# Performance Evaluation of a Hot-Air Groundnut Cabinet Dryer

**A. Adegbola[1], L. A. S. Agbetoye[2*], Lawson, O.S.[3], S. A. Olaleye[4]**

**[1]Graduate Student, Agricultural and Environmental Engineering Department, Federal University of Technology, Akure, Nigeria.**

**[2]Professor, Agricultural and Environmental Engineering Department, Federal University of Technology, Akure, Nigeria.**

**[3]Chief Lecturer, Department of Agricultural and Bio-resources Engineering, Rufus Giwa Polytechnic, Owo Ondo State Nigeria.**

**[4]Lecturer, Agricultural and Bio-Environmental Engineering Technology Department, Federal College of Agriculture, Akure, Nigeria.**

***Corresponding Author**

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## ABSTRACT

Groundnut, also known as peanut, is an important source of food and oil, with the seeds being high in protein, fibre, and healthy unsaturated fats which are consumed in large quantities in most parts of the sub-Saharan Africa and the world at large. The post-harvest processing of peanut, most-especially drying that involves dehydrating the crop to safe moisture content for home and commercial purposes still need more attention as local drying prevailed in the country. An existing hot-air cabinet dryer was improved and evaluated for the drying of peanuts under the humid rainforest climate of Akure, Nigeria. The dryer was tested using three varieties of groundnut (red, white and kampala varieties), three drying air temperatures of $40^0$C, $50^0$C and $60^0$C, two drying air velocities of 1.67 m/s and 2.78 m/s and two product loadings of 3 kg and 4.5 kg per batch. The thermal efficiency, drying rate, drying time and moisture loss were determined as the evaluation parameters of the dryer. The evaluation conducted revealed thermal efficiency range of 46% – 96% with average thermal efficiency of 71.31%. The drying rate of the dryer ranges from 0.36 kg/h – 0.21 kg/h, with an average drying rate of 0.28 kg/h at maximum and minimum drying time of 10 h and 6 h respectively. The moisture loss by the groundnut in the dryer ranges from higher value to lower value of 1.05 kg to 0.55 kg for the red variety; 5.4 kg to 1.01 kg for the white variety; and 1.02 kg to 0.55 kg for the kampala variety respectively. Results further revealed that the drying air temperature has the greatest effect on the thermal efficiency, drying rate, drying time and moisture loss as compared with the drying air velocity. It was further discovered that the drying rates of the three varieties were relatively equal. However, the drying rates were in the order: white > kampala > red variety. It can be concluded that the hot-air dryer handled the drying of the three varieties of groundnut optimally with higher performances and in conformity to standard practices.

**Keywords:** Groundnut, drying, moisture loss, thermal efficiency, drying rate.

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# INTRODUCTION

Groundnut, also known as peanut, is a significant and widely cultivated crop globally. Groundnuts are important sources of food and oil, with the seeds being high in protein, fiber, and healthy unsaturated fats. The crops are grown mostly in the tropical and subtropical regions of the world, with major producers including India, China, Nigeria, and the United States. Peanut is grown in about 120 countries in the world in a total area of 24.6 million ha, with a world production of 38.2 million tons (Mt). The world's average productivity in 2007 was about 1490 kg/ha. It is cultivated in as many as 90 countries. Groundnut is therefore an oilseed crop on a global scale (Prasad *et al*., 2011), with Nigeria ranked 3rd largest producer of the crop with annual production of 3.08 million tons (Atlas Big, 2022).

The postharvest handling and processing of groundnut are essential to safeguard it from microbial attack, causing development of aflatoxins in groundnut due to high moisture content after harvest, which has greater impact on the shelf life and economical value of the crop. Drying is one of the most essential postharvest activities needed to keep the nutritional and economical values of the crop (Jonathan *et al.*, 2018). This involve dehydration of the moisture level of the crop to safe level either by sun drying or mechanical means. The dehydration of crop (drying) is a function of the heat source and heat distribution pattern (Ajuebor *et al.,* 2017). A thin layer cabinet dryer has been reported as highly suitable for drying of groundnut for the purpose of its economical, qualitative and nutritive preservation, keeping the crop intact with prolonged shelf life (Munir and Asif, 2012).

Common crop drying heat sources includes sunlight, fossil fuel, electricity, hydrothermal and biomass (Ibrahim *et al.,* 2014). An hot-air cabinet dryer utilizes these sources to generate heat energy aided by pneumatic air drawn from the atmosphere (ambient air) to increase the temperature of air, providing hot-air that flows tangentially into stationary products (agricultural product to be dried) placed in the trays of the cabinet. This action leads into kinetic energizing of the moisture molecules present in the agricultural products, leading into thermal energy that drives away this moisture off the agricultural products, achieving dehydration of the crop, resulting into drying of the product for storage and further utilization. Nukulwar and Tungika (2020) conducted comprehensive review of research conducted on various solar dryers and their performances in different applications. The solar dryers reviewed in their research were evaluated by the use of moisture reduction, moisture removal rate, and different efficiencies as the parameters to evaluate the performance of the solar cabinet dryers. He identified that despite the advantages associated with these dryers, their commercial utilization has been highly limited due to high initial investment costs, long payback periods, and intermittent usage. He concluded by suggesting solar dryers as a source of cheap, safe, adaptive and economical means of food preservation, most especially in the rural areas.

Owolarafe *et al.* (2021) conducted a research on the performance evaluation of a small-scale dryer designed for agricultural products. The dryer consisted of a heating chamber, heat exchanger, drying trays, a 3-phase blower, three 1800 W heating elements, and a control box with temperature control, contactor, thermocouple, and circuit breaker. The Performance evaluation conducted on the dryer revealed the energy consumed to vary for different agricultural products, with plantain chips, Moringa leaves, okra, and locust beans consuming 346.55, 55.92, 110.63, and 49.64 kJ respectively. It was reported that energy consumption increased with higher moisture removal and drying time in the dryer. The drying rate depended on the initial moisture content of the product and the air velocity, ranging from 34.80 g/h to 6.00 g/h for different products. The drying efficiency ranged from 62.1% – 65.5% and decreased with increased moisture removal and drying temperature. The findings indicated that the small-scale dryer demonstrated satisfactory performance for the tested products, making it suitable for small-scale applications. A mix-mode solar dryer was developed by Bukola and Olalusi (2008) while Ezekuoye and Enebe (2006) developed and evaluated the performance a of modified integrated passive solar grain dryer. Comprehensive review of the application of solar drying technologies for agricultural products in Nigeria and elsewhere has also been reported (Ade *et al.*, 2018; Udomkun *et al.*, 2020)

Improving the efficiency of groundnut drying is essential for reducing post-harvest losses and improving the quality of the final product. The evaluation of the performance of a groundnut dryer using a thin layer drying method for three different groundnut varieties under batch loading can have significant implications for smallholder farmers and groundnut-processing industries, which ultimately would improve the livelihoods of those involved in the production and processing of this important crop. The objectives of the research were to test and carryout performance evaluation of a hot-air groundnut cabinet dryer in the humid rainforest climate of Akure, Nigeria

## MATERIALS AND METHODS

An existing hot-air cabinet dryer (Lawson *et al.*, 2023) was improved and evaluated under the humid rainforest climate of Akure, South-western Nigeria. The performance of the machine was tested and analysed with necessary adjustments in order to improve the overall performance of the hot-air groundnut cabinet dryer.

