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## COFFEE DRYER WITH DEHYDRATED AIR: A TECHNICAL AND ECONOMIC VIABILITY ANALYSIS

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### KEYWORDS

artificial drying,  
*Coffea Arabica L.*,  
electric dryers, quality  
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postharvest losses.

### ABSTRACT

The defects that drying in concrete yards impose on coffee beans and the search for gourmet coffee production have prompted the emergence of new drying technologies. This work verified the technical and economic feasibility of drying coffee with dehumidified air with a refrigerating capacity of 422,908.7 J s<sup>-1</sup>, compatible with static capacity dryers equal to 75 m<sup>3</sup>. Considering the sale price of coffee, the cost of electric energy acquisition, the monthly interest rate and maintenance time, expenses that are equivalent to the depreciation of the concrete yard, a central compound rotational design was considered with 28 tests for the feasibility analysis, including the internal rate of return, net present value and the return on investment. The results showed that in the electric drying units, the dried coffee presents fewer broken and defective beans and has higher retention in a N<sup>o</sup>. 17 sieve. With a higher beverage quality and a price 12.11% higher, drying with dehydrated air showed a PBD of 2.27 years and a return of US\$ 2.49 million. The optimisation results were 98.98% desirable. It was concluded that it is economically feasible to dry coffee with dehydrated air and without using a concrete yard.

### INTRODUCTION

Coffee is a beverage that is consumed worldwide, and its quality is determined by counting defects and impurities and bean uniformity (Brasil, 2003). Its price is defined by the sensory drink test, which follows the specifications of the Specialty Coffee Association of America (SCAA).

Brazilian production comes mainly from family farming, representing a relevant socioeconomic influence (Aparecido et al., 2015; Zelber-Sagi et al., 2015; Aparecido et al., 2017). Production has grown significantly in recent years, from 1.73 million tons (1.73×10<sup>9</sup> kg) in 2003 to 2.70 million (2.70×10<sup>9</sup> kg) in 2017, a year in which Brazil maintained 221 thousand hectares of coffee planted area with an average productivity of 1.49×10<sup>-1</sup> kg m<sup>-2</sup> (Brasil, 2017).

Drying is used to prolong food quality from harvest to actual consumption (Duan et al., 2016). It should be noted that a poorly conducted postharvest can cause

damage to the coffee quality, such as fermentation, breakage, cracking, and fungal smoke odours. There are a few reports that when poorly administered, drying in concrete yards devalues coffee (Martinez et al., 2013), and since the largest portion of coffee harvested is still dried in concrete yards, new drying technologies have been studied to minimise such losses.

Modified atmospheres are the subject of recent studies, including the freeze-drying of foods (Duan et al., 2016; Cumhur et al., 2016; Rahman & Saidur, 2016), whose results highlight the high cost of this process as a factor preventing its diffusion, and the use of dehydrated air in convection drying (Krzyzanowski et al., 2006a; Krzyzanowski et al., 2006b; Levien et al., 2008), which showed viability in the drying of peanuts and soybeans.

The quality of dry coffee with partially dehumidified air was presented by Konopatzki et al. (2019). In their study the authors used electric coffee drying units (DUs) and concluded that the dry product in DUs has a higher quality of beverage and reaches a higher market value.

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The DU components are: 1) electric dehumidifiers developed by Barreto (2012) and 2) a mechanical dryer also developed by Barreto (2013). The simplified structure of these components was presented by Konopatzki et al. (2019) and a DU will be presented in chapter 2 (Methods).

The current literature does not show drying coffee in DUs as economically viable. An economic evaluation of a project implementation through the analysis of economic indicators, such as discounted payback (PBD), internal rate of return (IRR), net present value (NPV) and return on investment (ROI), is the most commonly used indicator in the literature (Fernandes et al., 2016; Ávila et al., 2017).

This study aimed to verify whether the drying of coffee with dehydrated air is economically feasible compared to the drying done in a concrete yard. To do so, we compared the cash flows, the cost of acquiring an air dehydrator system and the costs of construction and maintenance of a concrete yard, comparing drying with dehydrated air and in the concrete yard.

### MATERIAL AND METHODS

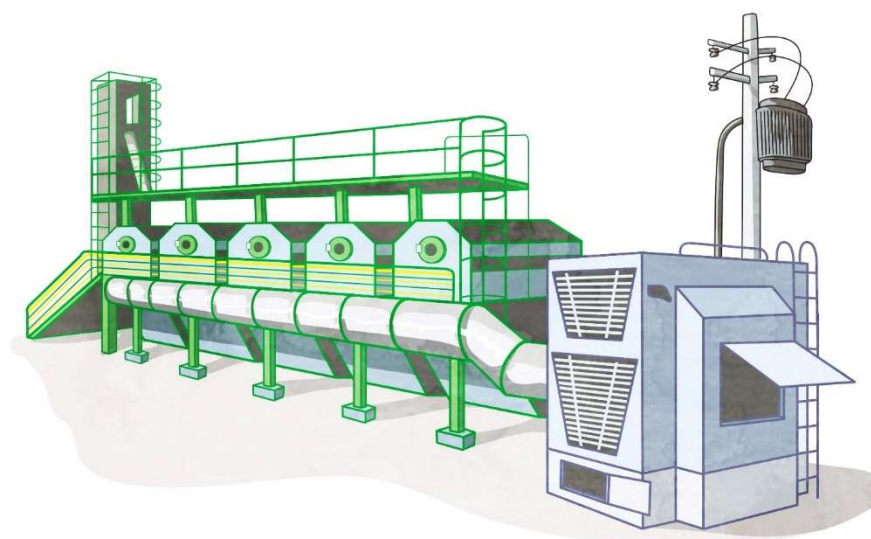
Coffee drying was monitored on four coffee-growing farms (see Table 1) during the annual harvest period in 2016 and 2017, when three drying lots were monitored.

