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HEAT CONDITIONING AND OIL STABILIZATION OF FLAXSEEDS UNDER TWO DEFERENT HEATING METHODS

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Abstract

The present work aims tot Study the effect of using two different heating methods on stabilization of flaxseeds using a rotating cylindrical dryer with conduction & infrared heating systems. The study also tested and evaluated two different mathematical models to describe the drying behavior of flaxseed, with linking the constants in the Mathematical examined equations to the experimental variables. The most appropriate mathematical model to describe the behavior of flaxseed moisture loss was also determined. The samples used for experimental work were fresh flax seed at moisture content 11±1 % wb. Four different temperatures of the surface of the cylinder (90, 105, 120 and 135ºC at 3, 6. 9, 12, 15 and 18 minutes were examined for the conduction heating dryer. At Infrared treatments fixed feeding rate of 2 kg was used at radiation intensity of 53.01, 331.6, 477.5, 848.89 and 1,326.39 w/m^2 and exposure times of 3, 6. 9, 12 and 15 minutes. The results showed that, for conduction heating process using heat treatment at 105 ^{0}C for min gives the best result in terms of lower free fatty acids and peroxide value, But in Infra-red treatment the best result was obtained at 331.59 w/m^2 for 15 min.

Key words: *flax, heat treatment, Infrared, time, temperature, free fatty acid, peroxide value*

INTRODUCTION

Flax (Linum usitatissimum) is a plant, which belongs to the family of linaceae with seeds commonly known as flaxseed or linseed. Brown flax and golden flax (sometimes called yellow flax) are the two basic varieties of flax with similar nutritional composition. However, golden flaxseed has a nutty-buttery flavor and an eye-appealing golden color, which makes it an attractive and tasty addition to our diet.

Flax knew in Mesopotamia five thousand years ago and was cultivated in Egypt by more than three thousand years. It has been known since ancient medical abilities, but his fame has recently discovered a lot of medical benefits such as: source of omega three necessary for the safety of the heart, protection against breast cancer, reduction of the symptoms of menopause and facilitated digestion and relieved symptoms of constipation (Rajju et al., 2016) [10].

Soni *et al.* (2016) [11] reported that flaxseed cultivated in many parts of world for fiber, oil as well as for medicinal purposes and also as nutritional product. Flax was valued in Ancient and Early Modern times as both a food and medicine. In this review, nutrients, anti-nutrients, functional properties and health benefits of bioactive molecules viz, essential fatty acids, lignans and dietary fiber of flaxseed are discussed. Flaxseed contains good amount of Alpha-Linolenic Acid (ALA), omega-3 fatty acid, protein, dietary fiber, lignan specifically Secoisolariciresinol diglucoside (SDG).

Coskuner and Karababa (2007) [3] studied the length, width, thickness and geometric mean diameter of flaxseeds.

El-Kholy and Tharwat (2008) [4] carried out a study to test and evaluate the effect of accelerated drying of canola on seeds moisture content, fungal load on seeds surface and stabilization of the extracted oil using a conduction heating rotary dryer. The results showed that all the drying process occurred at the falling rate period in which the rate of evaporation tends to fall as the moisture content decreases and the drying curve decays exponentially towards the equilibrium moisture content. Rapid moisture removal from seeds was obvious in all experiments particularly at higher heating surface temperature and longer exposure time.

Matouk *et al.* (2012) [8] tested and evaluated the effect of accelerated drying of sunflower seeds on seeds moisture content, fungal load on seeds surface and stabilization of the extracted oil using a conduction heating rotary dryer. The drying temperatures were set at approximately 75, 85, 95, 105, 115, 125, 135 and 145ºC and the drying times were set at 3, 6, 9, 12 and 15 min. The results showed that all the drying process occurred at the falling rate period in which the rate of evaporation tends to fall as the moisture content decreases and the drying curve decays exponentially towards the final moisture content .Rapid moisture removal from seeds was obvious in all experiments particularly at higher heating surface temperature and longer exposure time. The results also showed that the simple equation was satisfactorily described the drying behavior of sunflower seeds and predicted the change in seeds moisture content as indicated by the higher coefficient of determination (R^2). Meanwhile, high temperature conduction heating reduced the fungal load in sunflower seeds in an effective manner. Also, the extracted sunflower oil was stabilized at certain combinations of heating surface temperature and exposure time as indicated from the lower values of free fatty acids of the these samples. It can be said that, the accelerated drying and heat stabilization of sunflower seeds using the conduction heating rotary dryer may be considered as an effective procedure for moisture reduction, fungal inactivation and oil stabilization. In general , heating surface temperature of 145ºC and the exposure time of 15 min are recommended to decrease the moisture content of sunflower seeds to the safe level of 5.8% (w.b), the fungal load to 102 colonies/g. and the percentages of free fatty acids to1.97% .