### Principle of Operation of Hot-Air Cabinet Dryer

The hot-air cabinet dryer shown on Figure 1, has the heat energy source, hot-air duct, plenum chamber, cabinet, trays and chimney as the components of the machine. Its principle of operation utilizes the process of drawing an ambient air from the environment with the aid of a centrifugal blower which has 3 kW heat elements embedded to it. This heat elements receive electrical energy and convert it to thermal energy, which in turn increases the temperature of the air inlet to very high level which are controlled to needed value by the aid of temperature control attached to the heat energy source. The pre-set heated air are conveyed tangentially through the hot-air ducts into the plenum chamber for the attainment of stable and uniform hot-air velocity needed in the drying chamber. The constant velocity heated air are further conveyed to the drying unit of the dryer. Groundnuts at an average of 19.1% moisture content of the three varieties, which includes red variety, white variety and kampala variety were loaded into the drying chamber by spreading each variety on the tray at an individual loading of 1kg per tray per variety per batch and 1.5 kg per tray per variety per batch giving a total of 3 and 4.5 kg loadings of the three varieties in the cabinet, respectively. The perpendicular movement of hot air at a constant speed drives out moisture (which undergoes a phase change from liquid to vapour) from the groundnut placed in the cabinet until safe moisture level of an average of 8% is achieved. The velocity of the heated air, as controlled by the pneumatic centrifugal blower was selected as 1.67 or 2.78 m/s for the purpose of effective drying and evaluation exercise. The removed moisture and excess hot-air from the drying chamber exited the dryer through its chimney.

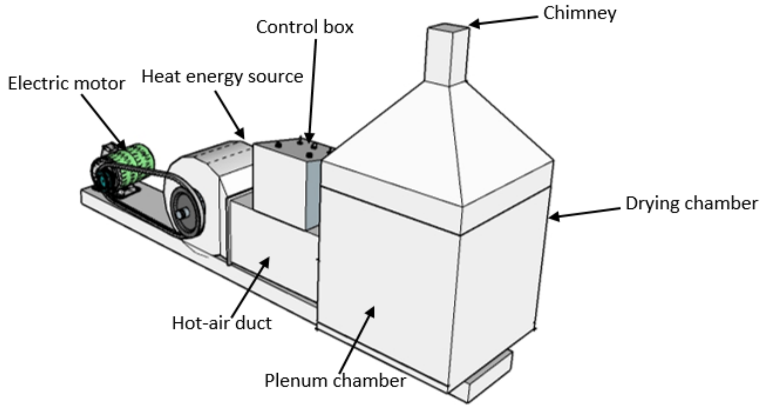


Figure 1: Schematic diagram of the hot-air cabinet dryer

**Testing of the Dryer**

The hot-air cabinet dryer was tested using three varieties of groundnut which are red, white and kampala varieties. The products were loaded in batches into the dryer with each variety loaded on each tray of the dryer subjected to drying variables of drying air temperature, drying air velocity and loading. The selected drying temperature were $40^0$C, $50^0$C, and $60^0$C, with drying air velocity of 1.67 m/s and 2.78 m/s and product loading of 1 and 1.5 kg per variety per tray loading per batch of drying. At the point of loading the dryer, the ambient air temperature, relative humidity, duct air temperature, duct air velocity were recorded. During drying, the chimney air temperature was recorded. After every one hour, the cabinet is opened and product offloaded for weighing. The weight of the product were recorded at interval and the drying continued till the product attain safe moisture content and the total time taken to complete the drying process was recorded. After drying, the final weight of the product were recorded. The wet bulb temperature of the duct and chimney were obtained using psychometric chart for the drying process. These variables were used to determine the drying rate, drying time, moisture loss and thermal efficiency of the dryer with appropriate formula as presented below.

According to Owolarafe *et al.* (2021), the mass of moisture released by the groundnut at interval of drying can be obtained using the expression:

$$M.L=M_i-M_f \qquad 1$$

Where, $M.L$ is moisture loss (kg), $M_i$ is initial mass of product and $M_f$ is final mass of product.

According to Ajuebor *et al.* (2017), the rate at which moisture leaves the groundnut being dried can be determined with the expression:

$$D.R=(M.L)/t \qquad 2$$

Where, $D.R$ is drying rate and $t$ is time taken for drying.

According to Owolarafe *et al.* (2021), the percentage of total moisture content loss in the product can be estimated using equation:

$$M.C=(M_i-M_f)/M_i \qquad 3$$

According to Munir and Asif (2012), the thermal efficiency of the hot-air cabinet dryer can be expressed by the ratio of the temperature drop of the heated air in passing through a bed of groundnut to the temperature rise of the entering air, expressed as:

$$D.T.E=b/d\times 100 \qquad 4$$

Where $b$ is temperature drop of drying air and $d$ is wet-bulb depression of the drying air.

$$b=D.A.T_{db}-C.A.T$$

$$b=D.A.T_{db}-D.A.T_{wb}$$

Where $D.A.T_{db}$ is duct air temperature (dry base), $D.A.T_{wb}$ is duct air temperature (wet base) $C.A.T$ and is chimney air temperature (dry base).

**Statistical Analysis**

The exit chimney and duct air temperatures, ambient temperature, chimney and duct air velocities, initial and final weight of groundnut, drying time, and relative humidity were obtained from the test of the machine and analyzed using graphical representations and statistical regression and correlation analysis using XLSTAT 2016 software.

# RESULTS AND DISCUSSION

**Effects of Drying Air Temperature and Air Velocity on Drying Rate of the Machine**

The graphical representation of the relationship between the drying air temperature and air velocity on the rate at which the dryer removes moisture from the product (drying rate) are presented in Figures 2 and 3. The drying rate of the machine increases as the drying temperature (duct air temperature) increases for both 3 and 4.5 kg loading at drying air velocity of 1.67 m/s and 2.78 m/s, respectively. The coefficient of determination ($r^2$) between the data and fit values were used to determine the quality of the fit. The degree of linearity between the two variables for 1.67 m/s, 3 kg loading and 2.78 m/s, 4.5 kg loading were 0.99 and 0.91, respectively, which described the degree of change of drying air temperature to be exactly the same as the degree of change in the drying rate of groundnut. This agreed with Ajuebor *et al.* (2017), who reported that an increase in the drying air temperature of a cabinet dryer causes increase in the drying rate of plantain, okra and chili pepper. However, slight changes were recorded in the two variables for 1.67 m/s, 4.5 kg loading and 2.78 m/s, 3 kg loading with coefficient of determination ($r^2$) as 0.66 and 0.68, respectively. This explained that an increase in the drying air temperature does not necessarily cause exact degree of increase in the drying rate of the groundnut.

