ISSN 0798 1015

REVISTA ESPACIOS

Vol. 38 (Nº 29) Año 2017. Pág. 27

State of the art of coffee drying technologies in Colombia and their global development

Estado de las tecnologías de secado de café en Colombia y avances a nivel mundial

Luis Carlos OLMOS Villalba 1; Eduardo Alexander DUQUE Grisales 2; Elizabeth RODRIGUEZ 3

Recibido: 16/01/2017 • Aprobado: 12/02/2017

Content

ABSTRACT:
One of the most relevant stages of coffee processing is drying due to the fact that it affects the quality of the organoleptic properties of the product. At this stage, there are crucial variables such as the drying time, temperature, airflow, and the physical-chemical characteristics of the drying agent in contact with the grains, and the thickness of the drying layer, among others. This research shortly reviews the coffee drying process, the current technologies used at a national level and international technological development opportunities in order to identify the current status of the process.
Key words Colombia, coffee drying process, coffee quality, drying technologies, organoleptic properties

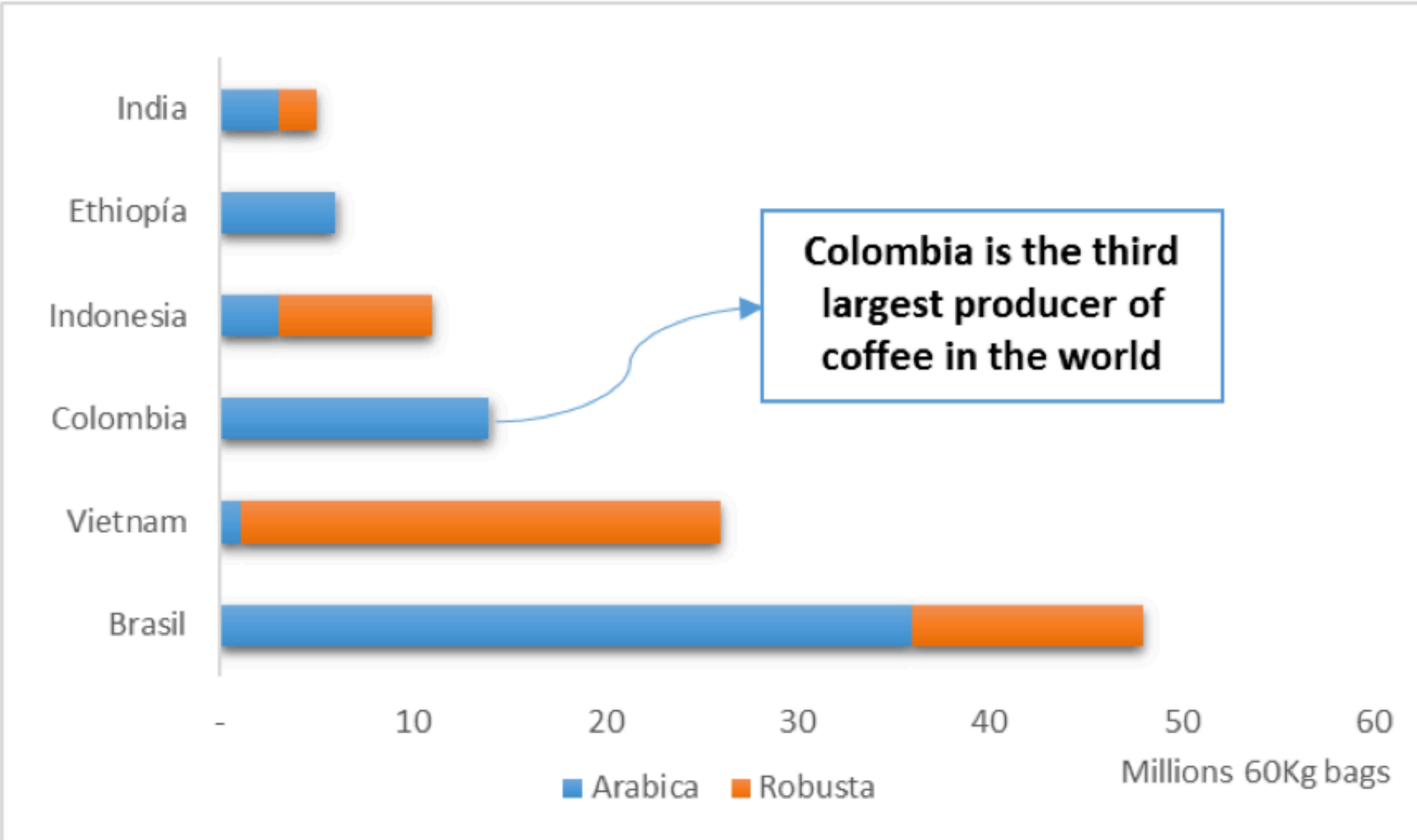
RESUMEN:
En el proceso de beneficio del café, la operación de secado es de gran importancia puesto que afecta significativamente la calidad de las propiedades organolépticas del producto; en esta etapa existen variables cruciales como son el tiempo de secado, la temperatura, el flujo y las características fisicoquímicas del agente de secado que entra en contacto con el grano, el espesor de la capa de secado, entre otras. En este trabajo se realiza una revisión sobre las tecnologías de secado de café a nivel nacional y los avances tecnológicos y oportunidades de mejoramiento a nivel mundial con el fin de identificar el estado actual del proceso.
Palabras clave: Colombia, proceso de secado del café, calidad del café, tecnologías de secado, propiedades organolépticas.