Grompone *et al.* (2013) [5] mentioned that the fatty acid composition as well as the antioxidant composition and content of two commercially available chia oils of different origins were studied. The purpose of this work was the study of the oxidative stability from different methods and the antioxidant content of the chia oils compared with other commercial oils. The oxidative stability of the oils was determined based on the oxidative stability index test (OSI test) conducted at 110 °C and isothermal as well as non-isothermal differential scanning calorimeter (non-isothermal DSC) for the chia oil and the linseed oil. The OSI induction time of chia oil was compared with that of commercially available linseed, canola, sunflower and high-oleic sunflower oils, chia oil being the least stable oil among those studied. The inherent stability value and oxidazibility for linseed oil was lower than the chia oil A may be ascribed to a lower linolenic acid content of the former. The induction time (It) quotient at 110°C calculated for chia oil A and linseed oil were similar, suggesting a high degree of consistency between the results obtained by the two methods. The activation energy and specific reaction rate constant of chia and linseed oils were compared based on the results of isothermal and non-isothermal DSC. An apparent inconsistency in the experimental data results from the temperature-dependence of the activation energy of each fatty acid which can explain because the methods conditions were different.

Turner *et al.* (2013) [12] reported that flaxseed pasteurization at 148°C for 16.25 minutes was found to be detrimental to the oxidative stability of flaxseed once milled. Significant ($P \leq 0.05$) elevation of peroxide values in the pasteurized samples was found after two weeks of storage at room temperature compared to the raw flaxseed treatments. The progression of oxidation was observed through the elevation of peroxide values and propanal content over the course of the storage study. The application of heat to pasteurize flaxseed likely resulted in damage to the seed, resulting in flaxseed instability and an increased predisposition to lipid oxidation. Milling pasteurized flaxseed under refrigerated conditions did not significantly ($P > 0.05$) increase the oxidative stability compared to pasteurized flaxseed milled under ambient temperatures over the 20 week storage period. Pasteurization of flaxseed at 148°C for 16.25 minutes using a dry heat with minimal packaging is not recommended, as it can significantly reduce the shelf life of milled flaxseed.

The main objective of this research to test two different heating methods on stabilization of flaxseeds using conduction and infrared heating systems. The study also evaluated two different mathematical models to describe the drying behavior of flaxseed.

MATERIALS AND METHODS

The present study aims at testing and evaluating two different methods of heating (conduction and infrared) in moisture reduction, heat stabilization, microbial load reduction and oil quality of the flaxseeds. An accelerated rotary dryer with two different sources of heat (conduction heating and Infrared heating) was developed to be suitable to heat the seeds of flax for moisture reduction, surface sterilization and oil stabilization. The experimental work was conducted at the Rice Mechanization Center, Agric. Eng. Res. Institute, Kefir El-Sheikh Governorate.

Sampling

Flaxseeds variety (Evona) was used for the experemintal work. Physical and mechanical charactarities of tested seeds are presents in Table (1).

Table (1) Physical and Mechanical Properties of flax seeds Var. (Evona)

Properties	Whole seed	Properties	Whole seed
Length (mm)*	5.50±0.23	Moisture (%)	5.08±0.45
Width (mm)*	2.68±0.18	Fat (%)	39.51±1.05
Thickness (mm)*	1.17±0.24	Protein (%N×6.25)	21.38±0.38
Geometric mean diameter (mm)	2.58±0.18	Ash (%)	2.83±0.20
Sphericity (%)**	42.31±0.49	Crude fiber (%)	3.57±0.48
True density (kg/m^{-3})	1025.33±2.89	Carbohydrate (%) **	28.04±0.36**
Bulk density (kg/m^{-3})	696.67±1.15	Trypsin inhibitors (TIU/g)	29.33±0.23
Angle of repose (°)	26.29±0.46	Flavonoid compounds(mg/100g)	39.99±1.41
Rupture force (N)	41.97±0.38	Total phenolics as gallic acid (mg/100g)	230.0±1.04
Deformation (mm)	0.37±0.13	Phytic acid (mg/100 g)	770.0±0.5
1,000 seed mass (g)	7.38±0.14		

Source: Ministry of Agriculture and Reclamation, Agricultural Research Center laboratory [9].