The coefficient of determination between the drying air velocity and drying rate of the groundnut at the three selected temperatures are graphically illustrated in Figures 4 – 6. It can be deduced that the increase in the drying air velocity causes increase in the drying rate of the groundnut. The coefficient of determination ($r^2$) for the combination of the variable 40$^o$C, 3 kg to 4.5 kg; 50$^o$C, 3 kg to 4.5 kg and 60$^o$C, 3 kg approached unity ($r^2 = 1$), which implies that the level of increase in the drying velocity has exactly the same level of increase in the drying rate of the groundnut. However, the situation differs for 60$^o$C, 4.5 kg that produced no increase in the drying rate as the drying air velocity increases.

The statistical regression and correlation analysis presented in Tables 1 and 2 further described the extent and effects of the drying air temperature and velocity on the drying rate of the machine. It can be extracted from the statistical result that an increase in the drying air temperature and velocity had a positive increase on the drying rate of the groundnut with overall significant value (p-value = $8.43 \times 10^{-51}$). The individual p-value for the drying air temperature and air velocity gave 0.0027 and 0.068, respectively, which determined the extent of the effects of selected variables on the drying rate. The result of the correlation analysis shown in Table 2 confirmed that the drying air temperature has greater effects on the drying rate than the drying air velocity. As such, the factors that influence the drying rate of the dryer mostly is the drying air temperature while the drying air velocity had minimal effect on drying rate as confirmed by Yadollahinia *et al.* (2008).

**Effects of Drying Air Temperature and Air Velocity on Moisture Loss from Groundnut Varieties**

The extent at which the three varieties of groundnut losses moisture at different drying air temperature and drying air velocity under different loading is represented graphically as shown in Figures 7-12. The coefficient of determination ($r^2$) with the functions that described the graphical relationship between the drying air temperature and velocity on the moisture losses of the three varieties presented $0.8211 \leq r^2 1$ with negative slopes. This explained that the increase in the drying air temperature and velocity at different loading produced nearly perfect linear decrease in the moisture loss from the three varieties at almost the same level. However, it was observed that the relationship between the drying air temperature and moisture loss for 2.8 m/s at 4.5 kg loading is quadratic and not linear. This implies that at this dryer's configuration, increase in drying air temperature has a geometric decrease in the moisture loss for the red variety.

The extent and effect of these variables on the moisture loss were further described by the statistical regression and correlation analysis presented in Tables 3 – 8. The result of the correlation coefficient (r) gave 0.9623, 0.977 and 0.981 for the red, white, and kampala varieties, respectively. This established the fact that the moisture loss in the groundnut is a function of the drying air temperature and velocity with significant effect (p-value) of $7.14 \times 10^{-5}$, $1.04 \times 10^{-5}$ and $4.89 \times 10^{-5}$ for the red, white, and kampala varieties, respectively. The individual significant value for the drying air temperature and air velocity gave 0.0025, 0.056, respectively for the red variety; 0.00022, 0.082, respectively for the white variety; and 0.00015, 0.071, respectively for the kampala variety. This explained that the effects of the drying velocity on the moisture loss is not significant, but air temperatures significantly affect the moisture loss. Comparing the result of the analysis of the three varieties, it can be concluded that the drying air temperature has the highest effect on the rate of moisture loss in the white variety as compared with both the red and kampala varieties as evident in its correlation value of -0.481, followed by the kampala variety correlation value of -0.466, and lastly the red variety with correlation value of -0.417.

**Effects of Drying Air Temperature and Air Velocity on Dryer Thermal Efficiency**

The graphical representation of the relationship between the thermal efficiency of the dryer and the drying air temperature and velocity for the two selected loadings is presented in Figures 13 – 18. The coefficient of determination ($r^2$) with the linear function that described the graphical relationship between the drying air temperature and velocity on the thermal efficiency of the dryer at different loadings of the three varieties of groundnut presented $0.8812 \leq r^2 \leq 1$ with positive slopes. This explained that the increase in the drying airtemperature and velocity at different loadings produced a perfect linear increase in the thermal efficiency ofthe dryer at the same degree. The extent and effect of these variables on the thermal efficiency were furtherdescribed by the statistical regression and correlation analysis presented in Table 9 – 10. The result of thecorrelation coefficient (r) gave 0.8611, which described the thermal efficiency to be a function of the dryingair temperature and velocity with an overall significant effect (p value=$1.63 \times 10^{-27}$). The individual significant value for the drying air temperature and air velocity gave p-values of $1.62 \text{ X } 10^{-18}$ and $2.31 \text{ X } 10^{-7}$, respectively. This confirmed the assertion that the thermal efficiency of the dryer is positively affected by the drying air temperature and velocity, according to Oseni *et al.* 2021.

Considering the effects of the drying air temperature and the drying air velocity under the selected product loading on the thermal efficiency of the dryer, it can be deducted that the highest thermal efficiency of 96% was recorded at drying air temperature of $52^0$C and drying air velocity of 2.78 m/s for the 4.5 kg loading (Figure 14) and the lowest thermal efficiency of 46% was recorded at drying air velocity of 1.67m/s and drying air temperature of $40^0$C for the 3 kg loading (Figure 15). This implies that to operate the dryer at its peak thermal efficiency, the dryer should be operated at drying air temperature of $52^0$C, drying air velocity of 2.78 m/s and product loading of 4.5 kg.

**Effects of Drying Air Temperature and Air Velocity on the Drying Time**

The graphical representation of the relationship between the drying time of the dryer and the drying air temperature and velocity for the selected product loadings were presented in Figures 19 – 21. The coefficient of determination ($r^2$) between the drying air temperature and drying air velocity as they affect the thermal efficiency of the dryer, considering the three varieties of the groundnut, were obtained as $0.9643 \leq r^2 \leq 1$ with negative slopes. This explained that the increase in the drying air temperature and drying air velocity at different product loadings produced a direct linear decrease in the drying time of the groundnut varieties. This also agreed with the claim of Ajuebor *et al.* (2017), who reported that an increase in the drying air temperature of a cabinet dryer causes decrease in the drying time of plantain, okra and chili Pepper.

The extent and effect of these variables on the drying time were further described by the statistical regression and correlation analysis presented in Tables 11 and 12. The correlation coefficient (r) gave 0.9749, which described the drying time to be a function of the drying air temperature and velocity with an overall significant effect (p-value = $1.45 \times 10^{-5}$). The individual significant value for the drying air temperature and air velocity gave p-values of $2.5 \times 10^{-6}$ and 0.0082, respectively. This logically confirmed that the time taken to dry the groundnut products will decreases with an increase in the drying air temperature and drying air velocity. The correlation result established that the drying time is mostly affected by the drying air temperature (r = -0.98562) when compared with the drying air velocity (r = -0.27472), which had minimal effect on the drying time. It can be concluded that the time taken to dry the three varieties of groundnut used for this research is highest (10 h) at the drying configuration of $40^0$C, 1.67 m/s and 3 to 4.5 kg for drying air temperature, drying air velocity and product loading, respectively and lowest (6 h) at the drying configuration of $60^0$C, 2.78 m/s and 4.5 kg for drying air temperature, drying air velocity and product loading respectively.