1. Introduction

Coffee is one of the most consumed products worldwide despite of the difficulties coffee growing sectors face related to lack of technology, economic resources and plagues among others. The International Coffee Organization (ICO) presents this grain as one of the most valuable commodity products and therefore, very important for the world's economy. For many countries, coffee exports constitute a crucial part of their income in foreign currency. According to the ICO, the world coffee production in 2015-2016, represented an equivalent to 147,994 thousand 60Kg bags; that's 9,17% more than the quantity registered in 2014-2015 [1,2].

Globally the two most economically important species of coffee are Coffea arabica (Arabica coffee), a high quality coffee which constitutes over 60% of world production, and Coffea canephora (Robusta coffee) which is of relatively low quality compared to Arabica. Colombia produces Arabica coffee, and has been the world's fourth largest producer after Brazil, Vietnam, and Indonesia. The following graph shows this production according to the variety.

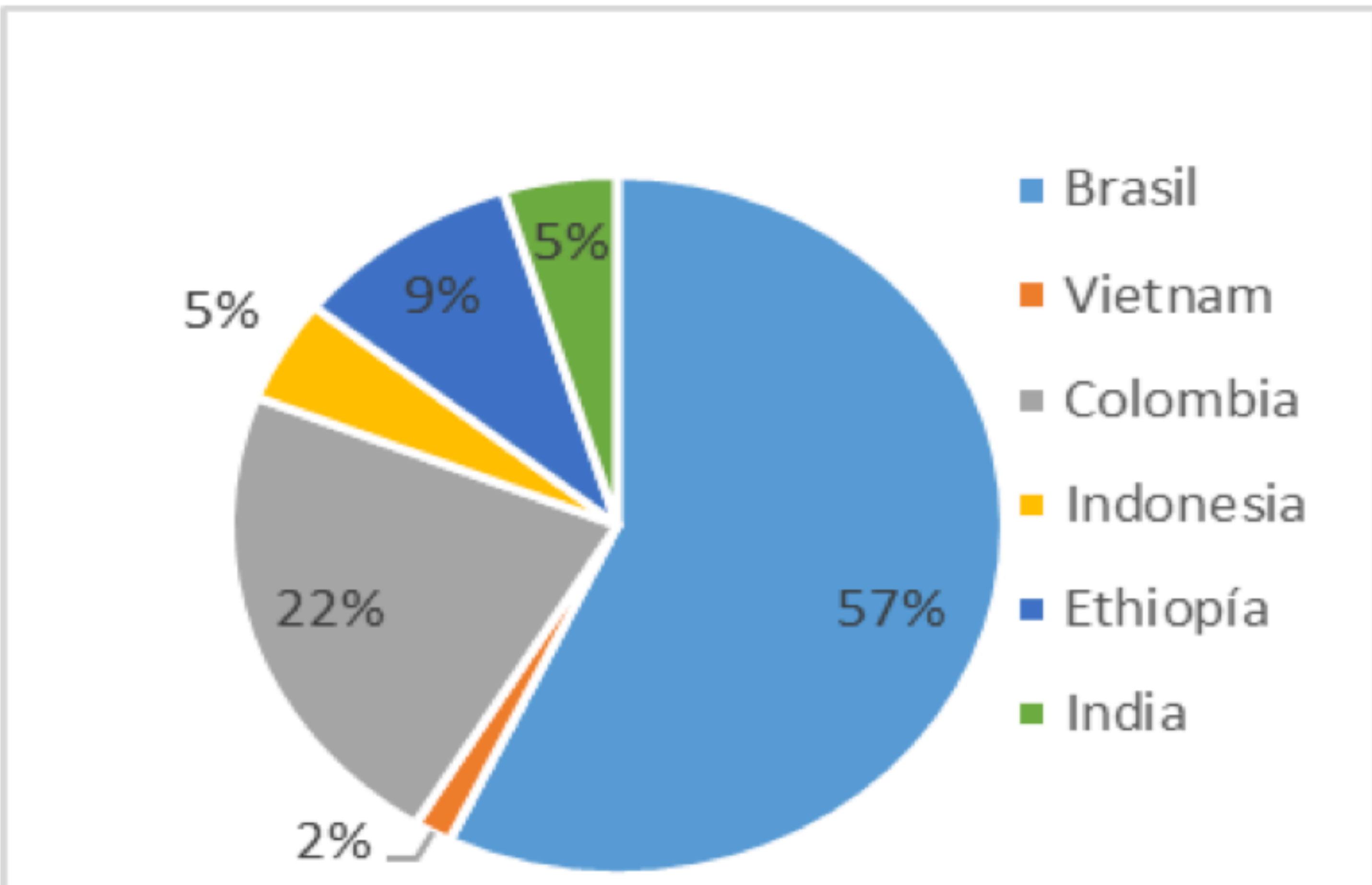
Graph 1. World's coffee production in 2015 in millions of bags.



Source: Own elaboration from [1]

As for the variety of Arabica coffee, Colombia produces 22% of the world's arabica coffee with a value of 14 million 60Kg bags. Brazil ranks first with 57% of the total production.

Graph 2. World's Arabica coffee production in 2015.



Source: Own elaboration from [1]

Due to coffee's production and commercialization chain, it is necessary for the grain to maintain its physical and sensorial quality, and its innocuousness, which is closely related with the drying process; this helps its conservation [4,5]. This process also allows substantial modifications in the physical chemical and functional properties of some elements or important nutritional components which provide functionality to the feeding material [6,7].

