Asian Journal of Biology

11(1): 8-14, 2021; Article no.AJOB.64446
ISSN: 2456-7124

Energy Evaluation of the Mechanical Drying of the Grain of *Coffea arabica* from Honduras

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Authors' contributions

This work was carried out in collaboration among all authors. Authors FTM, JMF, RSA and JTM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors FHB, SK, IMF and IV managed the analyses of the study. Authors JMF, SK and IMF managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJOB/2021/v11i130131
Editor(s):
(1) Dr. Md. Abdulla Al Mamun, The University of Tokyo, Japan.
Reviewers:
(1) Dwi Santoso, Borneo Tarakan University, Indonesia.
(2) Claudia-Maria Simonescu, Politehnica University of Bucharest, Romania.
Complete Peer review History: http://www.sdiarticle4.com/review-history/64446

Received 28 October 2020
Accepted 03 January 2021
Published 27 January 2021

Original Research Article

ABSTRACT

The aim of this research work was to evaluate the methods of mechanical drying of coffee beans (*Coffea arabica*) from energy evaluations. The control variables were the drying of the grain and energy was used as the response variable, measured in Tonnes of Oil Equivalent (TEP), Barrels of Oil Equivalent (BEP), and Tonnes of Carbon Dioxide Equivalent (Ton CO_2eq). The evaluations on the three methods of mechanical coffee drying indicate that the rotary dryer requires 1.0 TEP equivalent to 1.017 kg CO_2eqkg^{-1} in dry parchment coffee (CPS), however, the vertical drying method requires 1.12 TEP (0.616 kg CO_2eqkg^{-1} in CPS) and the static dryer requires 0.5 TEP (0.33

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Kg CO_2eqkg^{-1} in CPS). Furthermore, the biomass energy consumption in the rotary dryer is 12.60 MJkg^{-1}, in the vertical dryer it is 7.46 MJkg^{-1}, and the static dryer is 3.91 MJkg^{-1}. These results indicate that the rotary dryer uses 91.95% of the biomass energy, the vertical dryer uses 90.31%, and the static dryer 90.68%. Concluding that rotary drying has a higher biomass energy consumption and reduces CO_2 emissions kg^{-1} in dry parchment coffee, this method is also preferred by cuppers, as it preserves the sensory qualities of the coffee and contributes to reducing the impact. the environment in the consumption of electrical energy and the reduction of CO_2 emissions. However, these predictors need more work to validate reliability.

Keywords: Coffee; biomass; energy; emissions; environmental Impact.

1. INTRODUCTION

Plants have several beneficial conditions for humanity, one of them is their medicinal contribution due to the presence of phytochemicals and antioxidants, characterized by these bioactive compounds as the main source of nutraceuticals [1]. Coffee has functional properties due to the content of polyphenols and antioxidants, which help in the prevention of cardiovascular problems, cancer, obesity, and diabetes [2-3].

Coffee is composed of more than 1000 different chemical substances, including alkaloids (caffeine, trigonelline, adenine, theobromine, and methylxanthine), flavonoids (anthocyanin, quercetin, and derivatives of quercetin and kaempferol), amino acids (histidine and pipecolic acid), it also has sugar, tannins (catechin and epicatechin), xanthonoid (mangiferin and isomangiferin) and phenolic acids (caffeine, chlorogenic, p-coumaric and ferulic) [4,5,6]. Other constituents such as melanoidins derive from non-enzymatic browning reactions or carbohydrate caramelization that occur during roasting [7].

Coffee is a plant of the genus *Coffea*, made up of approximately 100 species, the Arabica, *canephora, excelsa*, and *liberica* varieties being cultivated for commercial purposes. However, in Honduras, *C. arabica* is preferred for its sensory attributes, also, it is the largest coffee exporter in the Central American region, the third in Latin America and the fifth in the world, contributing around 35% to the Gross Domestic Product, benefiting some 120 thousand families and generating more than one million direct and indirect jobs [8,9,10].