## CONCLUSIONS

A hot-air cabinet dryer was modified and evaluated in the Department of Agricultural and Environmental Engineering, Federal University of Technology Akure. The dryer was evaluated using a combination of variables, which include: three drying air temperatures values of $40^0$C, $50^0$C, and $60^0$C, two drying air velocities of 1.67 and 2.78 m/s, three varieties of groundnuts and two product loadings of 3 and 4.5 kg per batch. The variables were used to determine the thermal efficiency, drying rate, drying time and moisture loss of the dryer. The evaluation conducted revealed the thermal efficiency of the machine with a range of 46% at drying temperature of $40^0$C, air velocity of 1.67 m/s and 3 kg loading to 96% at drying temperature of $52^0$C, air velocity of 2.78 m/s and 4.5 kg loading respectively with average efficiency of 71.31%. The drying rate of groundnut ranges from 0.36 to 0.21 kg/h with an average of 0.28 kg/h at maximum and minimum drying time of 10 h and 6 h respectively. The moisture loss by the groundnut in the dryer ranges from higher value to lower value of 1.05 to 0.55 kg for red variety; 5.4 to 1.01 kg for white variety; and 1.02 to 0.55 kg for kampala variety respectively. Results also revealed that the drying air temperature has the greatest effect on the thermal efficiency, drying rate, drying time and moisture loss as compared with the drying air velocity. It was further discovered that the drying rates of the three varieties were relatively equal. However, slight differences occurred with white variety having the highest drying rate, followed by the kampala variety and lastly the red variety. Data obtained from this study are useful for the development of mechanized groundnuts processing machines and methods for value addition in terms of drying to optimum moisture content required for roasting, dehulling, storage and other post-harvest processing operations. Further studies are suggested to investigate the effect of drying factors and conditions on the organoleptic and nutritional composition of the products.

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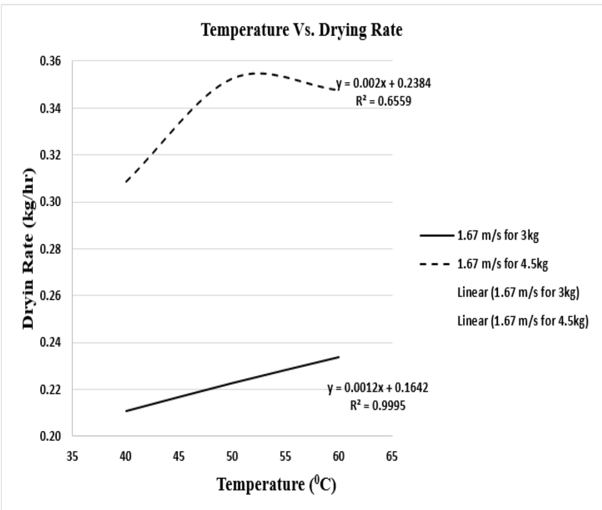


FIGURE 2: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND DRYING RATE OF THE MACHINE AT 1.67 M/S, 3 KG AND 4.5 KG LOADING

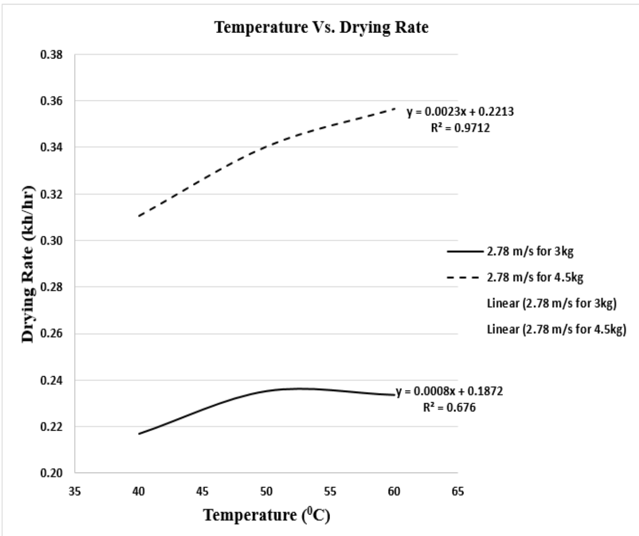


FIGURE 3: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND DRYING RATE OF THE MACHINE AT 2.78 M/S, 3 KG AND 4.5 KG LOADING

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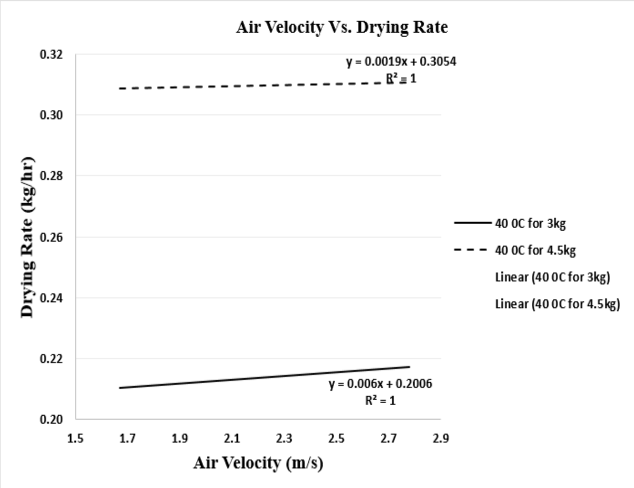


FIGURE 4: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR VELOCITY AND DRYING RATE OF THE MACHINE 40 $^{O}$C FOR 3 KG AND 4.5 KG LOADING.

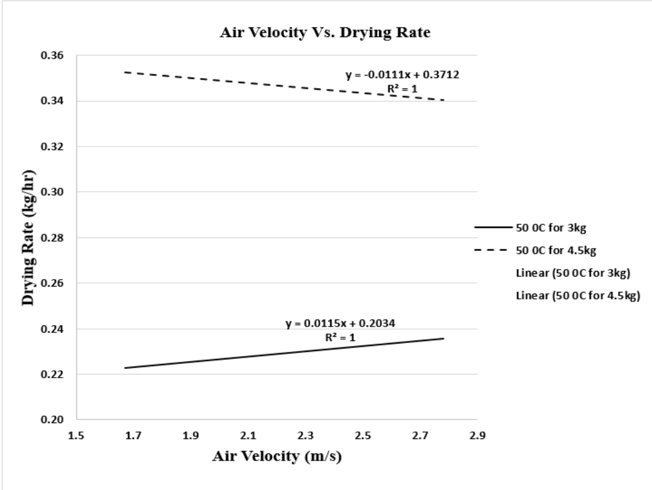


FIGURE 5: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR VELOCITY AND DRYING RATE OF THE MACHINE 50 $^{O}$C FOR 3 KG AND 4.5 KG LOADING.

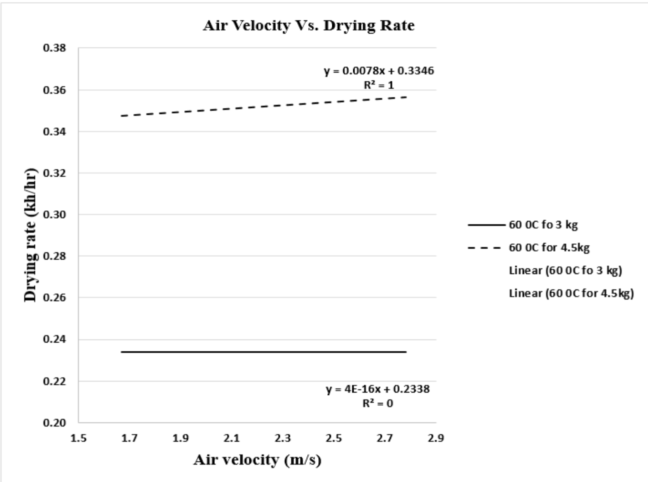


FIGURE 6: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR VELOCITY AND DRYING RATE OF THE MACHINE 60 $^{O}$C FOR 3 KG AND 4.5 KG LOADING.