There are two universally known methods for processing coffee: one by means of a dry method and the other one through a humid method. In the first one, the grain is not separated from the pulp; it means that coffee seeds are dried without being separated from the grain. The second one consists in extracting the seed before the drying process. In the dry method, there are variations in the process depending on the size of the coffee plantation, the premises, and the desired final quality. Normally this method involves sun drying. It may even take up to four weeks to dry the coffee beans due to their maximum level of humidity content (12.5%), depending on atmospheric conditions. In larger coffee plantations, the drying is made by a machine in order to accelerate the process after the grains have gone through sun drying. Dried coffee beans are then bulk stored in special grain storage units (silos) until they are sent to the mill; there they are winnowed, separated, classified, and put into bags. The peeler removes all exterior layers of the dried coffee cherry [1].

Regarding the humid method, the use of enormous quantities of water is required. When it is appropriately done, the intrinsic attributes of coffee beans are better conserved; the green coffee is homogeneous with few defective grains. Therefore, the coffee processed through this method is considered as better quality and consequently, it can obtain higher prices when traded. In this case, the grain is separated from the pulp of the coffee cherry; the mucilage shall be completely removed in order to prevent that coffee grains get contaminated resulting in degradation from mucilaginous substances. Grains which pulp has been removed are then placed in big fermentation tanks in which, the mucilaginous substances are decomposed under the influence of natural enzymes until they get dispersed and the water is taken away. For most coffees, the elimination of the mucilaginous substances takes between 12 and 36 hours [8]. After the coffee is washed, the grains should be dried in order to reduce its 53% humidity; due to the current trading conditions this percentage should reach a value between 10% and 12 % [4,9–13]. For reducing humidity, pergamino (in parchment) coffee is dried, either under the sun or in a mechanical dryer, or combining both methods. Sun drying is made on large smooth surfaces of bricks and cement called “patios”, or on fine mesh tables. This type of drying should take between 8 to 10 days (according to atmospheric temperature and humidity conditions). Mechanical drying is a technological answer to have control of the process independent from environmental conditions; it helps to reduce the drying time and increase capacity. Nevertheless, the process needs great care in order to obtain a satisfactory and economic drying without affecting the quality of the product. The lack of air during drying, the airflow, and the static pressure are generally the main difficulties in drying places; this can occur due to the use of inappropriate ventilators, design faults, selection or operation. The inappropriate selection of ventilators can lead to excessive periods of drying [12,14]. The following table shows the most common defects in coffee almonds related to inappropriate drying

Table 1. Most common defects in coffee almonds related to inappropriate drying

Defect	**Cause**
Black coloration	Prolonged fermentation or interruptions during drying or incorrect drying.
Crystallization	Exposure to temperatures higher than 50°C during drying.
Bleached or seamed beans	High surface or air temperatures; excessive drying time or re-humidification of grains after drying.

Source: Own elaboration from [15–17].

Due to the importance of the drying process in coffee quality, the status of this technology in Colombia and its main advances have been analyzed. After this, these advances will be compared to those in coffee process technology worldwide.

2. Coffee drying in Colombia

Some regions in the country have optimum conditions for coffee growing. These conditions and drying methods have made Colombian coffee one of the most valued ones worldwide [18,19].

Some developments in Colombia have contributed to improve the technification of the grain process; this fact increases the quality of the product, reduces costs and the environmental impact. In Colombia, the previously mentioned humid method is used. Consequently, the drying is carried out through a mix of mechanical methods and sun drying. Coffee growers combine both methods mainly during poor harvest seasons or to pre-dry the grains under the sun before using the mechanical drying [20–22].

Sun drying is used in farms with productions lower than 500 arrobas (one arroba equals 11,502 kilos) of dried coffee per year [23]. This drying is made on cement patios with a one-degree inclination slope, drying carts, elbas (wooden boxes with wood or cement floor and zinc roofing), marquesinas (a cement slab covered with a dome-like plastic structure) or parabolic dryers; these are the most efficient methods. The drying areas are between 12 and 150 square meters; they are exclusively used in farm production. The required time for drying is between 7 and 15 days depending on temperature variations and rains; there are different configurations including rotating, parabolic, and the conventional carts [24]. However, Sun drying can be both inefficient and time consuming in terms of heat utilization.

The mechanical drying is used in farms with a production higher than 500 arrobas of dried coffee per year. It is made in chambers, in which hot air is introduced under a maximum temperature of 52 degrees centigrade driven by a ventilator [25]. The air may be heated with burners or stoves, which run with ACPM, mineral carbon and electricity [26]. In silos, the coffee lasts between 25 and 32 hours. There are different configurations such as the static dryer (the simplest one) and layers of coffee up to 40 cm of thickness may be used. The air goes in through the upper part and is inverted every 6 or 12 hours in order to obtain better uniformity in the humidity content of the grain. There is also the drying silo, which has an air heating unit, a ventilator and two chambers in which the grain is deposited; one for pre-drying and the other for drying. Additionally, there is the Vertical drying silo; in this, the air leaving the lower chamber goes to the higher chamber, making pre-drying in an ascending way. The smoke from combustion vapors cannot be in contact with the grain [25,27,28].

The most used mechanical dryers in Colombia are those of static layer in which the air is forced to pass through a heat exchanger, through the drying chamber and through the layers of coffee grains. When they pass through the first one, the air increases its temperature, reduces both its relative humidity and vapor pressure, which is the one that finally provides the air its drying potential. The maximum temperature to which coffee grains may be exposed without suffering irreversible damages in their internal structure, is 50 degrees centigrade (energetic requirement of 7,000 kJ/kg of evaporated water); in atmospheric conditions of the coffee plantation zone in Colombia, this heating corresponds to a relative humidity under 20 % [4,29–31].