TABLE 1. Transformed parameters of the variables used in the central compound rotational design.

| Name | Location                 | SAD69            | Height, sea level (m) | Coffee varieties                    |
|------|--------------------------|------------------|-----------------------|-------------------------------------|
| DU-A | Franca (SP)              | - 22.21, - 49.66 | 688.00                | Topaz                               |
| DU-B | Araraquara (SP)          | - 21.79, - 48.18 | 675.00                | New world                           |
| DU-C | Garça (SP)               | - 20.54, - 47.42 | 1,040.00              | Catuai                              |
| DU-D | São Tomás de Aquino (MG) | - 20.78, - 47.10 | 979                   | New world + Catuai<br>(80%) + (20%) |

Notes: DU-[ ]: Drying unit; SAD69: type of geographical coordinate system. “New world + Catuai”: moisture of coffee varieties New World (80%) and Catuai (20%).

The fruits of the harvested coffee were distributed between the concrete yard and the DU (see Figure 1).



(a)

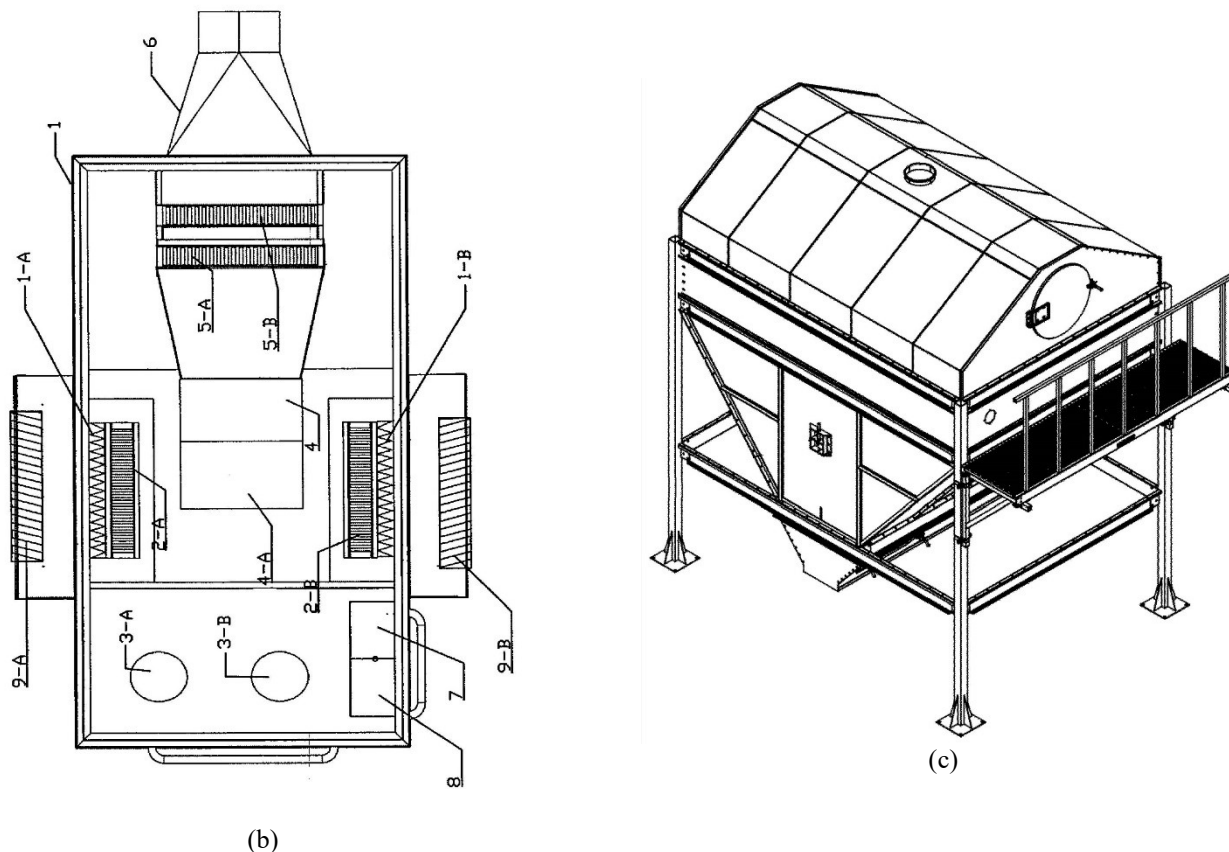


FIGURE 1. Drying unit installed in a farm (a); top view of the air watering unit equipment, AWU<sup>®</sup> (b) and front view of a static tray dryer module, STD<sup>®</sup> (c).

Source: Adapted from Konopatzki et al. (2019); Barreto (2012) and Barreto (2013).

Notes: 1: AWU metal structure body; 1-A and 1-B: pleated air filters with great capacity for the retention of air, dust and dirt; 2-A and 2-B: evaporator coils; 3-A and 3-B: compressors; 4: fan; 4-A: fan motor; 5-A and 5-B: condenser coils; 6: drying air outflow ducts; 7: control panel; 8: power table; 9-A and 9-B: dumpers (two) outdoor air intake.