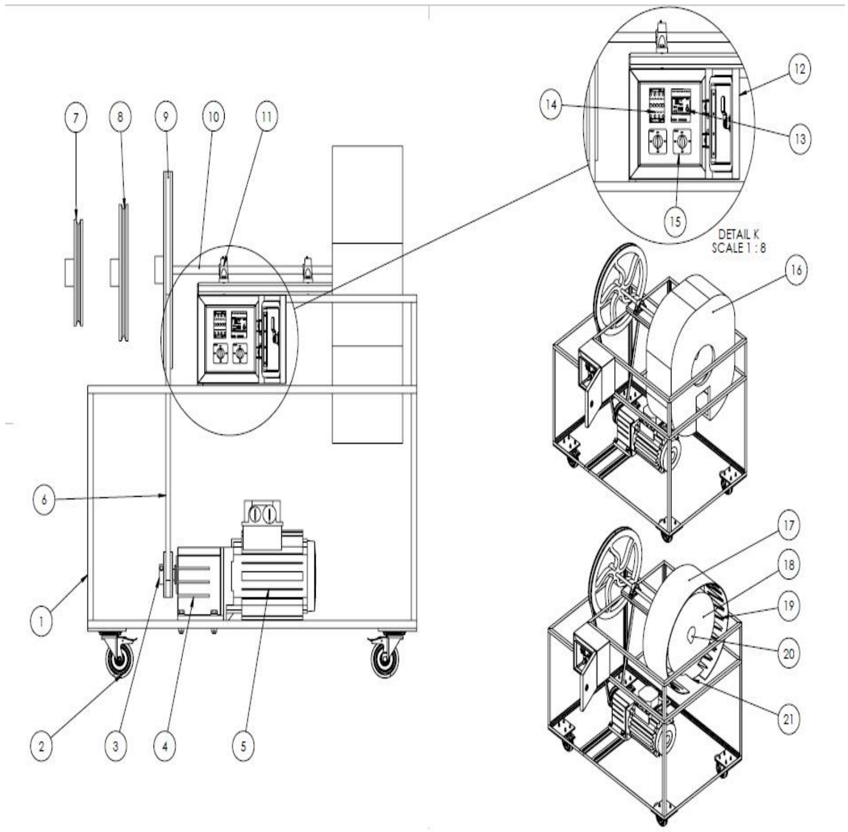
The harvesting and threshing operations of the tested flaxseeds were executed at initial moisture content of (11 ± 1 %) (w.b). Unfilled seeds and other impurities were discarded from the harvested seeds. The flax seeds were sealed in separate polyethylene bags. The bags were stored in a freezer adjusted at temperature of - 5 ± 1°C to prevent moisture loss and fungal growth throughout the storage period. Before each test, the required quantities of seeds were taken out from the freezer and allowed to reach the normal room temperature. The moisture content of the samples was measured just before each test.

The accelerated rotary dryers (Conduction and Infrared heating):

The heat treatment units for conduction and infrared processes are presented in Figures 1 and 2.

The two heating units were fabricated at the workshop of Rice Mechanization Center, Agric. Eng. Res. Institute, Kafr El-Sheikh Governorate. Each units consists of a rotary cylinder (0.6 m in diameter and a 0.2 m long) made of 1 mm galvanized iron steel sheet enclosed by a fixed insulated cylinder (0.8 m in diameter and 0.3 m long).

One side of the rotary cylinder connected to a driving mechanism consists of 0.15 m diameter steel flange fixed to the side cover of the rotary cylinder and welded to a steel bar riding into a heavy-duty ball bearing.



No.	Part Name
1	Chassis
2	Wheel
3	Motor Pulley
4	Gearbox
5	Motor
6	V-belt
7	35 cm Pulley
8	45 cm Pulley
9	60 cm Pulley
10	25 mm Shaft
11	Earing with housing
12	Control unit
13	Differential thermostat
14	Magnetic conductor
15	On/Of switch
16	Fiberglass insulation
17	Outer Cylinder
18	Inner Cylinder
19	Heater
20	Inlet gate
21	Outlet gate

Fig. 1. Schematic diagram of the accelerated drying unit
Source: Authors' drawing.
Note: The surface temperature of the conduction heating rotary cylinder could be raised up to 175°C and maintained within ± 1°C using a precise thermostat controlled by an electric contactor.

