food Systems, 5*, 115. https://doi.org/10.3389/fsufs.2021.650690

Zhang, W. P., Chen, C., Pan, Z., Xiao, H. W., Xie, L., Gao, Z. J. and Zheng, Z. A. (2019). Design and performance evaluation of a pilot-scale pulsed vacuum infrared drying (PVID) system for drying of berries. *Drying Technology, 38*(10), 1340–1355. https://doi.org/10.1080/07373937.2019.1639725