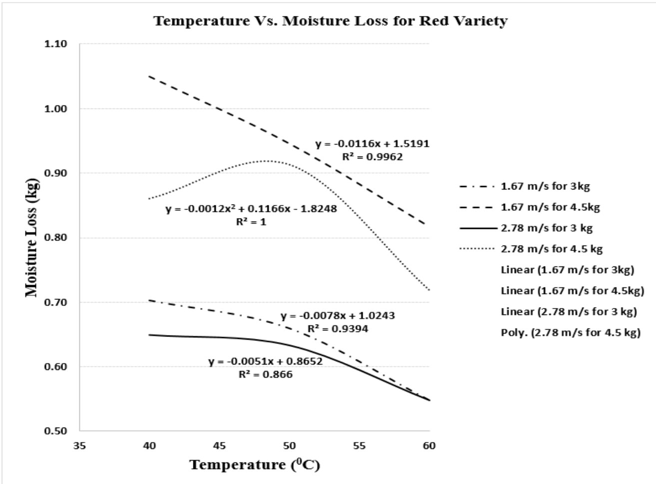


FIGURE 7: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND MOISTURE LOSS IN THE DRYER FOR RED VARIETY.

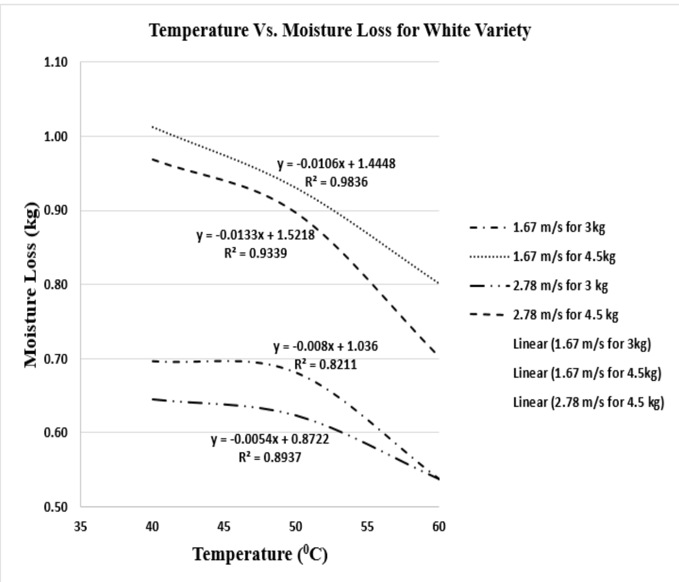


FIGURE 8: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND MOISTURE LOSS IN THE DRYER FOR WHITE VARIETY.

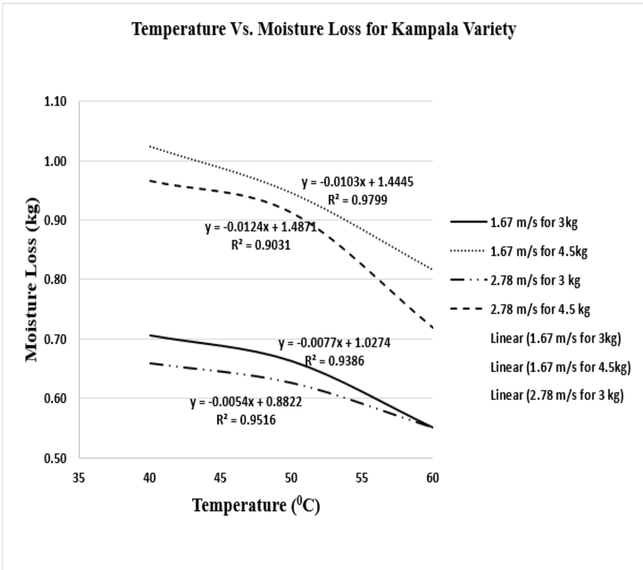


FIGURE 9: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND MOISTURE LOSS IN THE DRYER FOR KAMPALA VARIETY.

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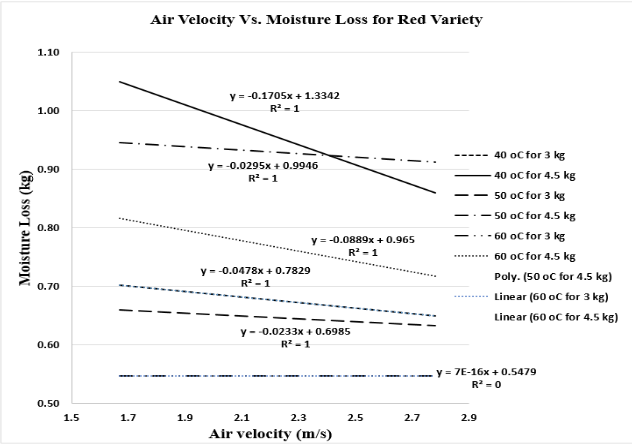


FIGURE 10: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR VELOCITY AND MOISTURE LOSS IN THE DRYER FOR RED VARIETY.

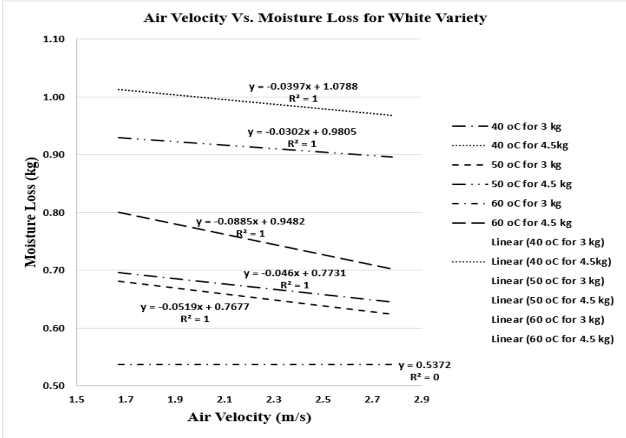


FIGURE 11: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR VELOCITY AND MOISTURE LOSS IN THE DRYER FOR WHITE VARIETY.