The sun drying brings biological and chemical risks directly related to the permanence of coffee grains with high contents of humidity for large periods. The aspegillus fungus ochraceus may produce ochratoxine A (OTA) in humid coffee. This a toxic and carcinogenic substance that has been monitored in several foods besides coffee; its effects range from contamination due to the contact with animals to diseases such as Leishmaniasis due to operational practices in coffee plantations [10,32].

Early research in coffee drying operations conducted by Centro Nacional de Investigaciones de Café, CENICAFE (The national coffee research center) indicated that sun drying was mainly used for small farms with good results. In 1978, studies were directed to analyze the variables involved in the sun drying process. Among the obtained results, there were: an increase in the drying efficiency for thickness up to 5 cm; an efficiency of 65 % [33]. Unfortunately, due to scarcity of techniques, one of the frequent results were the excessive drying of coffee or crystallization (see Table1). This problem increased the costs of coffee processing; when coffee presented from 10 to 7 % of humidity, the economic loss for coffee growers was between 1.7 % and 4.8 % (out of the costs due to the higher wear of the equipment) [34].

Due to the deficiencies in drying capacities, the lack of resources for investing in technology and the lack of knowledge on appropriate coffee drying, in 2001, the trade of humid pergamino increased; this increased the risk of quality deterioration of grains. Studies carried out at that moment showed that the sale of properly dried coffee is economically more advantageous; the product obtains good profit besides the increase of coffee quality which, in turn, may also increase the value [16].

Normally, to determine the humidity of grains, workers used subjective methods based on the color and hardness of the grain, which is not a precise method and generates excessive costs in the process besides affecting the quality of the product since it favors chemical degradation. In solar and mechanical coffee dryers, the Gravimet method was developed. This allows taking the grain to the recommended humidity levels between 10% and 12 % through concentric cylinders; they are filled until a certain level with coffee grains, without pulp or coffee husk. The height depends on the bed's thickness; through matter balance, the necessary weight to reach a humidity of 10% to 12 % is obtained. After a specific time, it is weighed again; for a bed of 40 cms, it takes approximately 15 hours [21]. The Gravimet method developed by Cenicafe, allows determining with more precision the humidity in the grain, decreasing the unnecessary use of fuel, manpower, and electrical energy. It also determines if grains have been taken to lower humidity levels, if fungi are produced or if standards are being met. This allows obtaining grains with better uniformity without sudden changes of infrastructure and better quality in the final product [21,22,35]. Regarding the sun drying, the Gravimet method offers a better precision to coffee growers. A study carried out by twenty coffee growers found that the 92 % of the product to be dried, after using the Gravimet method, presented 10% to 12 % humidity [36].

Concerning the static layer dryers, a control system to maintain constant specific airflows and temperature was developed [29]. Bearing in mind other studies, in which it was defined that for an air airflow of 0.1 m3/minute.kg, coffee layers up to 34 cm may be dried in less than 24 hours and having into consideration the maximum temperature of 50 degrees C, recommended for drying, the system and cost reduction was analyzed, in which reductions of fuel and electrical energy were obtained from 27.6 % and 84.4 % respectively, for a coffee layer of 20 cm [29].

Another technology that is currently used in Colombia is the rotating solar dryer; it was popular in 1989. It surge due to the fact that the sun drying had been kept unchanged for more than 100 years, which results in threshing inconveniences, re-humidity, crystallization, and contamination due to the contact with animals. This new solar rotating dryer is assembled at a certain height off the ground and has the advantage that it rotates around its axis so that the grain is always perpendicular to solar radiation [37].

Parabolic dryers have been constructed and successfully used in different regions of the country, mainly by small coffee growers. Through this technology, there is a considerable reduction of drying time, as well as a more comfortable and easy access to coffee. With a parabolic dryer, it is possible to dry coffee between six and seven days [38].

Dryers with plastic covers, called parabolic ones, have been widely accepted by small coffee growers to dry all the coffee produced in their farms. Its adoption was favored due to low costs, easy construction and operation. Its maximum capacity is 260 kg. For its standardization, Federación Nacional de Cafeteros (Colombia's National Coffee Authority) managed the instructions for their construction [39]. Apart from the drying process, the control of plagues is a very important aspect which affects not only the quality of the product but also the stability of the sector. Integral management of plagues is promoted in coffee plantations to control plagues and diseases in a less harmful way for the environment than the use of pesticides. The adoption rate of this practice is variable, possibly influenced by social, economic, environmental, and institutional factors [40]. It was determined that between 66 % to 74 % of broca presence in farms, occurs during harvest and, it has been estimated that a very important percentage of this population escapes and returns to coffee plantations; modifications to parabolic dryers (adding muslin to the ends and lower lateral borders) allows controlling the re-infestation of broca [41].

In order to improve the efficiency of the mechanical dryers, particularly the fixed layer dryer silo, the inversion of air was evaluated through simulations. In this case, the airflow temperature and several types of inversions were also tested. It was found that the type of air inversion presented advantages over the conventional drying since it improves the uniformity of humidity content in the final product [42].

In 1990 through simulations, the performance of the intermittent dryer of synchronized airflows, for pergamino coffee was improved. The simulation model was validated by comparing the temperature estimations and the humidity content of grains in different drying parameter values with experimental values obtained such as IFC of 600 K at 2,000 kg of dried pergamino coffee [43].

