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RESEARCH ARTICLE

Economic analysis of low-temperature grain drying

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ABSTRACT

The main objective of this study was to simulate the economic feasibility of low-temperature grain drying systems considering Brazilian conditions and using three drying capacities, seven grain types and two furnace fuels. For this, 42 scenarios were simulated and compared among themselves by using an economic analysis based on the cash flow model with project lifetime of 20 years. The indices net present value, payback period, benefit-cost ratio and internal rate of return were applied during the analyses. Simulations showed that drying of coffee and beans in large systems presented higher economic feasibility, regardless of the furnace fuel used. All simulated scenarios were cost-effective provided that at least two drying cycles are performed per year. Labor costs, social taxes, grain type and drying capacity most affected the profitability of this kind of investment, while the furnace fuel less influenced the evaluated economic indices.

Keywords: Cash flow model; Economic feasibility; Post-harvest; Renewable fuel; Drying systems

INTRODUCTION

The grain drying process consists of removing water from the product up to a level that allows the safe storage for longer periods of time. As presented by Chen (2000) and Sharon et al. (2016), this process occurs by simultaneous heat and mass transfers, when moisture in the grain evaporates, diffusing out of the kernels, and heat energy flows in the opposite direction, causing the moisture to change from a liquid to a gas. Many works proved that drying makes possible the earlier harvest, minimizing the potential for field losses due to diseases, insects and other microorganisms (Tirawanichakul et al., 2004; Singh et al., 2014; Donlao et al., 2018). This process is also the most used for maintaining grain quality in long-term, since water content reduction slows down the biological activity of grain, as well as the chemical and physical reactions that can cause deterioration during storage (Pirasteh et al., 2014).

The low-temperature drying has been considered a low capital cost and energy efficient alternative to other drying systems (Jones et al., 2012). It is well-accepted by seed producers and some food industries since longer and constant drying periods increase the nutrient retention, while reducing stress cracking (Jittanit et al., 2010; Ondier et al., 2010). Furthermore, slow moisture loss contributes to maintain seed viability and longevity (Young et al., 2016). But in addition to technical factors, economic viability of grain drying is very important. According to Marquezan (2006), the main reasons for people to invest in infrastructure or new technologies are the retained earnings. A project is profitable only when its revenues are greater than the invested capital and expenses. This concept can be applied to grain drying projects. For this, careful economic analyses are required, considering all the risks involved in this process and searching for strategies that minimize investment failures (Valente et al., 2011; Mugabi and Driscroll, 2016).

A large number of variables affect the costs of grain drying, hampering comparisons and the establishment of a standard methodology for economic analysis and decision making about this kind of investment. The particularities of each grain, drying technology and region of study also contribute to these difficulties. Even so, several authors already evaluated the economic feasibility of grain drying by simulations or empirically, due to its importance for management purposes. But they considered products, dryers and bulk volumes in isolation.

Jasper et al. (2006) simulated the economic feasibility of investing in small in-bin dryers, considering the State of São Paulo (Brazil) and the storage of maize, concluding that this is a profitable option, provided that the selling

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price of maize is greater than the annual costs of the system. Valente et al. (2011) developed a decision support system to determine the costs and rates of unit operations regarding reception, cleaning, drying, storage and dispatch of grains in storage facilities. These authors considered high-temperature drying and focused specifically on the South region of Brazil. The drying costs were also analyzed by Lawrence et al. (2015) when evaluating the potential for low-temperature drying of rough rice in Arkansas (USA). Mugabi and Driscroll (2016) simulated the applicability of drying maize with low-temperature in Uganda, finding that both drying costs and profit were strongly influenced by the low prices for maize, as well as by the price fluctuations of fuel and electricity.

There is a need for a joint analysis involving the main technical and economic parameters of low-temperature drying, also considering different grain types, furnace fuels and bulk volumes in order to a more accurate estimate of expenses and revenues. The main objective of this study was to evaluate by simulations the impacts of the grain type, furnace fuel and bulk volume on the economic feasibility of low-temperature drying systems in Brazil.