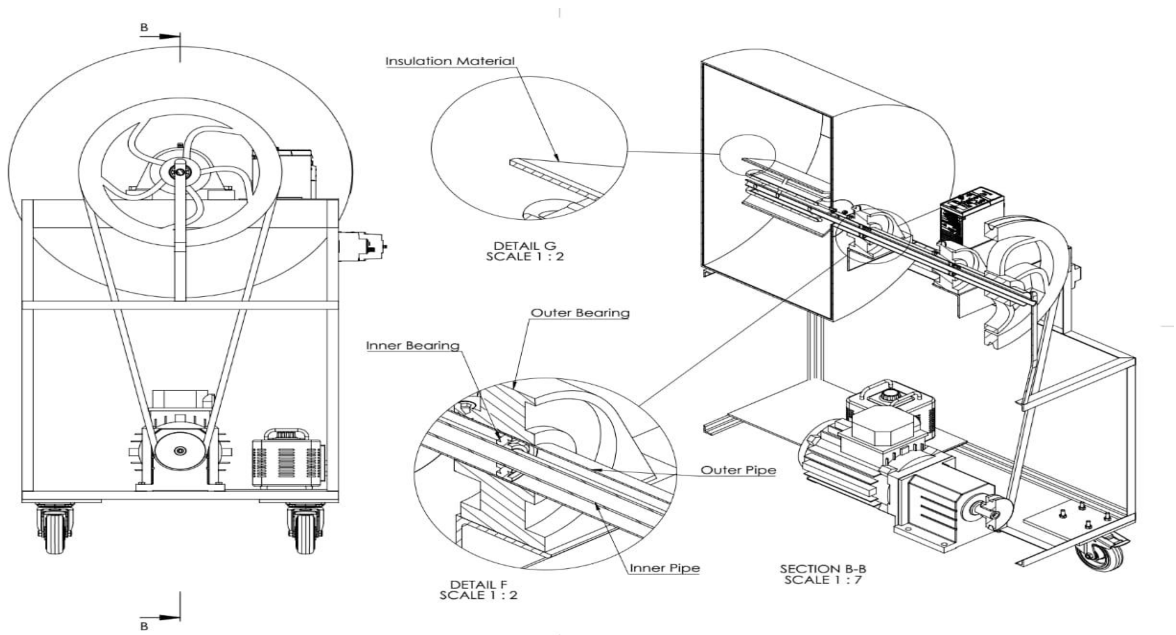


Fig. 2. Diagram of the infra red drying unit
Source: Authors' drawing.

A 0.5 kW low speed motor with different sizes of pulleys was used for power supply and speed control of the rotary cylinder.

The other side of the rotary cylinder serves as an inlet for flax seeds samples through a 0.1 m diameter center hole. The heat-treated flax seeds discharged through a perforated removable sector of the cylinder bottom. For heating and temperature control of the rotary cylinder units, the conduction heating unit was provided with 2 kW electric resistance heater placed at the inner surface of the fixed insulated cylinder (between the rotary cylinder and the insulated exterior cylinder) while the infrared heating unit was provided with 2 kW infrared heaters and dimmer for controlling the radiation intensity.

The seeds temperature of the conduction heating rotary dryer was depended upon the heating surface temperature of the rotated cylinder and the exposure time, while, the temperature of seeds treated by infrared heating surface was depended upon radiation intensity of the heat source and the exposure time.

Experimental Treatments

Flax seeds was tested under initial moisture content of (11±1 % w.b). The conduction heat treatments were proceeded at five levels of heating surface temperature (90, 105, 120, 135 and 150^{o}C) and six levels of exposure time (3, 6, 9, 12, 15 and 18 minutes) and feeding rate of 2 kg. While, the tests of infrared unit was conducted at five different intensity levels (53.01, 331.6, 477.5, 848.89 and 1,326.39 W/m^2) at exposure times of 3, 6. 9, 12 and 15 minutes with fixed feeding rate of 2 kg. Two different mathematical models were examined to describe the moisture loss behavior of flaxseed, with linking the constants of the examined models with the experimental variables. Beside that the most appropriate mathematical model to describe the behavior of flaxseed moisture loss was assessed and evaluated.

Test procedure and Measurements

Test procedure

For the conduction heating unit, prior to each experiment, a dummy sample was used. The temperature of the cylinder surface was adjusted at the required level. When the surface temperature of the rotary cylinder became stable, the dummy sample was discharged and replaced by the testing sample; similar procedure was also used for the infrared experimental work. After heating, the seeds were feed into the rotating cylinder and the dryer was operated to the required heating time for both heating methods. The heat treated samples were cooled to room temperature in wooden box covered with a perforated aluminium foil to allow gradual escape of steamer during the cooling process. After cooling process, the heat treated seeds were taken out from the cooling wooden box, and then divided into two sub samples, the first one was used to determine seeds final moisture content, while the second was used for oil extraction and determination of Free Fatty Acid (FFA %) and Peroxide value.

Experimental Measurements and Instrumentation

Surface temperature of the rotary cylinder

The remote–type infra red spot thermometer model (HT-11) was used to measure the rotary cylinder surface temperature of the conduction heating unit. The emissive of the thermometer was adjusted at 0.85 for iron sheet surfaces and the temperature was measured at different points. The heating surface temperature was considered as the average of the obtained readings.