In 2006, another alternative was introduced for drying pergamino coffee; a drying chamber of 1m2 with a capacity of 125 kg. This alternative has been integrated to coffee stoves in farms with the purpose of taking advantage of caloric energy when food was being cooked, using coke or coffee firewood. The thermal energy not used in food preparation was approximately 85 %; from it, more than 30 % was taken. Coffee drying took three days, working 15 hours per day which was equivalent to the habitual functioning of the farm stove. The entrance of air through two sliding doors to the current of hot air allowed regulating the air temperature of the drying chamber [26].

In 2009, a fuel alternative for the mechanical coffee dryers surged. Since traditional fuels used in mechanical coffee dryers (such as coal, coffee wood, oil derivatives or biomass from coffee husk) negatively affected the environment, the use of carburant alcohol was presented as an alternative. This fuel was obtained from the pulp and the mucilage of coffee [28]. It is relevant to note that the International Coffee Organization, through its sustainability initiative, sets up the basic requirements for the production, preparation and sustainably trading of coffee and the elimination of unacceptable practices, including environmental care [44–46].

Currently, there are studies in which the impact on efficiency levels is determined when a heat pump is coupled to the mechanical drying system. Through this system, humidity is taken out of the air and then, heated to a temperature near 50 degrees Celsius in order to provide better conditions to the air; this allows increasing efficiency in mass and energy transfer in the system. Through this system, it is expected that efficiency and drying times are improved and the environmental impacts associated to combustion are reduced.

3. Panorama and worldwide advances

Global studies related to coffee processing have been carried out in different fields. All of them in function of the quality of the final product; many of them in relation to the process as a phenomenon. Finzer et al. [47] evaluated heat and mass transfer in coffee drying, in which the drying was analyzed in lots of coffee cherries in rotating trays, in vertical fixed bed drying tunnels and varying vibration frequency, which increases the drying speed, the spreading of humidity and consequently mass and heat coefficients; having these conditions, the drying time with vibration, decreased in approximately 11 %, at 45 degrees Celsius. [47,48]. Another study carried out to analyze heat and mass transfer in coffee drying was made by Burmester & Eggers [11]. In this case, the heat transfer coefficient was related to different speeds of drying air, thermal conductivity and the effective spreading coefficients were related to humidity content, volume, and density of coffee grains. In this case, the drying speed is mainly influenced by the drying air temperature; however, this temperature is limited by the sensitivity at coffee grain temperature, which represents a limitation. A reduction in air humidity has low influence on drying speed but a strong influence in the humidity of coffee balance. This type of studies is not only experimental but also modeling and simulated [11,49].

The worldwide development of drying technologies is analyzed as well as the loss of organoleptic properties (flavor, odor, and color) in the roasting process because when heat is transferred to green coffee, this loses humidity and produces chemical reactions such as oxidation, reduction, hydrolysis, and polymerization, among others. There are also alterations such as in the pH, exploding coffee grains and volatile components. Consequently, the product may lose substances associated to its quality; this has been analyzed through nuclear magnetic resonance, models and simulations [50–55].

In the drying of instant coffee, vacuum drying has been evaluated; in this, density, structure, and flavor of the dried product was compared with commercial products. This product was obtained by freezing or drying by spray; this allows decreasing thermal impacts on the product and consequently its organoleptic properties are conserved and comply with technical requirements of the market. While spray drying is established as the most economical process for commercial production, freeze drying provides product with superior aroma quality [56].

The influence of coffee grain storing on its sensorial characteristics has also been studied since it promotes the oxidation of lipids and its commercial price decreases [57]. The improvements of coffee beverage quality through the addition of yeast stumps during fermentation in the coffee drying process have been also evaluated [58]. Several worldwide studies have evaluated the influence of drying processes on the content of lipids and fatty acids, which are considered as chemical descriptors in order to differentiate coffee variations [59,60].

Other isolated research but closely related to coffee quality, have analyzed the effects of high temperature methods such as UHT (Ultra High Temperature) on coffee teas, in which the treatment at

120 degrees Celsius, allows pasteurization; it means the microbiological security in coffee teas but it strongly affects caffeine concentration and some phenolic components [61]. The addition of sugar during the toasting process has been proposed as a technique to increase the anti-oxidant capacity of the product [62,63]. Other studies have led to the degradation of liquids and other coffee components when it is exposed to the process under drying and toasting temperatures [5,64]. Colombian and Spanish researchers have analyzed the aqueous concentration in the process of coffee extracts using freezing as a viable industrial process; they found that this process could be very efficient and acceptable [65,66].

Not only the drying processes but also the toasting processes are important to be studied because the latter affects the quality of the grain. Therefore, the toasting process shall be strictly controlled. At 200 degrees Celsius, a high and quick decomposition of coffee was observed; it is associated to the quantity of caffeine hydrates and caffeine anhydrous. Only under a strict control, the quality of the product shall be assured [67].

4. Conclusions

In Colombia, coffee drying has been made by traditional methods; advances generally have led to improve the existing technologies; this help having better efficiency and less pollution. Consequently, there is a need to carry out more advanced research in this field. This research process in Colombia is limited to the scarce knowledge of coffee growers in relation to innovation and to the lack of available resources in the sector to finance further research.

One great alternative to overcome the disadvantages of traditional open sun drying and the use of fossil fuels for coffee, is the development of solar dryers. The use of these technologies contributes to the mitigation of climate change, improves the quality of drying and prevents loss of material.

Worldwide, research is leading not only to technological advancements but also to determine and evaluate the efficiency of other methods for processing coffee; this provides advantages on coffee properties in order to obtain better quality and trading. There is a technological gap between worldwide developments and national research. Consequently, among the existing alternatives, there is foreign financing that supports developments in this important in Colombia’s economy.