METHODOLOGY

Technical simulation of low-temperature grain drying

Seven grain types (peanut, rice, coffee, bean, corn, soybean and wheat) were considered during simulations, since these crops play an important role as Brazilian commodities and are widely used both for internal consumption and exportation (Conab, 2018). Furthermore, three dryer volumes (10.6 m^3, 134.7 m^3 and 392.7 m^3) were simulated, representing the most common low-temperature drying systems built in Brazil (Jasper, 2006; Polidryer, 2018). Additionally, two furnace fuels (wood and grain residues) were used, totaling 42 simulation scenarios which were analyzed separately and compared among themselves afterwards (Fig. 1).

Low-temperature drying time is an important factor when studying the economic feasibility of this kind of system and was simulated by the energy balance equation. This method relates the sensible heat given off by the drying air and the energy for evaporation to bring grain from the initial to the equilibrium moisture content (Silva et al., 2009):

$$t = V_e h_v M_s (U_0 - U_e)/[60\, Q\, C_a (T_a - T_e)] \quad (1)$$

where Q is the drying airflow rate (m^3 min^{-1}), V_e is the specific volume of dry air (m^3 kg^{-1}), C_a is the specific heat of drying air (kJ kg^{-1}°C^{-1}), T_a is the drying air temperature (°C), T_e is the equilibrium temperature between drying air and grain (°C), t is the drying time (h), h_v is the latent

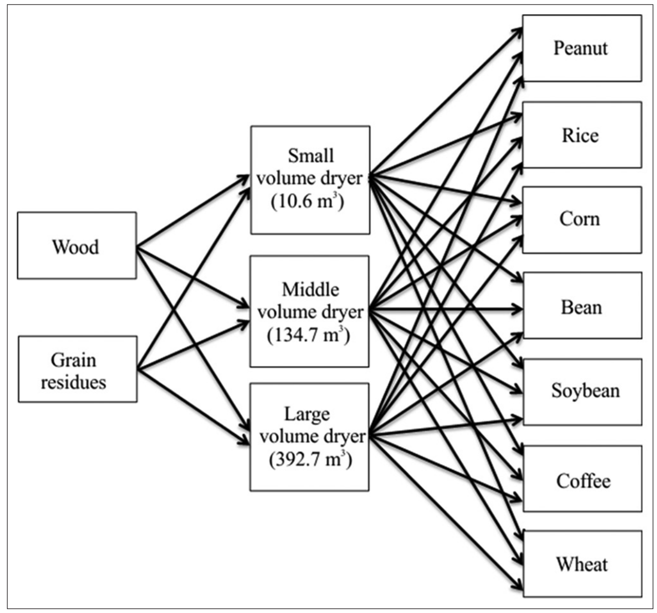

Fig 1. Schedule of simulated scenarios.

heat of vaporization of water (kJ kg^{-1}), M_s is the grain dry matter (kg), U_o is the initial moisture content of grain (dry basis) and U_e is the equilibrium moisture content of grain (dry basis).

During simulations, airflow rate was 2.0 m^3 min^{-1} t^{-1}, while relative humidity and temperature of drying air were equal to 70% and 40°C, respectively. These values followed the recommended ranges of drying temperature (30 - 40°C), relative humidity (65 - 70%) and airflow rate (1.5 - 2.0 m^3 min^{-1} t^{-1}), which were previously tested for low-temperature grain drying and were proved to be efficient for maintaining the product quality, also reaching the drying effects within an appropriate time and without requiring excessive energy consumption (Arinse et al., 1993; Tirawanichakul et al., 2004). Initial grain moisture contents of 20% (wet basis) were used during simulations, which were performed in such way that product was dried until equilibrium moisture content was achieved. This value was calculated by Chung-Pfost equation (Brooker et al., 1992) and varied from grain to grain as shown in Table 1. Other drying air conditions, such as the specific volume of dry air and the equilibrium temperature, were calculated based on the psychrometric relationships (Melo et al., 2004).

The equilibrium temperature was obtained following an adiabatic line by keeping the enthalpy constant until finding a value for the temperature at which relative humidity is equal to the equilibrium relative humidity, considering the initial grain moisture content and the drying temperature. This was performed using a numerical method, by calculating and recalculating the relative humidity as a function of absolute humidity and equilibrium temperature by using the psychrometric relationships, until it converges (Lopes et al., 2014).