Moisture content of flax seeds

The standard A.O.A.C (1991) [1] moisture measuring method was used for determining the seeds moisture content after each drying run. 100 grams of flax seeds were placed at 105^{o}C for 4 h, and then kept in a desiccators at room temperature. The dried samples were weighed again using an electronic digital balance and the moisture content of flaxseeds was calculated on wet and dry basis.

$$M_{wb} = \frac{w_o - w_d}{w_o} 100\%$$

While the moisture content on dry basis is the weight of moisture present in the product per unit weight of dry mater in the product and represented as

$$M_{db} = \frac{w_o - w_d}{w_d} 100\%$$

Mathematical models applied to the drying process

The simple drying equation Lewis's (1921) [7] and the modified simple drying equations Henderson and Pabis's (1961) [6] were examined for describing the drying behavior and predicting the change in flax seeds moisture content during the heat treating process. The examined drying equation written as follows:

$$MR = \frac{M - M_e}{M_o - M_e} = \exp(-k_s t)$$

$$MR = \frac{M - M_e}{M_o - M_e} = Ae^{-kt}$$

where:
MR: Moisture ratio, dimensionless
M: Instantaneous seeds moisture content at time t, (%, w.b)
Me: Equilibrium moisture content. (%, w.b)
Mo: Initial moisture content, % (w.b.).
t: Time, min
ks: Drying constant, min^{-1}
K, A: Drying constants.

There is no information available about the equilibrium moisture content of flax seeds in a temperature range of 90 to 135°C when the air relative humidity is very low.

However the flax seeds will be bone dried after prolonged heating under such condition. So the moisture ratio was approximated simply by dropping the equilibrium moisture content term and thus the ratio of instantaneous seeds moisture content to its initial moisture content was used for representing seeds moisture ratio.

The drying constant (ks) of the simple exponential model was obtained by applying linear regression analysis to the logarithmic value of (M/Mo) and the drying time (t). The slope of the best fit straight line represents the value of the drying constant (ks).

The simple exponential model (3-4) has been converted to the following from:

$$MIR = \frac{M}{M} = \exp(-k_s t)$$

While, The modified Simple Exponential model was Converted to the following form:

$$MR = \frac{M}{M_o} = A\exp(-k_h t)$$

The drying constant (k_h & A) of the modified simple drying model were obtained by applying linear regression analysis of the value Log (M/Mo) and the drying time (t). The slope of the best fit straight line represent the drying constant (k_h) and the intercept represents the Constant(A).

Quality evaluation tests of heat treated seeds

Oil extraction

Experiments were undertaken to extract flax seed oil and detremine the oil extractions percntage. The amount and the characteristics of the extracted oil in terms of FFA % and Peroxide value.

Acid value (A.V) of flaxseed oil

Acid value was determined according to the method descried by A.O.A.C (2005) [2]. A Known whight of the melted sample (ca 2.5 g) was dissolved in 25 ml of petroleum ether alcohol mixture (1:1, v/v). The contents of the flask were heated on a steam bath for 2 min. then titrated with alcoholic potassium hydroxide (0.1 n) in the presence of phenolphthalein as an indicator. The acid value was caculated according to the following equation:

$$AcidValue = \frac{V \times N \times 56.1}{W}$$

where:
V: Volume of alkali required to naturalize the free fatty acids.
N: Nomality of KOH.
W: Weight of sample.

Peroxide value (P.V) of flaxseed oil

Peroxide value was measured according to the method describe by A.O.A.C (2005) [2]. Five grams of melted lipid samples were dissolved by 50 ml of acetic acid chloroform mixture (2:1, v/v). One ml of saturated potassium iodide solution was added, then the mixture allowed to stand with occasional shaking for exactly 1 min and 30 ml of distilled water were added. The contents of flask were titrated with 0.1 N sodium thiosulphated solution until the yellow color had almost disappeared. Starch solution indicator (0.5 ml) was added and titration was continued until the blue color had just disappeared. The following equation was used to calculated the peroxide value of lipid samples under study.

Peroxide value= $\frac{S \times N \times 1000}{W}$

where:
S: Titration of sample, ml.
N: Normality of sodium thiosulphate.
W: Weight of lipid sample, g.

Free fatty acid (FFA%) of flaxseed oil

Oil samples were extracted from flaxseeds by cold mechanical extract machine. The FFA % of oil samples were calculated as oleic acid using the corresponding acid value of each sample according to the A.O.A.C. (2005) [2] as follows:

$$\text{FFA \%}= \frac{282 \times 100 \times Acidvalue}{56.1 \times 1000}$$

$$\text{FFA \%}= \frac{AV}{1.99}$$

where: A.V: Acid value.