Bibliographic references

[1] I.C.O. International Coffee Organization, Trade Statistics Tables, (2016). http://www.ico.org/trade_statistics.asp (accessed November 28, 2016).

[2] I.C. Council, ICC Development strategy for coffee, in: Int. Coffee Counc. 105th Sess., London, 2010: p. 21.

[3] P.S. Murthy, M. Madhava Naidu, Sustainable management of coffee industry by-products and value addition - A review, Resour. Conserv. Recycl. 66 (2012) 45–58. doi:10.1016/j.resconrec.2012.06.005.

[4] J. Gutiérrez, J. Sanz, C. Oliveros, C. Orozco, Ventiladores para secadores de café: Diagnóstico, diseño y construcción económica de ventiladores centrifugos, CENICAFÉ, Chinchiná, 2012.

[5] A.T. Toci, V.J.M.F. Neto, A.G. Torres, A. Farah, Changes in triacylglycerols and free fatty acids composition during storage of roasted coffee, LWT - Food Sci. Technol. 50 (2013) 581–590. doi:10.1016/j.lwt.2012.08.007.

[6] O. Castellanos-Onorio, O. Gonzalez-Rios, B. Guyot, T. a. Fontana, J.P. Guiraud, S. Schorr-Galindo, et al., Effect of two different roasting techniques on the Ochratoxin A (OTA) reduction in coffee beans (Coffea arabica), Food Control. 22 (2011) 1184–1188. doi:10.1016/j.foodcont.2011.01.014.

[7] L.W. Lee, M.W. Cheong, P. Curran, B. Yu, S.Q. Liu, Coffee fermentation and flavor – An intricate and delicate relationship, Food Chem. 185 (2015) 182–191. doi:10.1016/j.foodchem.2015.03.124.

[8] I.C.O. ICO, Code of Practice for prevention and reduction of ochratoxin A contamination in coffee, 2009.

[9] G. Puerta, Influencia del proceso de beneficio en la calidad del cafe, Cenicafe. 50 (1999) 78–88.

[10] G.I. Puerta, Riesgos para la calidad y la inocuidad del café en el secado, (2008) 8.

[11] K. Burmester, R. Eggers, Heat and mass transfer during the coffee drying process, J. Food Eng. 99 (2010) 430–436. doi:10.1016/j.jfoodeng.2009.12.021.

[12] A. Parra-Coronado, G. Roa-Mejía, C.E. Oliveros-Tascón, SECAFÉ Parte II: recomendaciones para el manejo eficiente de los secadores mecánicos de café pergamino, Rev. Bras. Eng. Agrícola E Ambient. 12 (2008) 428–434. doi:10.1590/S1415-43662008000400014.

[13] P. Ghosh, N. Venkatachalapathy, Processing and Drying of Coffee – A Review, Int. J. Eng. Res. Technol. 3 (2014) 784–794.

[14] C.E. Oliveros Tascon, J.R. Sanz Uribe, C. a. Ramírez Gomez, A. Peñuela Martínez, Secador solar de túnel para café pergamino, Fed. Nac. Cafe. Colomb. (2006).

[15] A.S. Franca, L.S. Oliveira, J.C.F. Mendonça, X. a. Silva, Physical and chemical attributes of defective crude and roasted coffee beans, Food Chem. 90 (2005) 89–94. doi:10.1016/j.foodchem.2004.03.028.

[16] H. Duque-orrego, F. Saldarriaga-s, Economía del secado del café: Un estudio de caso 1, (2001) 1–8.

[17] M. Kleinwächter, G. Bytof, D. Selmar, Coffee in Health and Disease Prevention, Elsevier, 2015. doi:10.1016/B978-0-12-409517-5.00009-7.

[18] T. Oberthür, P. Läderach, H. Posada, M.J. Fisher, L.F. Samper, J. Illera, et al., Regional relationships between inherent coffee quality and growing environment for denomination of origin labels in Nariño and Cauca, Colombia, Food Policy. 36 (2011) 783–794. doi:10.1016/j.foodpol.2011.07.005.

[19] X. Rueda, E.F. Lambin, Linking Globalization to Local Land Uses: How Eco-Consumers and Gourmands are Changing the Colombian Coffee Landscapes, World Dev. 41 (2013) 286–301. doi:10.1016/j.worlddev.2012.05.018.

[20] C.E. Oliveros Tascón, J.R. Sanz Uribe, Ingeniería y café en Colombia, Rev. Ing. Univ. Los Andes. (2011) 99–114.

[21] C.E. Oliveros-tascón, A. Peñuela Martínez, J. Pabón, GRAVIMET SM Tecnología para medir la humedad del café en el secado en silos, CENICAFÉ. (2013) 8.

[22] C.E. Oliveros, L. López, C.M. Buitrago, E.L. Moreno, Determinación del Contenido de Humedad del Café Durante el Secado en Silos, Cenicafé. 61 (2010) 108–118.

[23] C. Café de Colombia, The Coffee Drying Process is another Key for the High Quality of Colombian Coffee., (2012). http://www.cafedecolombia.com/cci-fnc-en/index.php/comments/the_coffee_drying_process_is_another_key_for_the_high_quality_of_colombian_/ (accessed October 31, 2014).

[24] J. Cárdenas, J. Pardo, Caracterización de las etapas de fermentación y secado del café la primavera, Escuela Colombiana de Ingeniería Julio Garavito, 2014.

[25] C. Oliveros, J. Sanz, C. Ramírez, P. Aída, Aprovechamiento eficiente de la energía en el secado mecánico del café, Av. Técnicos Cenicafé. (2009) 8.