Technical data required to perform the economic analysis also included the energy consumption (Eq. 2-4), which depended on the drying airflow rate, the bulk static pressure (Brooker et al., 1992) and the amount of fuel considering a furnace efficiency of 80% (Lopes et al., 2001).

$$P = (0.075\ Q\ Pe)/(4500\ \alpha) \quad (2)$$

$$Pe = (1.5\ H\ a\ K2)/\ln(1+b\ K) \quad (3)$$

$$K = Q/(60\ A) \quad (4)$$

$$Mc = [60\ \rho\ Q\ Ca\ (Ta - T)]/(\eta\ P_{CI}) \quad (5)$$

where P is the fan power (kW), P_e is the bulk static pressure (Pa), α is the fan efficiency (decimal), H is the grain bulk height (m), K is specific drying airflow rate ($m^3\ s^{-1}\ m^{-2}$), a and b are coefficients that depend on the product ($Pa\ s^2\ m^{-3}$ and $m^2\ s\ m^{-3}$, respectively), A is the bottom area of the dryer (m^2), M_c is the fuel consumption ($kg\ h^{-1}$), ϱ is the drying air density ($kg\ m^{-3}$), T is ambient air temperature (°C), is the furnace efficiency (decimal) and P_{CI} is the low calorific power of fuel ($kJ\ kg^{-1}$).

Table 2 presents the yields, harvesting availability factors and low calorific powers of the grain residues used in this study. The low calorific power of wood was simulated as 12970 $kJ\ kg^{-1}$ (Epe, 2017).

Table 1: Equilibrium moisture contents of simulated grain at 70% of relative humidity

Grain	Equilibrium moisture content (%bs)
Corn	15.0
Peanut	8.0
Coffee	15.0
Bean	16.0
Soybean	14.0
Wheat	14.0
Rice	14.0

Table 2: Yields, availability factors and low calorific powers of the studied grain residues

Residue	Yield (tdb/t)*	Harvesting availability factor (%)	Low calorific power (kJ/kg)
Soybean straw	2.30	30	14600
Corn straw	1.68	40	17700
Rice straw	1.55	40	16000
Rice husk	0.19	40	16000
Wheat straw	2.90	40	12400
Bean straw	1.16	40	14000
Coffee husk	2.00	50	15500
Peanut husk	1.04	25	12900

*tdb expresses tons of residues in dry basis and t expresses tons of grain
Adapted from Epe (2017), Fasina (2008) and Lopes et al. (2001)

Dry matter losses of 0.5% due to transportation and drying were simulated, indicating high grain quality, but at the same time affecting the total volume of commercialized product (Nourbakhsh et al., 2016; Jasper et al., 2006).

Economic analysis of low-temperature grain drying

The methodology applied to the economic analysis was the cash flow model. A project lifetime of 20 years was considered based on the average useful life of grain dryers and other equipment used in the process (Jones et al., 2012). Further, the real (R$) to US dollar conversion was $3.62 (Bank of Brazil, 2018). A cash flow was calculated for each one of the 42 simulated scenarios of low-temperature drying, representing the balance of the amount of revenues and expenses of the process during the lifetime of the project. The number of drying cycles was variable during analyses in order to identify the minimal value required to guarantee economic feasibility for each studied condition. More drying cycles tend to improve the profitability of the grain drying.

The year zero of each cash flow considers no revenues and the capital investment as expenses. The capital invested in the drying systems was calculated according to data presented by Polidryer (2018) and Jasper et al. (2006) with monetary corrections, corresponding to $ 2,655.50; 10,673.46 and 27,343.79 for small, middle and large drying systems, respectively.

For the other years, costs comprised labor, taxes, maintenance, fuel and electrical energy, also considering the depreciation and the inflation rates. Revenues were associated with the grain sale corrected by inflation.

Table 3 shows that average selling prices, which were obtained by agribusiness websites, varied for different grain types, as well as bulk volumes varied for equal dryer sizes due to their different densities.

Straight-line depreciation was used to estimate the system obsolescence for each year of the lifetime of the project (20 years), considering a 10% discount rate (Silva et al., 2009). Maintenance costs were calculated as 3% of the capital invested on the drying system and represented the expenses with repair and part replacement (Mugabi and Driscroll, 2016). Labor costs were simulated as $ 22.10 per employee per day, while social taxes were 68% of the payroll (IEA, 2018; Occupational Guide, 2018). Other taxes and fees related to the low-temperature drying process corresponded to 10% of the capital invested in the system (Conab, 2018).