RESULTS AND DISCUSSIONS

A typical plot showing the change in seeds moisture contents as related to drying temperature during the conduction and infrared heating of high moisture flaxseeds is illustrated in Figs. 3, 4 and 5, respectively. As shown in the Figures rapid moisture removal from flaxseeds was obvious particularly at higher levels of heating surface temperature and infra red intensity.

Change in seeds bulk temperature

A typical plot showing the change in grain bulk temperature as related to heating temperature for both conduction and infrared heating methods are illustrated in Fig. 5.

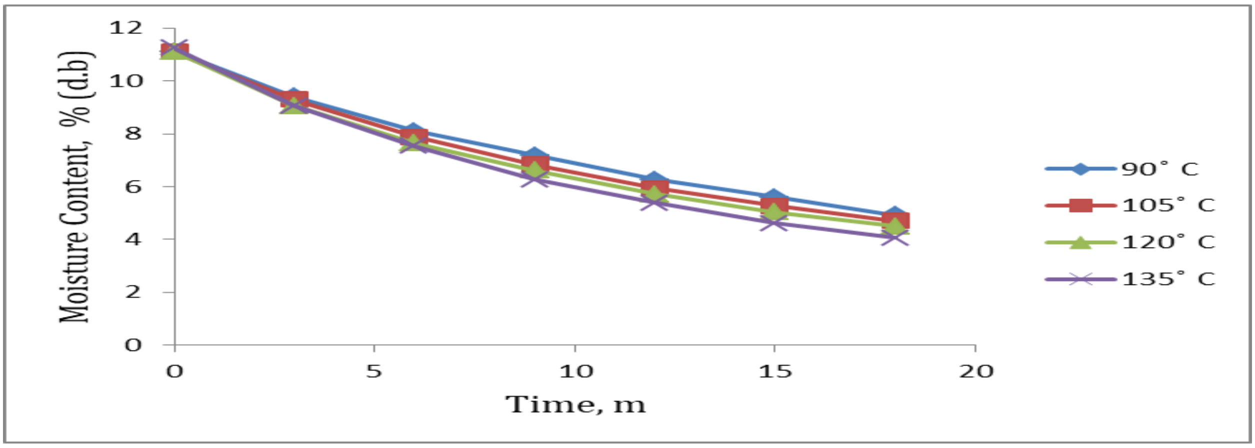


Fig. 3. Change in grain moisture content as related to heating time, at different surface temperature and rotation speed 15 r.p.m.
Source: Authors' determination.

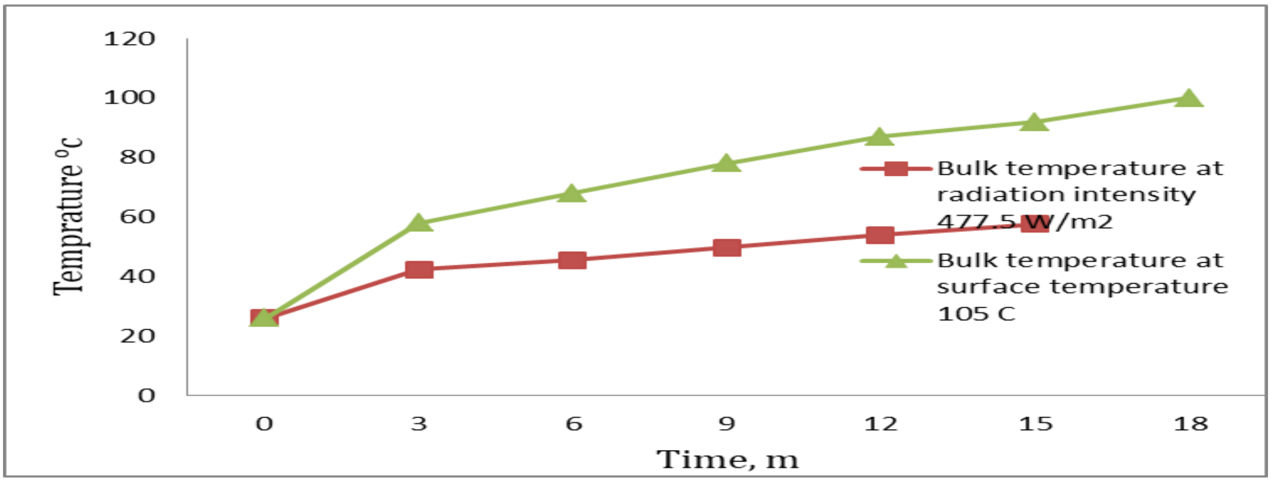


Fig. 4. Change in grain moisture content as related to heating time, at different radiation intenisity and rotation speed 15 r.p.m.
Source: Author determination.