The quality of the coffee (*C. arabica)* depends on many factors, among which the beneficiation process stands out, the drying of the bean being part of it, being carried out to avoid its decomposition, reduce humidity, facilitate marketing and agro-industrial transformation, this is carried out using solar energy or by mechanical means (forced convection) [12]. Drying consists of the process of removing water (dehydration) from the humid parchment grain from 50% to 55%, until it reaches 10% or 12% humidity, this can be done through natural means taking advantage of the sun's rays or by mechanical means [13]. The traditional way of drying to obtain dry parchment coffee from cherry coffee is solar drying, where the final quality is not always optimal since it depends on the climatic conditions of the area. Likewise, an alternative to improve this process has been the use of mechanical dryers [14].

Fig. 1. Lempira coffee variety
World Coffee Research (2020) [11]

The mechanical drying of coffee is carried out in systems that consist of a heat source, a heat exchanger, a fan and a dryer with one or more compartments, it has a mesh floor on which the beans are deposited and to heat the air, equipment has been designed that uses electricity, gas, coal and other inputs such as coffee husk [15,16]. Solar drying consists of directly exposing the coffee beans to radiation, until reaching the humidity established under quality control, in this way the global solar radiation and the enthalpy of the air are used for drying, which lasts for 7 to 8 days depending on the climatic conditions of the region, it is the most economical method and guarantees to maintain the physical-chemical, bromatological and sensory properties of the coffee bean [17,18].

Therefore, this research presents as a scientific novelty, being the first study that evaluates the methods of mechanical drying of coffee beans, based on the consumption capacity and energetic production, and its potential environmental impact during its use.

2. MATERIALS AND METHODS

The method used in this research is of a qualitative-quantitative cross-sectional order based on on-site visits, in three coffee mills located in the department of El Paraíso, Honduras. The mechanical drying process of coffee was evaluated estimating quantities of biomass and electrical energy, energy (joule), Equivalent Tons of Oil (TOE), Equivalent Barrels of Oil (BEP) and Equivalent Tons of Dioxide of Carbon (Ton CO_2 eq) [19,20].

The different types of equipment for mechanized drying evaluated were: rotary dryer type Guardiola (Joca, San José, Costa Rica) of the coffee exporter "AGROCAFE" located in the "La Guadalupe" mill, with a capacity of 2.545 ton. Also, a vertical cascade dryer were used in the Nelson Toledo coffee exporter with a capacity of 5.680 ton and a static or stationary dryer of the Penagos Brand (Bucaramanga, Colombia) of the COMICAOL exporter with a capacity of 4.545 ton for wet coffee (Fig. 2).

2.1 Handling of Experimentation

To achieve the objectives, different experimental phases described below were used:

Phase 1. On-site visits and collection of information on types of drying for a cycle of machine operation through the use of inspection instruments.

For its scope, the number of engines with their respective power was inventoried and the time that they work in a drying cycle was measured for each type of grain dryer, also, the amount of biomass (pine wood and coffee parchment) consumed was determined by the ovens during the time of a drying cycle. Similarly, biomass energy was calculated by estimating the lower calorific value (PCI) in $kJkg^{-1}$ of each biofuel (pine wood and coffee parchment), and the total energy consumed by each drying equipment was calculated (MJ). Comparisons and analyzes of the biomass and electrical energy consumed in the mechanized grain drying cycle were made in three types of mechanical dryers.

Phase 2. Calculation of biomass energy

The coffee parchment or husk is the part that surrounds the bean immediately after the mucilaginous layer, constitutes 4 to 5% of the weight of the dry bean, and has a humidity of 12%. Its chemical composition in dry matter is 47.2% carbon, 4.6% hydrogen, 0.12% sulfur, 48.1% oxygen, and 9 to 12% humidity. Besides, it has a calorific value of 17,500 kJkg-1 and due to its characteristics, it is an optimal fuel [21]. However, the chemical composition of coffee parchment is lower compared to the chemical composition of wood, since it contains 51.6% carbon, 6.3% hydrogen, 41.5% oxygen, 0.6% nitrogen, among other elements [22].