The annual inflation rate, which is a measurement of the rise in prices of a product, project or service over a year,

Table 3: Average selling prices of grain used in simulations and bulk masses depending on the dryer size

Grain	Selling price ($ t^{-1})	Grain bulk mass (t)		
		Small dryer	Middle dryer	Large dryer
Peanut	464.09	5.42	68.83	200.67
Rice	212.71	6.26	79.47	231.69
Coffee	2,049.72	5.30	67.35	196.35
Bean	690.61	7.95	101.02	294.52
Corn	127.07	7.90	100.35	292.56
Soybean	295.78	6.68	84.86	247.40
Wheat	174.03	8.54	108.43	316.12

was 10% (Lopes and Steidle Neto, 2017; Bank of Brazil, 2018). Costs of electrical energy ($ 0.11 kWh^{-1}) were based on the current fees in Brazil (Cemig, 2018; Eletropaulo, 2018; Cemar, 2018). An attractiveness rate of 7% was also employed, representing a perceived quality and utility of grain drying systems and contributing to the evaluation of their economic feasibility (Marquezan, 2006; Mugabi and Driscroll, 2016). An average wood cost ($ 0.04) was calculated based on data from agribusiness websites, while grain residues were considered costless since they are recycled from the cultivation area.

The economic indices Net Present Value (NPV), Benefit-Cost Ratio (BCR), Internal Rate of Return (IRR) and Payback Period (PP) were used for evaluating the cash flows.

The NPV (Eq. 6) corresponds to the algebraic sum of the present values that compose the cash flow. That is, it is the sum of capital expenditure, operating expenses and income generated by the project, discounting the inflation rate to the initial moment of the project lifetime (Lopes et al., 2013). Low-temperature grain drying will be profitable only if NPV is greater than zero (Marquezan, 2006).

$$NPV = V_0 + \sum_{i=1}^{N}\left[(F_L)_i\left(1+\frac{j}{100}\right)^{-i}\right] \tag{6}$$

where V_0 is the capital investment ($), i is the year considered in the cash flow (dimensionless), N is the project lifetime (dimensionless), F_L is the cash flow ($) and j is the inflation rate (%).

The BCR is defined as the quotient between the benefits and costs of the project, discounting the inflation rate (Eq. 7). Thus, a low-temperature drying system will be economically feasible only if BCR is greater than one (Lopes and Steidle Neto, 2017).

$$BCR = \left|\frac{NPV - |V_0|}{|V_0|}\right| \tag{7}$$

The PP refers to the time required for recovering the initial investment by the cumulative revenues. This index was calculated iteratively by applying Eq. 8 for each year of the project lifetime until a value greater than the initial investment was found (Lopes, 2002). Thus, PP was associated with the last year considered at the end of iterations and the drying system was profitable if this index was smaller than the project lifetime.

$$(V_p)_i = (V_p)_{i-1} + \frac{(F_L)_i}{\left(1+\frac{j}{100}\right)^i} \tag{8}$$

where V_p is the annual recovered value ($).

The IRR is the rate of return at which NPV equals zero. That is, this index represents the ratio of return where the sum of benefits is equal to the sum of costs. IRR was calculated iteratively by inverse Lagrange interpolation (Lopes, 2002). Worthwhile drying systems have IRR greater than the attractiveness rate, which is the minimum acceptable return percentage that this kind of project must earn in order to be profitable.

After all economic analyses were performed, the feasible and unfeasible scenarios were identified, as well as a comparison among them was made and the main factors that affected their economic feasibility were evaluated. All calculations and analyses were accomplished by using electronic worksheets.