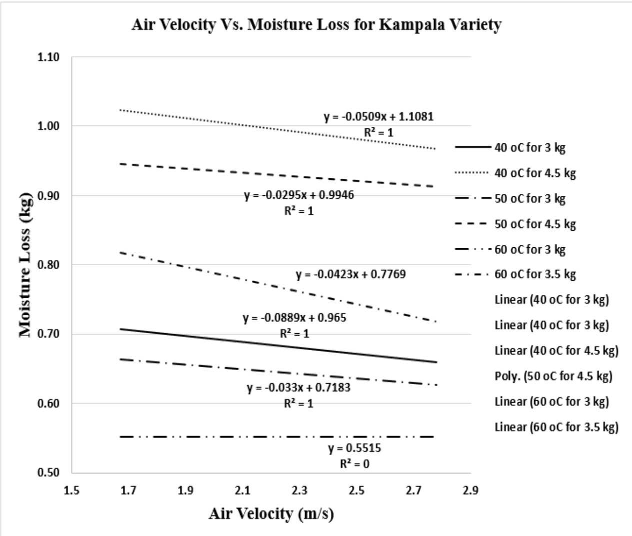


**Figure 12: Graphical relationship between drying air velocity and moisture loss in the dryer for kampala variety.**

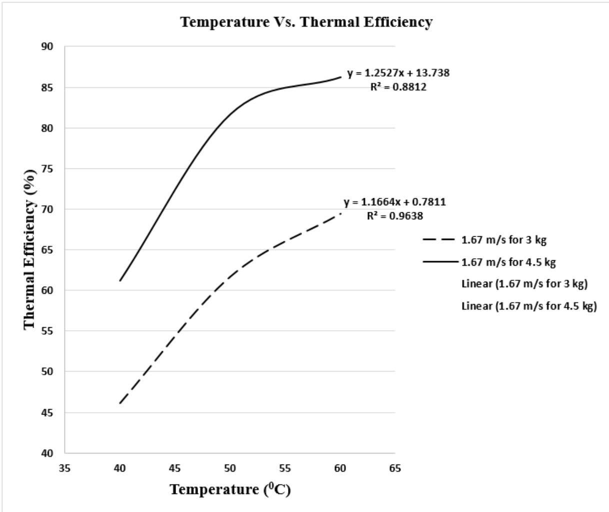


FIGURE 13: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND THERMAL EFFICIENCY OF THE DRYER AT 1.67 M/S WITH 3 KG AND 4.5 KG LOADING.

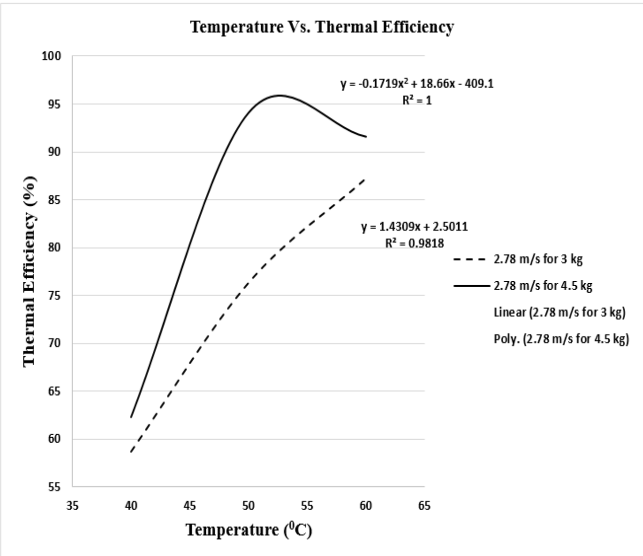


FIGURE 14: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND THERMAL EFFICIENCY OF THE DRYER AT 2.78 M/S WITH 3 KG AND 4.5 KG LOADING.

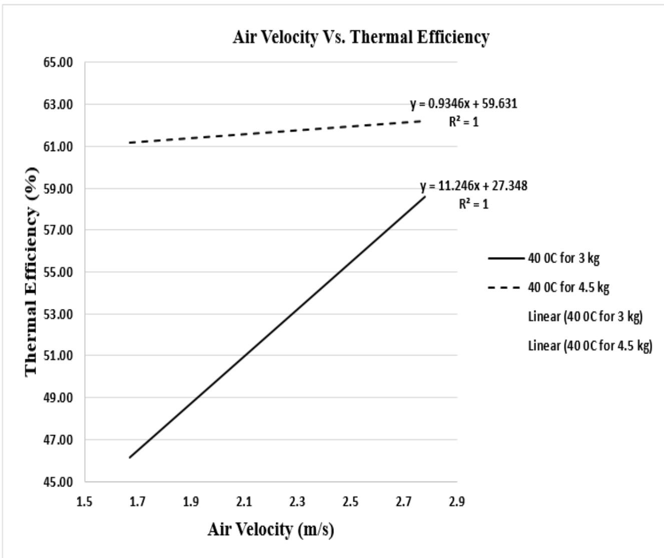


FIGURE 15: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND THERMAL EFFICIENCY OF THE DRYER AT 40 $^0$C M/S WITH 3 KG AND 4.5 KG LOADING.

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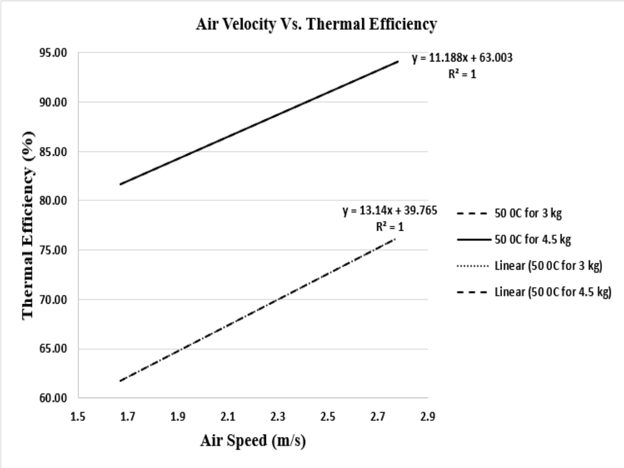


FIGURE 16: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND THERMAL EFFICIENCY OF THE DRYER AT 50 $^0$C M/S WITH 3 KG AND 4.5 KG LOADING.

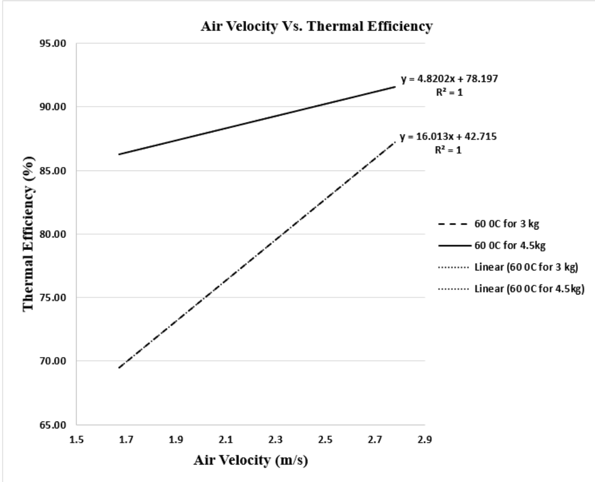


FIGURE 17: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND THERMAL EFFICIENCY OF THE DRYER AT 60 $^0$C M/S WITH 3 KG AND 4.5 KG LOADING.