The calculation of the Lower Calorific Power (PCI) of the parchment was developed from the formulas proposed by [23], for the calculation of the lower calorific power of agricultural and forestry residues, and the calculation of biomass energy.

a) Rotary dryer type Guardiola b) Stationary dryer of the Penagos Brand

Fig. 2. Different types of equipment for mechanized drying

Formula 1. Lower Calorific Value

$$PCI(x\%)\left[\frac{kJ}{kg}\right] = PCS(0\%)\left[\frac{kJ}{kg}\right] * \left(\frac{100-X}{100}\right) - 24.49 * \left(x + 9\frac{\%H}{100} * (100-x)\right)$$

Where:
PCI = Lower Calorific Value
x = 12% Biomass moisture.
PCI = Lower Calorific Value ($kJkg^{-1}$).
PCS = 17 500 ($kJkg^{-1}$) Higher Calorific Power
%*H* = 4.6% of hydrogen contained in biomass.

Formula 2. Obtaining biomass energy

$$E_{Biomass} = PCI_{Biomass} * \left(\frac{kg\ Biomass}{drying\ cycle}\right)$$

Where:
E = Biomass Energy (kJ)
PCI = Lower calorific value of wood or parchment, ($kJkg^{-1}$)
kg Biomass per drying cycle

3. RESULTS AND DISCUSSION

3.1 Calculation of Heat Energy of Biomass for Dryers

Based on the findings of the in situ investigation, it was determined that the amount of parchment bags used in the kiln for 12 hours is 300 bags equivalent to 7.5 tons, and 10.5 m^3 of pine wood used in the boiler for each cycle, distributed in six "Guardiola" dryers with a capacity equivalent to 6 543 tonnes of wet coffee. From these data through the use of formulas, the Lower Calorific Power (PCI) was determined and the amount of biomass consumed was estimated. Table 1 shows the amount of carbon dioxide equivalent emission per kilogram of dry parchment coffee for each type of dryer machine, determining that the rotary dryer emits 1 017 $kgCO_2eqkg^{-1}$ CPS, the vertical dryer emits 0.616 kg CO_2eqkg^{-1} CPS and the static dryer emits 0.33 kg CO_2eqkg^{-1} CPS. These results validate what was stated by the Institute for Energy Diversification and Saving (IDAE, 2007) [24]. The use of biomass as an energy resource, instead of commonly used fossil fuels, entails first-order environmental advantages, such as the reduction of sulfur emissions, reduction of particle emissions, reduced emissions of pollutants, such as gases greenhouse effect.

Mendivil et al., [25], expresses that one of the main attractions of biofuels is the lower environmental impact during its combustion, compared to that of fossil fuel. However, it is important to consider the energy expenditure and the waste generated during its production, that is, it is still necessary to select an optimal process for maximum use of biomass. For this, it is necessary to make a homogenization of the techniques to compare the energy generation routes and their products, based on energy yields, co-products, and waste generation.

According to Caraballo et al., [26], the threat of climate change, dependence on energy imports, and the finite nature of fossil resources have caused widespread concern about energy in terms of security of supply, since the environmental impacts are associated with its production and consumption.

Table 2 summarizes the biomass energy and electrical energy consumed per kg of dry parchment coffee (CPS) in three types of mechanical dryers (rotary, vertical, and static), the results indicated that the biomass energy consumption for the dryer rotary is 12.60 $MJkg^{-1}$ CPS and 1.10 $MJkg^{-1}$ CPS of electrical energy consumption, however, the vertical dryer uses 7.46 MJkg-^{1} CPS of biomass energy and 0.80 $MJkg^{-1}$ CPS of electrical energy, besides, the dryer Static uses 3.91 $MJkg^{-1}$ CPS of biomass energy and 0.40 $MJkg^{-1}$ CPS of electrical energy consumption (Fig. 3). These results indicated that the coffee bean drying equipment exceeded