The air DU is served by an air watering unit (AWU). This machine dehydrates the air that will be used in the drying process. The dehydration process occurs by cooling the air. Then the air is heated so that it reaches the coffee mass deposited in the static tray-type dryer (STD) with a greater capacity for absorbing water.

In the concrete yards of the evaluated properties, the coffee was conditioned in re-rows every hour for the first five days. After the fifth day, the coffee was spread in a layer with a thickness of  $0.15 \pm 0.05$  m and turned over four times a day. A wooden ruler was attached to a broom and adjusted to a free height of 0.15 m. In this way, when passing the broom through the coffee mass, it was ensured that the layers were formed at that height.

When turning the coffee with the motorcycle, the broom is installed so that the tyres always rotate between the windrows; this machine has already been developed to avoid losses due to crushing or breakage. Manual labour was also used in this task.

For the nocturnal period, the product was collected in estimated heights of 2.0 m and covered with canvas, and it was examined and spread out at dawn. The height of the coffee pile was estimated at 2 m by the reach of the loader arm coupled to the tractor used in this task. This procedure was also repeated at the beginning and end of the rainy periods.

Dehydrated air was injected into the five mechanical dryers, simultaneously, for approximately 12 hours daily, after which time the movement of the coffee

beans between the vats was promoted and the coffee mass was left to rest for the remaining period. This process made it possible to homogenise the moisture between the coffee beans in a similar way to the process of revolving the mass of coffee in the concrete yard.

Samples containing 1 kg of dry coffee in the DUs were collected in triplicate, randomly numbered and presented by the average of each property.

The DUs were randomly named DU-A, DU-B, DU-C and DU-D for the characterisation of the properties in the coffee quality assessment process, as required by the owners.

### Technical analysis

The sampling procedure and characterisation of coffee quality followed Konopatzki et al. (2019).

The average drying time of each lot in the DU was measured and compared to the average drying time of the lots using the concrete yard. These time intervals were used for economic feasibility to ensure the productive equivalence of the drying systems.

The coffee quality analysis was performed by qualified tasters using the 10 cup beverage technique, according to the norms established and presented by the Ministry of Agriculture, Cattle and Supplying (Brasil, 2003). The drinking tests were carried out in the municipalities of Franca (SP) and São Sebastião do Paraíso (MG).

The scoring was assigned using the methodology described by the SCAA (Lima et al., 2016; Alves et al., 2017). The tasters presented the commercial value of the analysed samples and the price per kg, based on the results of the beverage tests. The values were defined on September 12, 2017.

The samples were analysed by the means of each DU, which were compared to each other by analysis of variance (ANOVA) at the 5% significance level using Tukey’s test, and compared to the means of the control at the 5% level using Dunnett’s test. The normality of the drink quality data was analysed by the residual distribution at the 5% significance level using the Shapiro–Wilk (W) statistic.

The energy consumption and demand were obtained with a digital kilowatt-hour meter model, the Power Quality (IMS) energy meter, manufactured by IMS Energy Solutions Ltda, with flexible pliers-type current transformers (CT) in a 1:1 ratio and the potential transformers (TP) in a 1:1 ratio in the measuring instrument, all of which were calibrated by the manufacturer.

The meter was connected to both the electrical circuit supplying the AWU and the electric motors of the treadmills and elevators. The data were collected at five minute intervals during the drying period of batch monitoring, and were analysed using the Smart Analyzer T software provided by IMS<sup>®</sup>.

**Economic analysis**

The economic viability was based on the evaluation of four economic indicators applied to the drying cash flow in the concrete yard and to the drying cash flow in the DU for the analytical comparison (Fernandes et al., 2016; Ávila et al., 2017).

PBD is defined as the time interval necessary to reach financial equality between the realised investment and the accumulated net profit considering the discount rate related to compound interest in time, as presented in [eq. (1)].

$$\sum_{t=1}^{PBD} \left( \frac{FC_t}{(1+X_3)^{PBD}} \right) \quad (1)$$

In this study, the time interval of the PBD is presented in years. In [eq. (1)], FC<sub>t</sub> is the cash flow in the period, and X<sub>3</sub> is the interest rate.

NPV is analogous to the return on investment taken with cash flows brought in at the date of capital application, as presented in [eq. (2)].

$$NPV = \sum_{t=1}^{n=30} \left( \frac{FC_t}{(1+X_3)^t} \right) - INV_{DU} \quad (2)$$

In the formula, n is the estimated useful life of the concrete yard and dryer unit in years, and INV<sub>DU</sub> is the amount spent on the construction of the drying system.

IRR is understood as the discount rate necessary to make the NPV null. The rule is presented in [eq. (3)].

$$NPV = 0 = \sum_{t=1}^{n=30} \left( \frac{FC_t}{(1+IRR)^t} \right) - INV_{DU} \quad (3)$$

In the equation, IRR is presented in dimensionless form and transformed afterwards into a percentage.

We also analysed the return on investment (ROI) according to [eq. (4)], which comprises the relation between the investment gain and the invested capital.

$$ROI = \frac{NPV - INV_{US}}{INV_{US}} \quad (4)$$

ROI is therefore dimensionless, and values greater than one indicate economic viability.

In the economic analysis, income and cash flow expenses were accounted for on a monthly basis, considering harvest and drying from May to September. Subsequently, these amounts were used in the NPV in January each year. The cash flow revenues and expenses were considered as the difference in price between the drying systems (DU and the concrete yard).

**Prediction of the independent variables**

The CCRD was constructed using the parameters and their variations presented in Table 2.