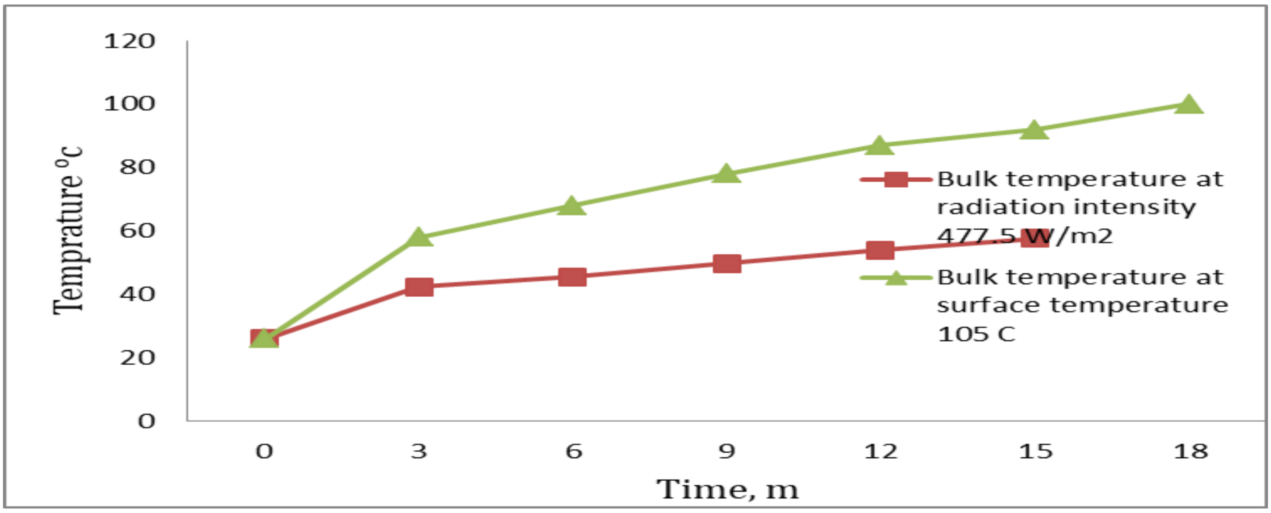


Fig. 5. A typical plot of the change in seeds bulk temperature as related to drying time at 105 °C heating source.
Source: Authors' determination.

As shown in Fig. 5, the grain bulk temperature was lower during the early stage of heating process and it was increased with longer exposure duration. In general, for all levels of heating surface temperature and radiation intensity, as the exposure time increased, the difference between the seeds bulk temperature and the heating sources decreased and the heat transfer rate also decreased.

Simulation of flax seeds Moisture reduction Behavior

In this section of study, analysis of moisture reduction of flax seeds was proceeded under different combination of cylinder surface temperature (90, 105, 120 and 135°C) and exposure time for the conduction heating process and different levels of radiation intensity and exposure time for the infrared heating process.

Analysis of flax seeds drying using Lewis's model [7]

Figures 6 and 7 present the linear relationship at surface cylinder temperatures of 105°C at rotation speed of 15 r.p.m and 2 kg feeding rate for conduction heating and radiation intensity of 477 W/m^2 at rotation speed of 15 r.p.m and 2 kg feeding rate for infrared heating.