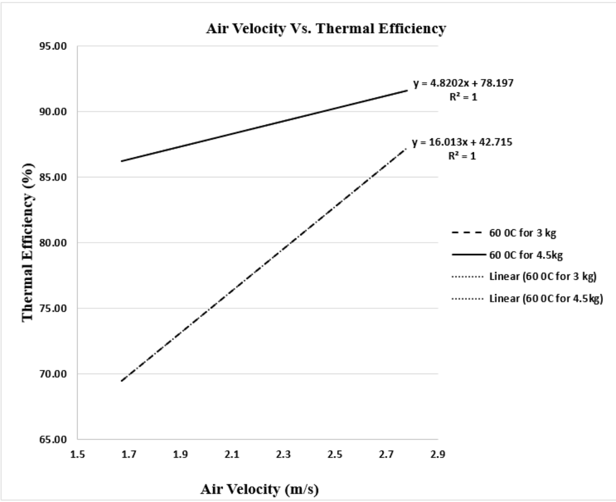


FIGURE 18: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND THERMAL EFFICIENCY OF THE DRYER AT 60 $^0$C M/S WITH 3 KG AND 4.5 KG LOADING.

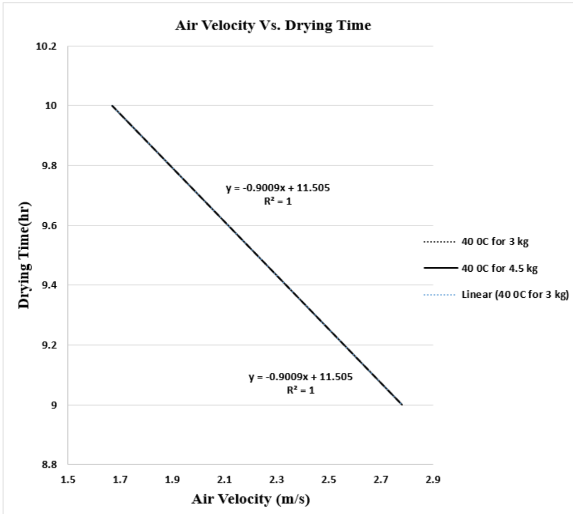


FIGURE 19: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND DRYING TIME OF THE DRYER AT 40 $^0$C M/S WITH 3 KG AND 4.5 KG LOADING.

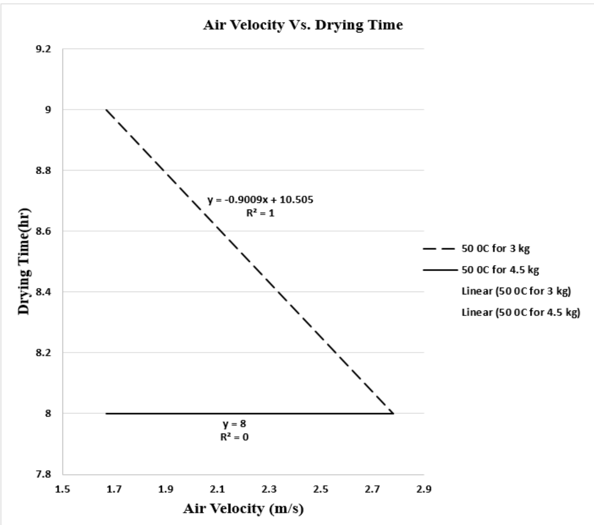


FIGURE 20: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND DRYING TIME OF THE DRYER AT 50 $^0$C M/S WITH 3 KG AND 4.5 KG LOADING.

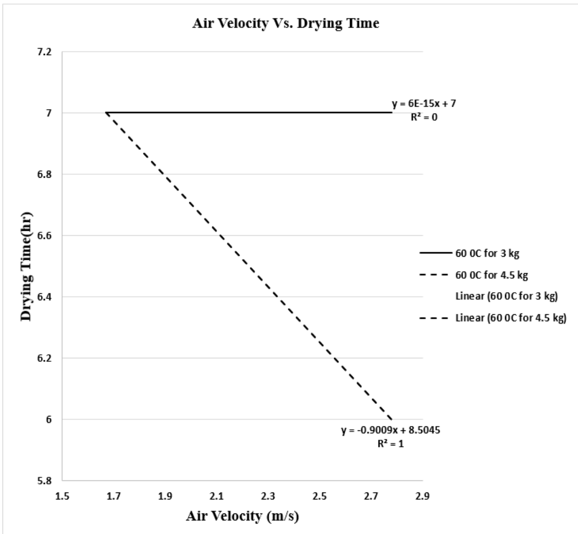


FIGURE 21: GRAPHICAL RELATIONSHIP BETWEEN DRYING AIR TEMPERATURE AND DRYING TIME OF THE DRYER AT 60 $^0$C M/S WITH 3 KG AND 4.5 KG LOADING.

Table 1**:** Regression analysis on the effect of the drying air temperature on the drying rate of the dryer

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.9579073 |
| R Square | 0.9175864 |
| Adjusted R Square | 0.9149562 |
| Standard Error | 0.0444667 |
| Observations | 98 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 2.06941 | 0.689803416 | 348.862952 | 8.42586E-51 |
| Residual | 94 | 0.185865 | 0.001977291 | | |
| Total | 97 | 2.255276 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* |
|---|---|---|---|---|---|---|---|
| Intercept | 0.0020764 | 0.033288 | 0.0623769 | 0.95039513 | -0.06401852 | 0.068171378 | -0.06401852 |
| D.A.T (oC) | -0.001741 | 0.000566 | -3.076034437 | 0.00274742 | -0.002864274 | -0.000617107 | -0.002864274 |
| A.V (m/s) | -0.014973 | 0.008111 | -1.846078108 | 0.06802801 | -0.031077248 | 0.001131009 | -0.031077248 |
| Mp(kg) | 0.163349 | 0.005067 | 32.2363008 | 1.311E-52 | 0.153287882 | 0.173410121 | 0.153287882 |

Table 2: Correlation analysis on the effect of the drying air temperature on the drying rate of the machine

| | D.R (kg/hr) | D.A.T ($^0$C) | A.V (m/s) | Mp (kg) |
|---|---|---|---|---|
| D.R (kg/hr) | 1 | | | |
| D.A.T ($^0$C) | 0.079990819 | 1 | | |
| A.V (m/s) | 0.010452707 | 0.006976289 | 1 | |
| Mp (kg) | 0.952026258 | 0.177875417 | 0.067770932 | 1 |

Table 3: Regression analysis on the effect of the drying air temperature on the moisture loss of the dryer for red variety

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.962309 |
| R Square | 0.926038 |
| Adjusted R Square | 0.898303 |
| Standard Error | 0.051541 |
| Observations | 12 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 0.266082 | 0.088694 | 33.38811 | 7.14285E-05 |
| Residual | 8 | 0.021252 | 0.002656 | | |
| Total | 11 | 0.287333 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.632021 | 0.132721 | 4.762013 | 0.001423 | 0.325964844 | 0.938077 | 0.325965 | 0.938077 |
| D.A.T (oC) | -0.0079 | 0.001822 | -4.33462 | 0.002496 | -0.012100824 | -0.0037 | -0.0121 | -0.0037 |
| A.V (m/s) | -0.06001 | 0.026808 | -2.23859 | 0.055548 | -0.121832175 | 0.001807 | -0.12183 | 0.001807 |
| Mp (kg) | 0.520074 | 0.059514 | 8.738655 | 2.3E-05 | 0.382833737 | 0.657313 | 0.382834 | 0.657313 |