TABLE 2. Transformed parameters of the variables used in the CCRD.

| Variable  | Code           | Level |      |       |       |       |
|---|----------------|-------|------|-------|-------|-------|
|   |                | -2    | -1   | 0     | 1     | 2     |
| Price of coffee dried in the concrete yard (US\$ kg <sup>-1</sup> ) | x <sub>1</sub> | 1.73  | 1.95 | 2.16  | 2.38  | 2.60  |
| Cost of electric energy acquisition (US\$ kWh <sup>-1</sup> )       | x <sub>2</sub> | 0.06  | 0.13 | 0.19  | 0.26  | 0.32  |
| Monthly interest rate, (%)  | x <sub>3</sub> | 0.21  | 0.38 | 0.55  | 0.72  | 0.89  |
| Period of maintenance (year)  | x <sub>4</sub> | 5.00  | 7.5  | 10.00 | 12.50 | 15.00 |

Notes: The price of coffee dried in the concrete yard (US\$ kg<sup>-1</sup>) is denoted X<sub>1</sub>; the cost of electric energy acquisition (US\$ kWh<sup>-1</sup>) is denoted X<sub>2</sub>; the monthly interest rate is denoted X<sub>3</sub>, as practised in Brazil in the years 2017 and 2018 (%). The period of maintenance (year) is denoted X<sub>4</sub> and is equivalent to the depreciation of the concrete yard.

In relation to the price of coffee, there is a great variation in the sales prices of this product. Considering a sieveless type 6 better hard drink 60 kg net bag of Arabica coffee in the city of São Paulo, Brazil, the price was US\$ 117.15 ± 6.38 in 2015, US\$ 128.38 ± 6.53 in 2016 and US\$ 120.95 ± 6.33 in 2017 (mean ± standard deviation) (CEPEA, 2018).

The highest sales value found was on 11/11/2016, according to CEPEA (2018), when a 60 kg bag was sold

for US\$ 149.94, while the lowest value occurred on 05/26/2016 and was US\$ 109.15.

The average value of a sack of coffee in 2016 was US\$ 126.81 (Turco et al., 2017). Although the nozzle, type and beverage in this price were not specified, the authors considered delivery in the state of São Paulo and commented that the great fluctuation in the price, added to a gradual increase in the costs of the chemical inputs, caused a loss of profitability in the coffee. In this way, the

introduction of new technologies in the production process is justified with the objective of avoiding a decline in profitability, seeking to increase both coffee productivity and bean quality.

In the model, the cost of the electric energy used, its variation and the susceptibility of costs to increase were due to the simple inclusion of thermal sources in the Brazilian energy matrix. Studies related to the value in the energy market have highlighted the tendency to reduce values with the adoption of policies to facilitate the introduction of microgenerators into the Brazilian national energy matrix, but did not indicate a convergent value for the expected tariff (Rudnick & Barroso 2017; Gil et al., 2016; Amaral et al., 2016; Chen et al., 2016; Li et al., 2015).

An interdependence between electricity and another source (natural gas) in the DU trial matrix, with the objective of managing the purchase price of these inputs and making the most economical decision, is suggested (Gil et al., 2016). Incentives to reduce the state ICMS may reduce the electricity tariff to approximately US\$ 0.12 kWh<sup>-1</sup> (Amaral et al., 2016), considering conventional residential and/or commercial low voltage class (B) consumers. Class B Brazilian consumers are served at voltages lower than 1,000 V.

The range chosen for the cost of electric power covered a wide range of prices practised in the distributor market; the value applied in 2017 was US\$ 0.08 for rural consumers of conventional class A3a with a demand higher than 75 kW and US\$ 0.20 for Class B residential consumers (Brasil, 2015).

The conventional class A3a consumers are served with a voltage level between 30 and 44 kV.

The electric energy demand rate was 6.68 US\$ kW<sup>-1</sup> (Brasil, 2015). The demand and consumption recorded in TABLE summed to 35.14%; from the social integration program (PIS): 1.09%; from the contribution to social security financing (COFINS): 5.05%, and from the tax on the circulation of goods and services (ICMS): 29%.

The interest rate ranged from 0.21% to 0.89% per month, and these amounts are equivalent to annual interest rates of 2.5 and 11.22%.

The useful life of a DU was estimated at 30 years, and the feasibility projects therefore accounted for this period in the cash flow. Mesquita et al. (2016) claimed that the concrete yard needs to be maintained annually. Thus, the maintenance period considered for the complete exhaustion of a concrete yard ranged from 5 to 15 years. This item represents the time when the amount spent on the maintenance of an existing yard is equal to the value of the construction of a new concrete yard.

The cash flow income and expenses considered the price difference between the drying systems (DU and concrete yard), and the results of the CCRD were presented in response surface graphs constructed in Statistica 8.0 software (version 8.0, by STAT Soft Inc.).

### Composition of the investment values and the cost of drying

Regarding the composition of the amount invested in a DU, the average acquisition cost was US\$ 324,675.32, the average occupation area was 500 m<sup>2</sup>, the useful life was 30 years and the standing drying capacity was 75 m<sup>3</sup>.

DU operator fees were considered as US\$ 3.74 h<sup>-1</sup>, with taxes included and a daily average of 12 hours worked in the drying period. With the energy meter data, Smarter T from IMS, it was possible to verify the average usage times of the AWUs and the motors used in bean handling. These periods in the connected machines were related to the energy costs and to the electric demand for the composition of cash flow expenses.