RESULTS AND DISCUSSION

All the 42 scenarios simulated were economically feasible provided that at least two low-temperature drying cycles are performed per year. NPVs (Fig. 2) varied from $ 10.8 thousand to $ 14.4 million, approximately, at the end of the project lifetime (20 years). The smallest NPVs were observed when drying small volumes of grain, mainly corn, rice and wheat. In addition to the amount of dried grain, products with low selling prices tend to result in smaller revenue. When observing the results of the systems based on middle and large dryers, wheat presents better results than rice, even though its selling price is small. This can be explained since it is possible to dry a greater amount of wheat than rice when using same capacity dryers, mainly due to their different bulk densities (Table 3). On the other hand, the greatest NPVs were verified for coffee and bean, indicating a higher profitability of these drying systems when compared to the other ones. Investments with grain of high economic value, such as coffee and bean, tended to be more profitable, earning more revenue at the end of the project lifetime for all drying capacities.

Among the 42 simulated scenarios, 36 resulted in immediate PP, including low-temperature drying of peanut, coffee, bean and soybean for all drying capacities, as well as wheat, corn and rice by using middle and large dryers. Following the trend verified for the NPV results, the high economic values of some products, as well as the large amounts of dried grain, contributed to the immediate recovery of the initial investments. The other scenarios presented PPs of 1.5 years when drying small volumes of wheat, 2 years when drying rice in small driers and 3 years when investing in small driers for corn. Greater PP values indicate that the capital invested in the drying system will be committed for several years, resulting in riskiest projects. But the observed PPs were all immediate or smaller than half of the project lifetime, evidencing all the simulated scenarios as low risk projects.

The simulated BCRs (Fig. 3) varied from 3 to 529, indicating that all simulated scenarios were potentially profitable since the sum of the benefits largely exceeded the costs in all drying systems. This economic index was more affected by the selling price of grain than by the drier capacity. As observed for the NPV and PP, the greatest BCRs were observed when drying coffee and bean, which are the products with higher economic values among those studied in this work.

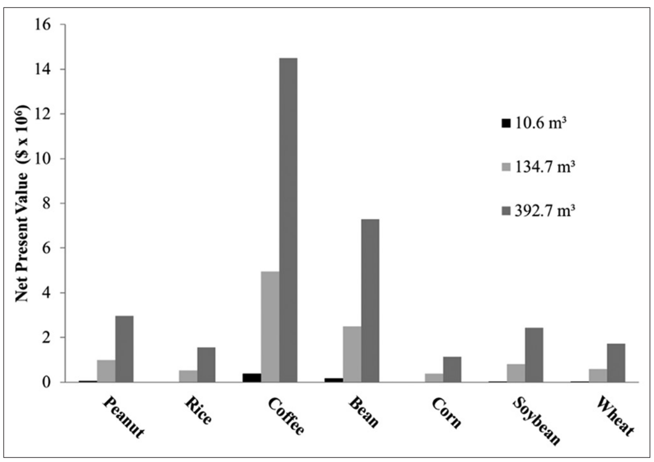

Fig 2. Average Net Present Values (NPV) of the simulated scenarios considering small (10.6 m^3), middle (134.7 m^3) and large (392.7 m^3) volume dryers.

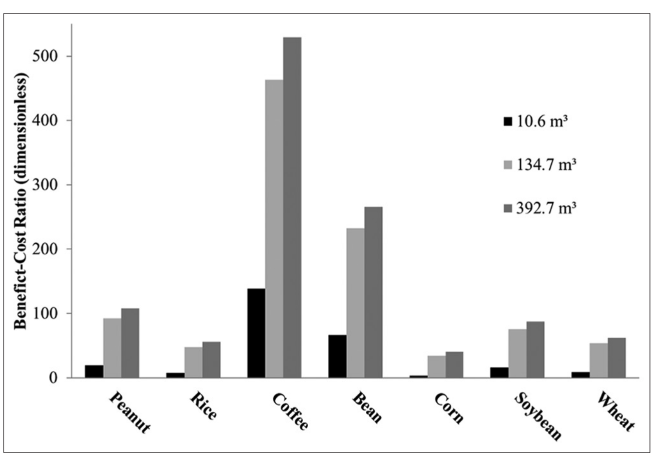

Fig 3. Average Benefit-Cost Ratios (BCR) of the simulated scenarios considering small (10.6 m^3), middle (134.7 m^3) and large (392.7 m^3) volume dryers.