[26] D. Martinez, J. Álvarez, Aprovechamiento de la Energía Calórifica de Estufas Campesinas para el Secado del Café en Fincas, Cenicafé. 57 (2006) 88–99.

[27] A. Parra-Coronado, G. Roa-Mejía, C.E. Oliveros-Tascón, SECAFÉ Parte I: modelamiento y simulación matemática en el secado mecánico de café pergamino, Rev. Bras. Eng. Agrícola E Ambient. 12 (2008) 415–427. doi:10.1590/S1415-43662008000400013.

[28] J. Gutiérrez, H. Copete, Hacia la mejora del secado mecánico del café en Colombia, Tecnológicas. 23 (2009) 109–132.

[29] C. González-Salazar, J. Sanz-Uribe, C.E. Oliveros-tascón, Control de caudal y temperatura de aire en el secado mecánico de café, Canicafé. 61 (2010) 281–296.

[30] J. Lee-Laverde, C. Delgado-Agudelo, Modelamiento y diseño de un secador estatico de café pergamino (silo de café), Universidad Tecnologica de Pereira, 2013.

[31] J. Gutiérrez, Metodologías para la construcción de ventiladores centrífugos para el secado de café en talleres rurales, Univ. Tecnológica Pereira. (2008).

[32] B. Alexander, L.A. Agudelo, J.F. Navarro, J.F. Ruiz, J. Molina, G. Aguilera, et al., Relationship between coffee cultivation practices in Colombia and exposure to infection with Leishmania, Trans. R. Soc. Trop. Med. Hyg. 103 (2009) 1263–1268. doi:10.1016/j.trstmh.2009.04.018.

[33] A. Valencia, Eficiencia de la energía solar en el secado del café, empleando varios espesores de

grano y tiempos de remoción, Cenicafe. 29 (1978) 18–28.

[34] J. Alvarez-Hernández, R. López-Alzate, A. Gallo-Cardona, Pérdidas causadas por el secado excesivo del café, Cenicafe. 84 (1978) 4.

[35] C.E. Oliveros, A. Peñuela, J.M. Jurado, Controle la humedad del café en el secado solar, utilizando el método gravimet, Av. Técnicos, Cenicafé. 387 (2009).

[36] J.M. Jurado-chaná, E.C. Montoya-restrepo, C.E. Oliveros-tascón, J. García-alzate, Café Pergamino En El Secado Solar Del Café, 60 (2009) 135–147.

[37] J. Alvarez, F. González, J. Alvarez-Hernández, A. Fernandez, R. López-Alzate, G. Roa-Mejía, El Secado Solar Rotativo para Café, Cenicafe. 144 (1989) 8.

[38] C.E. Oliveros-tascón, C. Ramirez-Gómez, J. Sanz-Uribe, A. Peñuela Martínez, Secador parabólico mejorado, Cenicafe. 376 (2008) 8.

[39] C. Ramirez-Gómez, C.E. Oliveros-tascón, G. Roa-Mejía, CONSTRUYA EL SECADOR SOLAR PARABÓLICO, Cenicafe. 305 (2002) 1–8.

[40] B. Chaves, J. Riley, Determination of factors influencing integrated pest management adoption in coffee berry borer in Colombian farms, Agric. Ecosyst. Environ. 87 (2001) 159–177. doi:10.1016/S0167-8809(01)00276-6.

[41] M. Vélez-Hoyos, Á. Bustillo-Pardey, J. Rafael-Álvarez, Secador solar parabólico modificado para el control de la broca del café, Cenicafe. 306 (2002) 1–4.

[42] C.E. Oliveros-tascón, J.B. Pinheiro-Filho, Simulación de secado de café en capa fija con inversión del sentido de flujo del aire, Cenicafe. 36 (1985) 3–21.

[43] E.C. Montoya-restrepo, C.E. Oliveros-tascón, G. Roa-Mejía, Optimización operacional del secador intermitente de flujos recurrentes para café pergamino. Avances técnicos, Cenicafe. 41 (1990) 19–33.

[44] J. Potts, M. Lynch, A. Wilkings, G. Huppe, M. Cunningham, V. Voora, The State of Sustainability Initiatives Review 2014, Standards and the Green Economy, 2014.

[45] I.T.C. ITC, The Coffee Exporter’s Guide, THIRD EDIT, Geneva, 2012.

[46] MSI, COMMON CODE FOR THE COFFEE COMMUNITY (4C): EVALUATION REPORT, 2013.

[47] M. a. Sfredo, J.R.D. Finzer, J.R. Limaverde, Heat and mass transfer in coffee fruits drying, J. Food Eng. 70 (2005) 15–25. doi:10.1016/j.jfoodeng.2004.09.008.

[48] J.R.D. Finzer, M. a. Sfredo, G.D.B. Sousa, J.R. Limaverde, Dispersion coefficient of coffee berries in vibrated bed dryer, J. Food Eng. 79 (2007) 905–912. doi:10.1016/j.jfoodeng.2006.03.011.

[49] W. Nilnont, S. Thepa, S. Janjai, N. Kasayapanand, C. Thamrongmas, B.K. Bala, Finite element simulation for coffee (Coffea arabica) drying, Food Bioprod. Process. 90 (2012) 341–350. doi:10.1016/j.fbp.2011.06.007.

[50] J. a. Hernández, B. Heyd, G. Trystram, Prediction of brightness and surface area kinetics during coffee roasting, J. Food Eng. 89 (2008) 156–163. doi:10.1016/j.jfoodeng.2008.04.026.