The value considered for the concrete yard was US\$ 9,012.99, which was based on the stationary coverage of beans at a height of 0.05 m and a drying capacity of 75 m<sup>3</sup>. The paving was designed with 1:4:8 concrete that was 0.08 m thick, and a mortar finish at a 1:3 ratio with 0.02 m finishing (Silva, 2001).

Simultaneously with the cost of setting up a concrete yard, the annual productive loss was considered for the definition of the investment as the difference in the area occupied by it (1,000.00 m<sup>2</sup>) using a population of 0.5 m<sup>2</sup> plants with an annual productive capacity of 0.15 kg m<sup>-2</sup> (Brasil, 2017).

For drying in the concrete yard, a motorcycle with a broom coupled with a daily use of 16 hours and an average consumption of 30 km l<sup>-1</sup> was considered, and the cost of gasoline was 0.85 US\$ l<sup>-1</sup>. The motorcycle operator's fee was US\$ 2.84 h<sup>-1</sup>, and the production assistant's fee was US\$ 1.91 h<sup>-1</sup> with taxes included.

Since the two evaluated processes present different annual drying capacities, the average residence time of the samples in the concrete yard and in the DU was measured. With this, the production factor was calculated, which showed the annual drying capacity.

## RESULTS AND DISCUSSION

### Evaluation of the quality of the dry coffee in the DU and in the concrete yards

Drying with dehydrated air presented technical characteristics viable for its use (Table 3).

TABLE 3. Technical characteristics of coffee dried with dehydrated air and in concrete yards.

|                           | DU-A                       | DU-B                        | DU-C                       | DU-D                        | Control                     |
|---------------------------|----------------------------|-----------------------------|----------------------------|-----------------------------|-----------------------------|
| Collect                   | 15.67 <sup>b</sup> ± 0.88  | 6.67 <sup>a</sup> ± 1.16    | 18.67 <sup>b</sup> ± 0.26  | 17.67 <sup>b</sup> ± 1.25   | 37.25 <sup>c</sup> ± 6.24   |
| Defects                   | 112.33 <sup>b</sup> ± 0.39 | 118.00 <sup>b</sup> ± 34.25 | 56.33 <sup>a</sup> ± 19.24 | 96.33 <sup>ab</sup> ± 14.53 | 346.50 <sup>c</sup> ± 50.93 |
| Sieve N <sup>o</sup> . 17 | 49.00 <sup>a</sup> ± 1.00  | 49.33 <sup>a</sup> ± 4.07   | 25.33 <sup>b</sup> ± 0.85  | 47.67 <sup>a</sup> ± 1.05   | 12.00 <sup>c</sup> ± 2.26   |
| SCAA                      | 83.33 <sup>a</sup> ± 2.14  | 80.00 <sup>a</sup> ± 0.33   | 83.33 <sup>a</sup> ± 2.70  | 81.33 <sup>a</sup> ± 1.07   | 77.83 <sup>b</sup> ± 1.19   |

Notes: DU-[ ]: Drying unit; Control: concrete yard drying. Means followed by the same letter in a line do not differ according to Tukey's test at the 5% level and the control treatment according to Dunnett's test (5%).

It was found that the tasting percentages and the defects in the dry samples in the DU were lower than those in the control samples (concrete yard), showing that drying in the DU had lower rates of broken and damaged beans in relation to drying in the concrete yards.

The presence of beans with high granulometry, which was verified in a retention test in a #17 sieve, was higher in the samples dried in the DU, indicating less bean breakage in their handling. The SCAA score was also higher in the samples dried in the DU, and for these reasons, these samples indicated a higher commercial value for a bag of coffee.

The granulometry of coffee has a direct relation with its value as well as the classification of flat beans or mochas.

The uniformity of the beans retained in high sieves is linked to acceptability in the export market and better remuneration (Chen et al., 2016). The measurement of particle size through sieves is a criterion widely used in cooperatives for the commercialisation of coffee (Wachholz & Poyer, 2014).

The quality of beverage SCAA points are US\$ 83.33 kg<sup>-1</sup> at DU-A; US\$ 80.00 kg<sup>-1</sup> at DU-B; US\$ 83.33 kg<sup>-1</sup> at DU-C and US\$ 81.33 kg<sup>-1</sup> for coffee dried in electrical units. These values had an average statistically higher than the coffee dried in the concrete yard (US\$ 77.83 kg<sup>-1</sup>).

The price of coffee dried in DU-A was US\$ 2.15 kg<sup>-1</sup>; in DU-B: US\$ 2.14 kg<sup>-1</sup>; in DU-C: US\$ 2.12 kg<sup>-1</sup> and in DU-D US\$ 2.09 kg<sup>-1</sup>. These are statistically higher than the value of dry coffee in the concrete yard (1.90 US\$ kg<sup>-1</sup>), and significantly higher (Dunnnett, 5%), with the DU coffees showing a 12.11% increase (0.21 US\$ kg<sup>-1</sup>).

A differentiation in the value of the best quality coffee is quite common in the coffee market. The best quality beans can lead to different prices and value propositions, and the final product is completely dependent on the bean quality and production and distribution processes (Boaventura et al., 2018).

The price of coffee dried in a yard may strongly depend on unfavorable climatic factors, causing drying delays and impairing the coffee quality. Drying in concrete

yards systems can also promote fermentation, further reducing the coffee quality (Martinez et al., 2013).

Drying is a critical step in the postharvest process (Fantazzini et al., 2018; Freitas et al., 2018; Osorio et al., 2016). In this context, the main risks that may arise are biological and chemical, and these may result in a product that is unfit for human consumption (Osorio et al., 2016).