The IRRs (Fig. 4) ranged from 29 to 100%, with corn, wheat and soybean dried by small farmers presenting the lowest values. All IRRs were well above the attractiveness rate of 7%, recommended by Mugabi and Driscroll (2016) as the minimum acceptable return on the invested capital throughout the drying system lifetime. These results confirm the simulated scenarios as low risk and profitable investments.

Besides grain type and dryer size, the labor costs and social taxes also affected the economic feasibility of low-temperature drying, representing around 40% of the costs related to this process. Additionally, some important technical parameters contributed to the results, including the drying time, electrical energy requirements and amount of fuel. The simulated drying times most depended on the grain type, corresponding to 233, 146, 137, 118, 137,

Table 4: Simulated amounts of furnace fuels (kg)

	Drier capacity					
	Small	Middle	Large	Small	Middle	Large
	Wood			Crop residue		
Peanut	168.8	2143.8	6250.0	169.7	2155.4	6283.9
Rice	121.7	1546.6	4509.0	98.7	1253.7	3655.1
Coffee	97.3	1235.6	3602.3	81.4	1033.9	3014.4
Bean	125.4	1593.4	4645.6	116.2	1476.2	4303.8
Corn	144.4	1834.5	5348.5	105.8	1344.3	3919.2
Soybean	138.6	1760.5	5132.6	123.1	1563.9	4559.6
Wheat	170.4	2164.8	6311.5	178.2	2264.3	6601.6

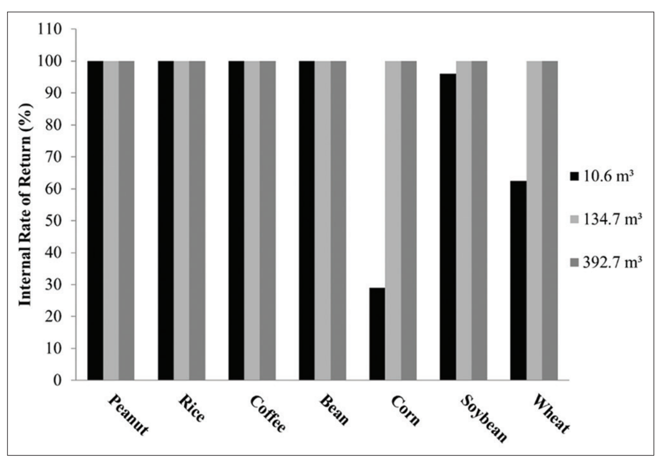

Fig 4. Average Internal Rates of Return (IRR) of the simulated scenarios considering small (10.6 m^3), middle (134.7 m^3) and large (392.7 m^3) volume dryers.

155 and 150 hours for each drying cycle when considering peanut, rice, coffee, bean, corn, soybean and wheat, respectively. The electric energy requirements most varied according to the drier capacity, and were 0.12, 4.94 and 32.08 kW for the small, middle and large driers, respectively. The amount of furnace fuel was affected by both grain type and drier capacity, as shown in Table 4.

The furnace fuel was the variable that less affected the simulation results. Scenarios where only furnace fuel varied did not present considerable differences when analyzing the economic indices. This can be explained by the low cost of wood in Brazil and by the small amounts of fuel required for low-temperature grain drying. Fuel costs tend to increase when considering wood freight and labor required for prepare wood or grain residues to be used into the furnace. In the case of wood, the distance between the dryer and the fuel supplier affects the freight cost directly, as well as the region where the wood is acquired.

Even presenting similar economic results to wood, it is worth to emphasize the importance of using agricultural residues as alternative fuel for grain drying. Besides the large amount and availability for immediate use, grain residues generally present low calorific values greater than that of wood, which implies in higher energy contents. Lim et al. (2012) affirmed that grain residues are considered one of the most promising energy sources due to its near-carbon neutrality. Further, grain residues can be used as fuel during grain drying without detrimentally affecting other agricultural practices where they are required, such as tillage, heating and animal feed. Wang and Mendelsohn (2003) reported that leaving 15% of crop residues in field is enough for providing adequate soil fertilization, protection and carbon, while 25% is generally used for animal feed and industrial raw materials. According to the results of simulations performed in this study, around 4% of the biomass from plantations was required as furnace fuel for low-temperature grain drying, thus guaranteeing residue availability for other agricultural practices.