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Table 4: Correlation analysis of the effect of the drying air temperature on the moisture loss for red variety

| | *ML1 (red)* | *D.A.T (oC)* | *A.V (m/s)* | *Mp (kg)* |
|---|---|---|---|---|
| ML1 (red) | 1 | | | |
| D.A.T (oC) | -0.41678 | 1 | | |
| A.V (m/s) | -0.21524 | 0 | 1 | |
| Mp (kg) | 0.840239 | 0 | 0 | 1 |

Table 5: Regression analysis on the effect of the drying air temperature on the moisture loss of the dryer for white variety

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.976965559 |
| R Square | 0.954461703 |
| Adjusted R Square | 0.937384841 |
| Standard Error | 0.0413613 |
| Observations | 12 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 0.286853 | 0.095618 | 55.8921 | 1.03883E-05 |
| Residual | 8 | 0.013686 | 0.001711 | | |
| Total | 11 | 0.300539 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.651350134 | 0.106508 | 6.115478 | 0.000285 | 0.405741182 | 0.896959 | 0.405741 | 0.896959 |
| D.A.T (oC) | -0.009322795 | 0.001462 | -6.37525 | 0.000215 | -0.012694963 | -0.00595 | -0.01269 | -0.00595 |
| A.V (m/s) | -0.042696865 | 0.021513 | -1.98466 | 0.082452 | -0.092307028 | 0.006913 | -0.09231 | 0.006913 |
| Mp (kg) | 0.529884763 | 0.04776 | 11.09476 | 3.89E-06 | 0.419750201 | 0.640019 | 0.41975 | 0.640019 |

TABLE 6: CORRELATION ANALYSIS OF THE EFFECT OF THE DRYING AIR TEMPERATURE ON THE MOISTURE LOSS FOR WHITE VARIETY

| | *ML2 (white)* | *D.A.T (oC)* | *A.V (m/s)* | *Mp (kg)* |
|---|---|---|---|---|
| ML (white) | 1 | | | |
| D.A.T (oC) | -0.48099 | 1 | | |
| A.V (m/s) | -0.14974 | 0 | 1 | |
| Mp (kg) | 0.837069 | 0 | 0 | 1 |

Table 7: Regression analysis on the effect of the drying air temperature on the moisture loss of the dryer for kampala variety

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.980995658 |
| R Square | 0.96235248 |
| Adjusted R Square | 0.94823466 |
| Standard Error | 0.037675665 |
| Observations | 12 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 0.290275 | 0.096758 | 68.1658 | 4.86859E-06 |
| Residual | 8 | 0.011356 | 0.001419 | | |
| Total | 11 | 0.301631 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.624400507 | 0.097018 | 6.435946 | 0.000201 | 0.400677351 | 0.848124 | 0.400677 | 0.848124 |
| D.A.T (oC) | -0.008971989 | 0.001332 | -6.73555 | 0.000147 | -0.01204367 | -0.0059 | -0.01204 | -0.0059 |
| A.V (m/s) | -0.040765863 | 0.019596 | -2.08027 | 0.071086 | -0.085955348 | 0.004424 | -0.08596 | 0.004424 |
| Mp (kg) | 0.541276281 | 0.043504 | 12.44196 | 1.63E-06 | 0.440955623 | 0.641597 | 0.440956 | 0.641597 |

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TABLE 8: CORRELATION ANALYSIS OF THE EFFECT OF THE DRYING AIR TEMPERATURE ON THE MOISTURE LOSS FOR KAMPALA VARIETY

| | *ML3 (kampala)* | *D.A.T (oC)* | *A.V (m/s)* | *Mp (kg)* |
|---|---|---|---|---|
| ML3 (kampala) | 1 | | | |
| D.A.T (oC) | -0.46573 | 1 | | |
| A.V (m/s) | -0.12377 | -0.12566 | 1 | |
| Mp (kg) | 0.924722 | -0.12566 | -0.1 | 1 |

Table 9: Regression analysis on the effect of the drying air temperature on the thermal efficiency of the dryer

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.861118124 |
| R Square | 0.741524423 |
| Adjusted R Square | 0.733275202 |
| Standard Error | 8.561152075 |
| Observations | 98 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 19765.06 | 6588.355 | 89.89024 | 1.63E-27 |
| Residual | 94 | 6889.573 | 73.29332 | | |
| Total | 97 | 26654.64 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* |
|---|---|---|---|---|---|---|---|
| Intercept | -25.98942323 | 6.408999 | -4.05515 | 0.000103 | -38.7146 | -13.2642 | -38.7146 |
| D.A.T (oC) | 1.195293083 | 0.10895 | 10.97102 | 1.62E-18 | 0.97897 | 1.411616 | 0.97897 |
| A.V (m/s) | 8.714170067 | 1.561562 | 5.580419 | 2.31E-07 | 5.613652 | 11.81469 | 5.613652 |
| Mp(kg) | 8.177201628 | 0.975592 | 8.381784 | 5.02E-13 | 6.240141 | 10.11426 | 6.240141 |

TABLE 10: CORRELATION ANALYSIS ON THE EFFECT OF THE DRYING AIR TEMPERATURE ON THERMAL EFFICIENCY OF THE MACHINE

| | *D.T.E (%)* | *D.A.T (oC)* | *A.V (m/s)* | *Mp(kg)* |
|---|---|---|---|---|
| D.T.E (%) | 1 | | | |
| D.A.T (oC) | 0.666305 | 1 | | |
| A.V (m/s) | 0.327722 | 0.006976 | 1 | |
| Mp(kg) | 0.571539 | 0.177875 | 0.067771 | 1 |

Table 11: Regression analysis on the effect of the drying air temperature on the drying time of the dryer

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.974921 |
| R Square | 0.950472 |
| Adjusted R Square | 0.931899 |
| Standard Error | 0.330719 |
| Observations | 12 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 16.79167 | 5.597222 | 51.1746 | 1.45121E-05 |
| Residual | 8 | 0.875 | 0.109375 | | |
| Total | 11 | 17.66667 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* |
|---|---|---|---|---|---|---|---|
| Intercept | 17.21134 | 0.851626 | 20.20997 | 3.75E-08 | 15.24748302 | 19.17519 | 15.24748 |
| D.A.T (oC) | -0.1375 | 0.011693 | -11.7595 | 2.5E-06 | -0.164463367 | -0.11054 | -0.16446 |
| A.V (m/s) | -0.6006 | 0.172019 | -3.49149 | 0.008181 | -0.99727622 | -0.20392 | -0.99728 |
| Mp (kg) | -0.66667 | 0.381881 | -1.74574 | 0.119001 | -1.547286542 | 0.213953 | -1.54729 |

TABLE 4.12: CORRELATION ANALYSIS ON THE EFFECT OF THE DRYING AIR TEMPERATURE ON DRYING TIME OF THE MACHINE

| | *D.T (hr)* | *D.A.T (oC)* | *A.V (m/s)* | *Mp (kg)* |
|---|---|---|---|---|
| D.T (hr) | 1 | | | |
| D.A.T (oC) | -0.92527 | 1 | | |
| A.V (m/s) | -0.27472 | 0 | 1 | |
| Mp (kg) | -0.13736 | 0 | 0 | 1 |