[51] M.L. Mateus, D. Champion, R. Liardon, a. Voilley, Characterization of water mobility in dry and wetted roasted coffee using low-field proton nuclear magnetic resonance, J. Food Eng. 81 (2007) 572–579. doi:10.1016/j.jfoodeng.2006.12.015.

[52] M. a. García-Alvarado, F.M. Pacheco-Aguirre, I.I. Ruiz-López, Analytical solution of simultaneous heat and mass transfer equations during food drying, J. Food Eng. 142 (2014) 39–45. doi:10.1016/j.jfoodeng.2014.06.001.

[53] R.M. Torrez Irigoyen, S. a. Giner, Drying-toasting kinetics of presoaked soybean in fluidised bed. Experimental study and mathematical modelling with analytical solutions, J. Food Eng. 128 (2014) 31–39. doi:10.1016/j.jfoodeng.2013.12.009.

[54] A. Fabbri, C. Cevoli, S. Romani, M.D. Rosa, Numerical model of heat and mass transfer during roasting coffee using 3D digitised geometry, Procedia Food Sci. 1 (2011) 742–746. doi:10.1016/j.profoo.2011.09.112.

[55] R.M. Torrez Irigoyen, S.M. Goñi, S. a. Giner, Drying-toasting kinetics of presoaked soybean. A mathematical model considering variable diffusivity, shrinkage and coupled heat transfer, J. Food Eng. 142 (2014) 70–79. doi:10.1016/j.jfoodeng.2014.06.002.

[56] K. Burmester, A. Pietsch, R. Eggers, A basic investigation on instant coffee production by vacuum belt drying, Procedia Food Sci. 1 (2011) 1344–1352. doi:10.1016/j.profoo.2011.09.199.

[57] M.Y. Rendón, T. De Jesus Garcia Salva, N. Bragagnolo, Impact of chemical changes on the sensory characteristics of coffee beans during storage, Food Chem. 147 (2014) 279–286. doi:10.1016/j.foodchem.2013.09.123.

[58] S.R. Evangelista, C.F. Silva, M.G.P.D.C. Miguel, C.D.S. Cordeiro, A.C.M. Pinheiro, W.F. Duarte, et al., Improvement of coffee beverage quality by using selected yeasts strains during the fermentation in dry process, Food Res. Int. 61 (2014) 183–195. doi:10.1016/j.foodres.2013.11.033.

[59] M.J. Martín, F. Pablos, a. G. González, M.S. Valdenebro, M. León-Camacho, Fatty acid profiles as discriminant parameters for coffee varieties differentiation, Talanta. 54 (2001) 291–297. doi:10.1016/S0039-9140(00)00647-0.

[60] G.N. Jham, R. Velikova, H. Vidal Muller, B. Nikolova-Damyanova, P.R. Cecon, Lipid classes and triacylglycerols in coffee samples from Brazil: Effects of coffee type and drying procedures, Food Res. Int. 34 (2001) 111–115. doi:10.1016/S0963-9969(00)00137-X.

[61] P. Sopelana, M. Pérez-Martínez, I. López-Galilea, M.P. de Peña, C. Cid, Effect of ultra high temperature (UHT) treatment on coffee brew stability, Food Res. Int. 50 (2013) 682–690. doi:10.1016/j.foodres.2011.07.038.

[62] I. a. Ludwig, J. Bravo, M.P. De Peña, C. Cid, Effect of sugar addition (torrefacto) during roasting process on antioxidant capacity and phenolics of coffee, LWT - Food Sci. Technol. 51 (2013) 553–559. doi:10.1016/j.lwt.2012.12.010.

[63] C. Lin, C. Toto, L. Were, Antioxidant effectiveness of ground roasted coffee in raw ground top round beef with added sodium chloride, LWT - Food Sci. Technol. 60 (2014) 29–35. doi:10.1016/j.lwt.2014.08.010.

[64] L. Zhou, A. Khalil, F. Bindler, M. Zhao, C. Marcic, S. Ennahar, et al., Effect of heat treatment on the content of individual phospholipids in coffee beans, Food Chem. 141 (2013) 3846–3850. doi:10.1016/j.foodchem.2013.06.056.

[65] F.L. Moreno, E. Hernández, M. Raventós, C. Robles, Y. Ruiz, A process to concentrate coffee extract by the integration of falling film and block freeze-concentration, J. Food Eng. 128 (2014) 88–95. doi:10.1016/j.jfoodeng.2013.12.022.

[66] D. Fissore, R. Pisano, A. a. Barresi, Applying quality-by-design to develop a coffee freeze-drying process, J. Food Eng. 123 (2014) 179–187. doi:10.1016/j.jfoodeng.2013.09.018.

[67] W. Rivera, X. Velasco, C. Gálvez, C. Rincón, A. Rosales, P. Arango, Effect of the roasting process on glass transition and phase transition of Colombian Arabic coffee beans, Procedia Food Sci. 1 (2011) 385–390. doi:10.1016/j.profoo.2011.09.059.

---

1. Magister en Ingeniería. Facultad de Ingeniería. Institución Universitaria Pascual Bravo. Medellín. Colombia. E-mail: luis.olmos@pascualbravo.edu.co

2. Magister en Ingeniería administrativa. Facultad de Ingeniería. Institución Universitaria Pascual Bravo. Medellín. Colombia. E-mail: e.duque@pascualbravo.edu.co

3. Magister en Ingeniería. Instituto Tecnológico Metropolitano. Medellín. Colombia. E-mail: elizabethrodriguez@itm.edu.co.

Revista ESPACIOS. ISSN 0798 1015
Vol. 38 (Nº 29) Año 2017