#### Economic viability of drying in DU

It took 1,500 m<sup>2</sup> in the concrete yard to dry 75 m<sup>3</sup> of espresso coffee with a height of 0.05 m, while the construction of a DU occupied 500 m<sup>2</sup> on average. The production area lost in the yard was thus considered to be 1,000 m<sup>2</sup>.

An average drying time per lot (TSL<sub>DU</sub>) of 9.2 days in the DU was observed, while drying coffee in a yard took an average of 19.4 days, with the drying time ratio being a production factor of 2.11. It is observed from this relation that the DU can dry an amount of coffee from a planted area that is more than twice the amount that can be dried in a concrete yard. Other studies have shown a rate higher than this, when coffee was dried in a hybrid concrete yard (from 50% to 9.5%). The time ratio was 3.1 according to Resende et al. (2011) and a time ratio of 6.7 was found by Donzeles et al. (2008).

Throughout the useful life of a DU (estimated at 30 years), the total drying capacity was 4,585,597.8 kg of coffee, while in the concrete yard in the specified area it was 43.49×10<sup>6</sup> kg in the same period.

Considering the annual drying capacity of a DU, 152,853 kg of coffee were produced, and the average yield was 0.15 kg m<sup>-2</sup> (Brasil, 2017); with an average harvest time of 150 days, the minimum planting area for optimum DU use should be equal to 1.05×10<sup>3</sup> m<sup>2</sup>. However, knowing the specific productivity of each crop, a coffee grower must correlate the planting area equivalent to the DU optimisation, since these are inversely proportional.

The analysis of variance (ANOVA) of the dependent variables (discounted payback, net present value, internal rate of return and return on investment) as a function of x<sub>1</sub>, x<sub>2</sub>, x<sub>3</sub> and x<sub>4</sub> is presented in Table 4, which shows the sum of squares (SQ), degree of freedom (GL), mean square (MQ), and Snedecor's F distribution.

TABLE 4. ANOVA summary of the response variables.

| Source of variation                        |            | SQ                      | GL    | MQ                     | F        |
|--|------------|-------------------------|-------|------------------------|----------|
| Payback (PB)<br>(year)                     | Regression | 75.38                   | 9.00  | 8.38                   | 319.44   |
|  | Residual   | 0.47                    | 18.00 | 0.03                   |          |
|  | Total      | 75.86                   | 27.00 |                        |          |
| Net present value (NPV) (US\$)             | Regression | 112.47×10 <sup>12</sup> | 6.00  | 18.74×10 <sup>12</sup> | 4478.68  |
|  | Residual   | 87.89×10 <sup>9</sup>   | 21.00 | 4.19×10 <sup>9</sup>   |          |
|  | Total      | 112.56×10 <sup>12</sup> | 27.00 |                        |          |
| Internal rate of return (IRR) (%)          | Regression | 3053.54                 | 7.00  | 436.22                 | 12940.15 |
|  | Residual   | 0.67                    | 20.00 | 0.03                   |          |
|  | Total      | 3054.21                 | 27.00 |                        |          |
| Return on investment (ROI) (dimensionless) | Regression | 86.77                   | 8.00  | 10.85                  | 1935.04  |
|  | Residual   | 0.11                    | 19.00 | 0.01                   |          |
|  | Total      | 86.88                   | 27.00 |                        |          |

Notes: PB: F<sub>9;18;0.05</sub>=2.46; R<sup>2</sup>=99.38% and p-value < 0.000001;  
 NPV: F<sub>6;21;0.05</sub>=2.57; R<sup>2</sup>=99.92% and p-value < 0.000001;  
 IRR: F<sub>7;20;0.05</sub>=2.51; R<sup>2</sup>=99.98% and p-value < 0.000001, and  
 ROI: F<sub>8;19;0.05</sub>=2.48; R<sup>2</sup>=99.88% and p-value < 0.000001.

It was found from the statistical treatment (Table 4) that all the F-values are greater than the tabulated F footnotes, showing that the software defined significant models.

The estimated PB [eq. (5)], given statistically significant regression coefficients, is as follows:

$$PB = 3.31 - 1.00 x_1 + 0.21 x_1^2 + 1.27 x_2 + 0.38 x_2^2 + 0.27 x_3 + 0.11 x_4 - 0.57 x_1 \cdot x_2 - 0.14 x_1 \cdot x_3 + 0.16 x_2 \cdot x_3 \quad (5)$$

At the 5% level, the PB had a significant correlation with the "price of a sack of coffee dried in the concrete system" in the linear and quadratic forms, as well as with the "cost of acquiring electricity". There was a linear correlation with the response to the "annual interest rate" and the period of maintenance of the yard equivalent to its depreciation.

The significance of the PB response to the relations between (1) the "price of a coffee bag dried in a concrete yard" and the "cost of electric power acquisition", (2) the "price of a coffee bag dried in a concrete yard" and the "annual interest rate", and (3) the "annual interest rate" and the "maintenance period of the yard equivalent to its depreciation" was also verified.

The estimated PVL equation, given as a function of the statistically significant regression coefficients, is presented in [eq. (6)].

$$NPV = [5.20 + 1.03 x_1 - 1.29 x_2 - 1.33 x_3 + 0.24 x_4^2 - 0.24 x_1 x_3 + 0.30 x_2 x_3] 10^6 \quad (6)$$

The NPV received a significant linear contribution from the variables "price of a coffee bag dried in a concrete yard", the "electric energy acquisition cost" and the "annual interest rate". A quadratic correlation of the response, NPV, with the "annual interest rate" was also observed, and significant dependence was verified in the relations between the "price of a sack of coffee dried in a concrete yard" and the "annual interest rate" and the "cost of acquiring electricity" and the "annual interest rate".