Another important factor is that the incomplete combustion of wood can generate toxic gases, such as the polycyclic aromatic hydrocarbons (PAHs). Lima et al. (2017) affirmed that these organic compounds are classified as environmental pollutants, since they are non-biodegradable, and are also known to have carcinogenic potential. Thus, the use of residues as grain drying fuels can minimize environmental impacts, contributing to more sustainable agricultural activities.

CONCLUSION

All the 42 scenarios simulated were economically feasible provided that at least two low-temperature drying cycles are performed per year. The most profitable drying systems were those with middle and large capacities operating with coffee and bean. The factors that main affected the economic feasibility of low-temperature drying were the grain type, dryer size, labor costs and social taxes. The furnace fuel did not interfere considerably in the evaluated economic indices. Despite this result, the use of grain residues as drying fuel was recommended due to their environmental benefits, as well as their large amount and availability for immediate use. The performed economic analysis can be easily adapted to other grains, country market conditions, furnace fuels, and drying capacities.

Author contributions

Pricila Araújo Santana performed the simulations, analyzed the results and prepared the manuscript. Daniela de Carvalho Lopes and Antonio José Steidle Neto analyzed the results and contributed for preparing the manuscript.

REFERENCES

Arinse, E. A., S. Sokhansanj and G. J. Schoenau. 1993. Development of optimal management schemes for in-bin drying of canola grain (rapeseed), Comput. Electron. Agric. 9: 159-187.

Bank of Brazil. 2018. Contracts and Tables. Available from: http://www.bb.com.br. [Last accessed on 2018 Dec 10].

Brooker, D. B., F. W. Barker-Arkema and C. W. Hall. 1992. Drying and Storage of Grains and Oilseeds. AVIBook, New York.

Cemar. 2018. Maranhão Power Company. Available from: http://www.cemar116.com.br/home. [Last accessed on 2018 Apr 03].

Cemig. 2018. Minas Gerais Power Company. Available from: http://www.cemig.com.br/pt-br/paginas/default.aspx. [Last accessed on 2018 Apr 03].

Chen, C. 2000. Factors that affect equilibrium relative humidity of agricultural products. Transac ASAE. 43: 673-683.

Conab. 2018. National Food Supply Company. Available from: http://www.conab.gov.br/conabweb/download/safra/custosproducaometodologia.pdf. [Last accessed on 2018 Jun 06].

Donlao, N., Y. Matsushita and Y. Ogawa. 2018. Influence of postharvest drying conditions on resistant starch content and quality of non-waxy long-grain rice (*Oryza sativa* L.). Dry. Technol. 36: 952-964.

Eletropaulo. 2018. São Paulo Power Company. Available from: https://www.aeseletropaulo.com.br/Paginas/aes-eletropaulo.aspx. [Last accessed on 2018 Apr 03].

Epe. 2017. Energy Research Company. Nota Técnica DEA 15/14 Inventário Energético de Resíduos Rurais, Rio de Janeiro.

Fasina, O. O. 2008. Physical properties of peanut hull pellets. Bioresour. Technol. 99: 1259-1266.

Occupational Guide. 2018. Labor Costs. Available from: http://www.guiatrabalhista.com.br/tematicas/custostrabalhistas.htm. [Last accessed on 2018 Oct 08].

IEA. 2018. Agricultural Economics Institute. Available from: http://www.iea.sp.gov.br/out/bancodedados.html. [Last accessed on 2018 Oct 03].

Jasper, S. P., Biaggioni, M. A. M and J. P. Ribeiro. 2006. Viabilidade econômica de aquisição de um silo-secador para pequenas áreas de produção. Eng. Agr. 26: 795-803.

Jittanit, W., Srzednicki, G. and Driscoll, R. 2010. Corn, rice, and wheat seed drying by two-stage concept. Dry. Technol. 28(6), 807-815.

Jones, C., Casada, M. and Loewer, O. 2012. Drying, handling, and storage of raw commodities. In: D. W. Hagstrum, T. W. Phillips and G. Cuperus (Eds.), Stored Product Protection. Kansas State University, Kansas, pp. 179-190.

Lawrence, J., G. G. Atungulu and T. J. Siebenmorgen. 2015. Modeling in-bin rice drying using natural air and controlled air drying strategies. Am. Soc. Agric. Biol. Eng. 58: 1103-1111.