Table 1. Energy consumption capacity of mechanized equipment per coffee bean drying cycle

Drying equipment	Capacity in wet coffee	Total energy consumed	TEP	BEP	Ton CO_2eq issued	kg CO_2eqkg^{-1}
Rotary	2556.82 kg (56 q)	9.7 MWh	1.0	6.0	2.5	1 017
Vertical	5682.82 kg(125 q)	13.0 MWh	1.12	8.0	3.5	0.616
Static	4545.45 kg(100 q)	5.4 MWh	0.5	3.6	1.5	0.330

For energy comparisons, we use the conversion units of a TEP equaling 41680 MJ, and 7.2056 BEP, and 3.09 Ton CO_2eq [23]

Table 2. Calculation of biomass energy and electrical energy used per kg of SCP

Drying equipment	Biomass energy $MJkg^{-1}$	$kgCO_2$ $eqkg^{-1}$	Electric power $MJkg^{-1}$	$kgCO_2$ $eqkg^{-1}$	Total energy $MJkg^{-1}$	Percentage of biomass used
Rotary	12.60	0.934	1.10	0.082	13.70	91.95
Vertical	7.46	0.553	0.80	0.059	8.26	90.31
Static	3.91	0.290	0.40	0.030	4.31	90.68

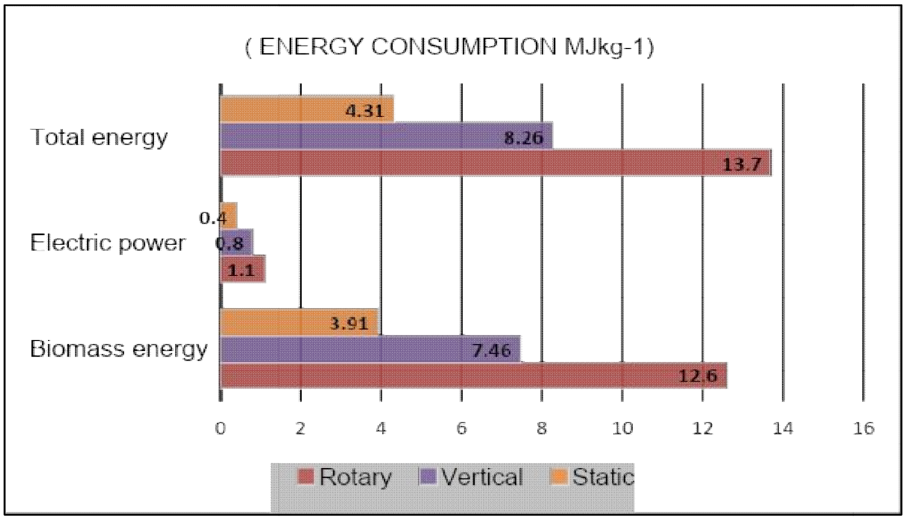

Fig. 3. Energy consumption, according to type of drying equipment

90% of biomass energy consumption. These results coincide with what is stated by Quantis, et al., [27], who details that small coffee producers use biomass energy as a drying system, generating a caloric power of 6.31 $MJkg^{-1}$ CPS (17 936 $kJkg^{-1}$) and exceeds as expressed by CENICAFE [28], which report approximate values of 4.02 $MJkg^{-1}$ of CPS.

4. CONCLUSION

Based on the estimates in three types of mechanical coffee dryers, it is determined that the rotary dryer needs 9.7 MWh for a coffee drying cycle, which has an equivalent energy impact of 1 TOE that corresponds to 1.017 kg CO_2eqkg^{-1} of dry parchment coffee, generating higher biomass energy consumption compared to the vertical dryer and the static dryer.

According to the biomass consumption of the coffee mills, and utilization greater than 90% is reported, with the rotary dryer being the one that consumes the most biomass energy, reducing the environmental impact by reducing emissions of equivalent carbon dioxide, doing this more sustainable drying process for the coffee mills of the Municipality of El Paraíso in Honduras.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/64446