When the NPV becomes null, the amount spent on project investment is equal to that received in proportion to the time and attractive interest rate [40]. In this way, it is understood that a positive NPV relates to projects whose financial return is higher than the investment of capital in the interest rate. Also, higher NPV positive values represent a greater recovery of the initial investment [16].

The estimated IRR as a function of the statistically significant regression coefficients is given in [eq. (7)].

$$IIR = 34.76 + 7.02 x_1 - 8.76 x_2 - 0.35 x_3 - 0.95 x_4 + 0.30 x_4^2 - 0.17 x_1 x_4 + 0.21 x_2 x_4 \quad (7)$$

The IRR was linearly correlated with all the independent variables and presented quadratic significance with the "period of time in maintenance of the yard equivalent to its depreciation" variable.

There was also a correlation between the response and the following relationships: the "price of a sack of coffee dried in a concrete yard" and the "period of time in maintenance of the yard equivalent to its depreciation", as well as the "cost of electric energy acquisition" and the "period of time in maintenance of the yard equivalent to its depreciation".

In this sense, production losses have a direct influence on the IRR, delaying the recovery of invested capital, and it is necessary to monitor coffee production to determine the renewal momentum of the plant [10].

The statistically significant regression coefficients of the return on investment (ROI) are given in [eq. (8)].

$$ROI = 4.54 + 0.91 x_1 - 1.14 x_2 - 1.17 x_3 + 0.21 x_3^2 - 0.12 x_4 + 0.04 x_4^2 - 0.21 x_1 x_3 + 0.26 x_2 x_3 \quad (8)$$

The ROI received significant linear contributions from all of the variables. It also presented a quadratic correlation with the "annual interest rate" and the "period of time in maintenance of the yard equivalent to its depreciation".

We also verified a significant correlation of the response with the following variables: "dry sack price in the concrete yard" and the "annual interest rate" as well as the "cost of electric energy acquisition" and the "annual interest rate".

The response surfaces constructed with the variables of greatest influence in each response are presented in Figure 2.

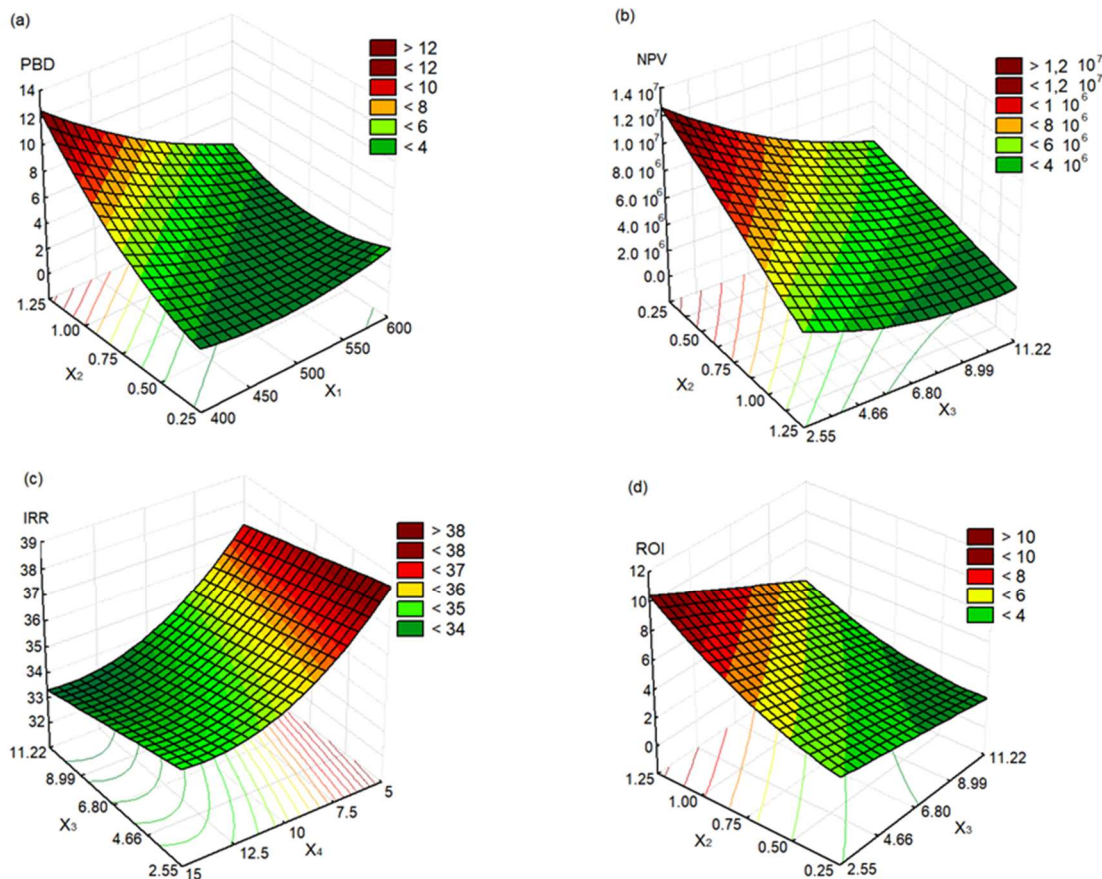


FIGURE 2. Response surfaces: a) payback (year); b) net present value (US\$); c) internal rate of return (% per year) and d) return on investment (dimensionless).