Lim, J. S., Z. A. Manan, S. R. W. Alwi and H. Hashim. 2012. A review on utilization of biomass from rice industry as a source of renewable energy. Renew. Sust. Energ. Rev. 16: 3084-3094.

Lima, R. F., R. G. Dionello, M. C. R. Peralba, S. Barrionuevo, L. L. Radunz and F. W. R. Júnior. 2017. PAHs in corn grains submitted to drying with firewood. Food Chem. 215: 165-170.

Lopes, D. C. 2002. Sistema Computacional de Análises Técnica e Econômica Para Adequação de Força Motriz. (M.Sc Thesis), Federal University of Viçosa, Brazil.

Lopes, D. C. and A. J. S. Neto. 2017. Preliminary economic study of biodiesel production from Pequi in Brazil. Open Access J. Sci. 1: 27.

Lopes, D. C., A. J. Steidle Neto, A. A. Mendes and D. T. V. Pereira. 2013. Economic feasibility of biodiesel production from Macauba in Brazil. Energy Econ. 40: 819-824.

Lopes, D. C., A. J. S. Neto and J. K. Santiago. 2014. Comparison of equilibrium and logarithmic models for grain drying. Biosyst. Eng. 118: 1-10.

Lopes, R. P., J. C. Sobrinho, J. S. Silva and J. N. Silva. 2001. Fontes de Energia Para Secagem de Café. Boletim Técnico 3. Engenharia na Agricultura, Viçosa.

Marquezan, L. H. F. 2006. Análise de Investimentos. Vol. 3. Vir Electro Engineering Pvt. Ltd., Maharashtra, India, pp. 1-10.

Melo, E. C., D. C. Lopes and P. C. Corrêa. 2004. Grapsi programa computacional para o cálculo das propriedades psicrométricas do ar. Eng. Agric. 12: 154-162.

Mugabi, R. and R. Driscoll. 2016. Study of maize drying in Uganda using an in-store dryer weather data simulation software. Int. J. Food Process. Technol. 3: 18-26.

Nourbakhsh, S. M., Y. Bai, G. D. N. Maia, Y. Ouyang and L. Rodriguez. 2016. Grain supply chain network design and logistics planning for reducing post-harvest loss. Biosyst. Eng. 151: 105-115.

Ondier, G. O., T. J. Siebenmorgen and A. Mauromoustakos. 2010. Low-temperature, low-relative humidity drying of rough rice. J. Food Eng. 100: 545-550.

Pirasteh, G., R. Saidur, S. M. A. Rahman and N. A. Rahim. 2014. A review on development of solar drying applications. Renew. Sust. Energ. Rev. 31: 133-148.

Polidryer. 2018. Design of Drying Systems. Available from: http://www.polidryer.com.br. [Last accessed on 2018 Apr 03].

Sharon, M., E. P. Priya and S. Subhashini. 2016. Thin layer and deep bed drying basic theories and modelling: A review. Int. J. Agric. Eng. 18: 314-325.

Silva, J. S. 2009. Secagem e Armazenagem de Produtos Agrícolas. Aprenda Fácil, Viçosa.

Singh, C. B., D. S. Jayas and R. Larson. 2014. Assessment of fan control strategies for in-bin natural air-drying of wheat in Western Canada. Can. Biosyst. Eng. 56: 3.25-3.36.

Tirawanichakul, Y., S. Prachayawarakorn, W. Varanyanond and S. Soponronnarit. 2004. Simulation and grain quality for in-store drying of paddy. J. Food Eng. 64: 405-415.

Valente, D. S. M., D. M. Queiroz, P. C. Correa, L. C. Silva and S. M. L. Vale. 2011. A decision support system for cost determination in grain storage facility operations. Eng. Agric. 31: 735-744.

Wang, X. and R. Mendelsohn. 2003. An economic analysis of using crop residues for energy in China. Environ. Dev. Econ. 8: 467-480.

Young, Z., G. Olatunde and G. Atungulu. 2016. Natural air Drying and Storage of Soybean Seed and Implications on Germination Rates, Vigor, and Oil Quality. In: 2016 ASABE Annual International Meeting. ASABE Press, St. Joseph, Michigan, p. 1.