Notes:  $X_1$ : Sale price of a 60 kg bag of coffee dried in the concrete yard in Reais,  $X_2$ : Cost of electric energy acquisition in US\$ kWh<sup>-1</sup>,  $X_3$ : Annual percentage rate of interest, and  $X_4$ : Maintenance period in the concrete yard with an amount equivalent to its depreciation in years. The two most striking variables on each response were used in the horizontal axes.

The PBD was influenced more by the variables of the selling price of a 60 kg bag of dry coffee in the concrete yard and the "cost of electric energy acquisition", as shown in Figure 2a. From the figure, it appears that the best results of this indicator occur with lower electric energy tariffs and higher coffee sale prices.

The variables with the greatest influence on the NPV (Figure 2b) and ROI (Figure 2d) were the "electric energy acquisition cost" and the "annual interest rate", and the relation was inversely proportional to the desirability of these indicators with the two response variables.

The variables "annual interest rate" and "maintenance period in the yard with an amount equivalent to its depreciation" had a greater influence on the IRR, as presented in Figure 2c, being inversely related.

Analysing scenarios with variation in productive systems can measure sufficient economic results for decision-making related to the study (Pereira et al., 2018; Oliveira et al., 2016; Araújo et al., 2018). In the research, the indicators corroborate the implementation of business strategies and the direction of coffee grower investments.

### Optimisation of investment in a drying unit

The PBD ranged from 7.68 to 2.04 years, the NPV ranged from 2.31 to 2.49 (US\$ million), the IRR ranged from 17.23 to 52.53% per year and the ROI ranged from 1.99 to 8.66, corroborating a project desirability factor of 98.98%.

The optimal desirability condition occurred with the following response variables: a PBD of 2.04 years, an NPV of US\$ 2.49 million, an IRR of 52.53% and an ROI of 8.66. The set of independent variables that gave rise to such a response was a sale price of US\$ 8,548.20 kg<sup>-1</sup>, the "cost of electric power purchase" as US\$ 0.13 kWh<sup>-1</sup>, an attractive annual interest rate of 4.66% and a maintenance period in the yard with an amount equivalent to its depreciation of 7.50 years.

With the analysis of the average values of the independent variables considered as a selling price of 129.70 US\$ sc<sup>-1</sup>, the "cost of electric power acquisition" as 0.19 US\$ kWh<sup>-1</sup>, an attractive annual interest rate of 6.80% and a period of maintenance in the concrete yard with a value equivalent to its depreciation of 10 years, the response variables were a PBD of 3.31 years, an NPV of US\$ 134,889.75, an IRR of 37.46% pa, and an ROI of 4.54.

When analysing the values of the independent variables, a selling price of 116.73 US\$ sc<sup>-1</sup>, the "cost of electric power acquisition" as 0.26 US\$ kWh<sup>-1</sup>, an attractive annual interest rate of 8.99% and a period of maintenance in the yard with an amount equivalent to its depreciation of 12.5 years were obtained as the most unfavourable response variables of the CCRD. In this configuration, the PBD was 7.68 years, the NPV was US\$ 601,815.82, the IRR was 18.47% pa and the ROI was 1.99.

An analysis of the scenarios susceptible to variation in a production system can help to measure the economic results with the objective of implementing business



strategies and directing the investments of coffee growers (Kumar et al., 2012).

The sale price of products directly influences their profitability in several agricultural activities, such as fruit growing and grain production (Siqueira et al., 2011). This is due to the uncertainties and seasonal characteristics of production.

A directly proportional relationship was verified between the viability of the investment and the price of a bag of coffee.

The relation was inversely proportional to the acquisition of electric energy and monthly interest rate. In fact, the viability of acquisition occurred when the electric energy values were above US\$0.16 kWh<sup>-1</sup> and, simultaneously, the monthly interest rate was above 0.38%.

Regarding the importance and use of economic indicators in feasibility projects, the use of appropriate economic discount indicators considers time and allows the identification of markets that are favourable or unfavourable to capital investment (Atallah et al., 2012). Furthermore, the IRR and PBD represent risk indicators that show the impact of an investment.

## CONCLUSIONS

An air dehydrator unit composed of a refrigerator system with a 422,908.7 J s<sup>-1</sup> refrigerant capacity coupled to tray dryers with a static capacity of 75 m<sup>3</sup> presents a mean drying time of 9.2 days for coffee lots with an initial humidity of 52% on average.

The annual drying capacity of 152.9×10<sup>3</sup> kg of coffee during the 150 day harvest period and the minimum planting area for this production, considering an average yield of 0.15 kg m<sup>-2</sup>, should be 1.05×10<sup>3</sup> m<sup>2</sup>. However, each coffee grower must size the air dehydrating machines according to their peculiar production characteristics.

The acquisition cost of electric energy and the selling price of coffee were the variables that had the greatest influence on the discounted payback and the internal rate of return, while the cost of electric energy and the interest rate were the variables that influenced the net present value responses and the return on investment the most.

The study showed the acceptability of the investment with an optimisation of the project, with a PBD of 2.27 years and a return of investment of US\$ 2.61 million, and the desirability was 98.98% for the project.

Drying with dehydrated air is technically feasible due to its higher SCAA score, the presence of larger beans and the lower presence of defective beans. Unlike the mechanical dryers that have existed until now, the drying system studied makes it possible to dispense with concrete yards for directly receiving the coffee fruits harvested.

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