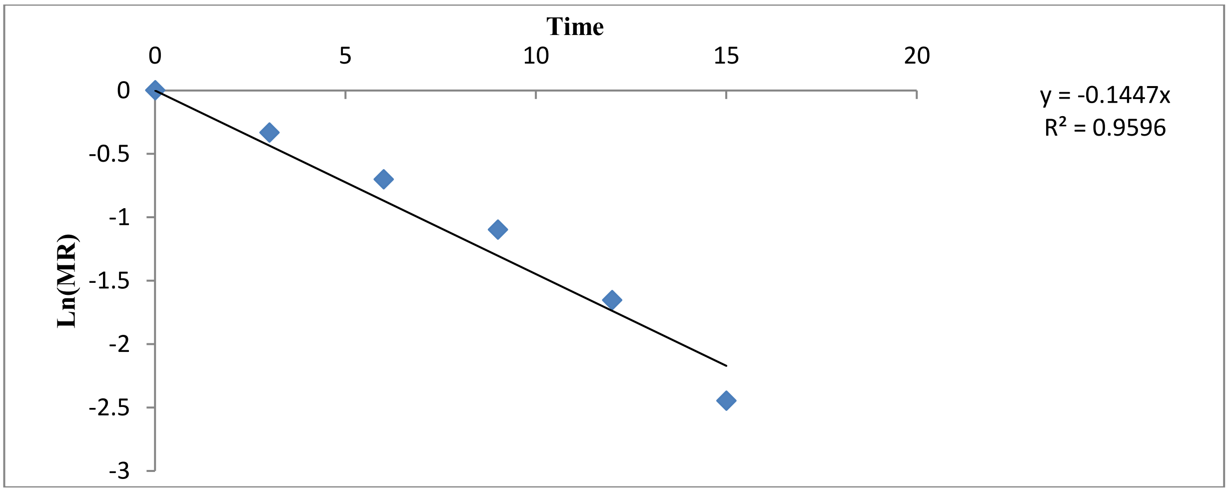


Fig. 6. Drying constant (k_L) of Lewis's model at rotation speed of 15 r.p.m, surface cylinder temperature of 105 °C and 2 kg feeding rate.
Source: Authors' determination.

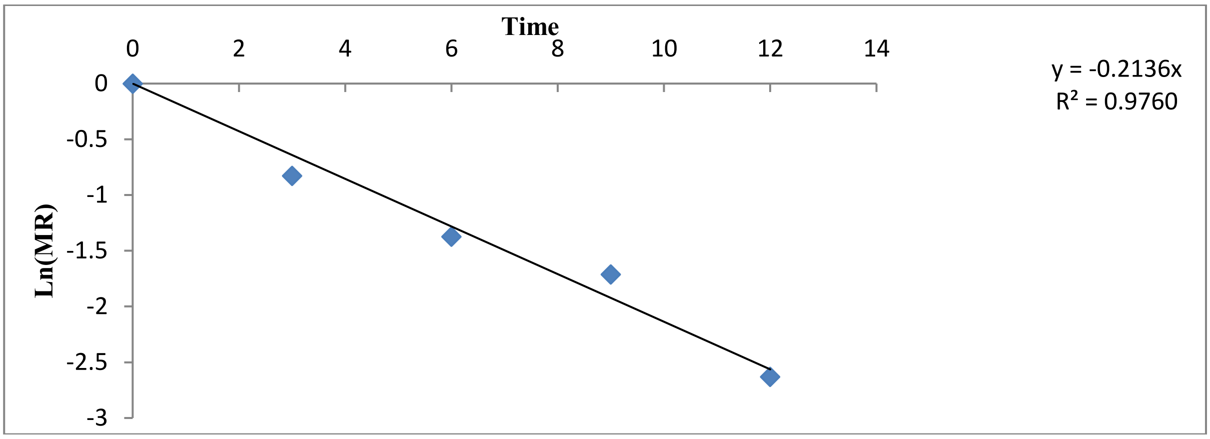


Fig. 7. Drying constant (k_L) of Lewis's model at rotation speed of 15 r.p.m, infrared intensity 477 W/m^2 and 2 kg feeding rate.
Source: Authors' determination.

The values of heating constants k_L for both conduction and infrared heating are listed in Table 2. As shown in Table 2, drying constant (K_L) increased with the increase of surface cylinder surface temperature and also increased with the increase of infrared intensity.

Table 2. The values of heating constants k_L for both conduction and infrared heating methods

Temperature, °C	Feed rate, kg	Rotational speed, 15 r.p.m
90	2	0.1330
105		0.1447
120		0.1485
135		0.1517
Infrared intensity, W/m2		
53.1		0.1917
331.6		0.2056
477.5		0.2136
848.9		0.2152
1,326.4		0.2297

Source: Authors' determination.

The applicability of Lewis's model in simulating the drying data

Figures 8 and 9 show the observed and the calculated values of flaxseeds moisture ratio at 105°C, rotation speed 15 r.p.m. and feeding rate 2 kg/patch for conduction heating and radiation intensity of 477.5 W/m^2, rotation speed 15 r.p.m. and feeding rate 2 kg/patch for infrared heating.

The results indicated that, Lewis's model can satisfactorily describe the moisture behaviour of the flaxseeds during conduction and infrared heating processes.

Analysis of flax seeds drying using Henderson and Pabis's model

Figures 10 and 11 present the linear relationship between Ln MR and exposure time at cylinder surface temperatures of 105°C at rotation speed of 15 r.p.m and 2 kg feeding rate for conduction heating and radiation intensity of 477 W/m^2 at rotation speed of 15 r.p.m and 2 kg feeding rate for infrared heating.

The values of heating constants (K_H) and A for both conduction and infrared heating are listed in Table 3.

As shown in Table 3, drying constant (K_H) increased with the increase of cylinder surface temperature and also increased with the increase of infrared intensity.

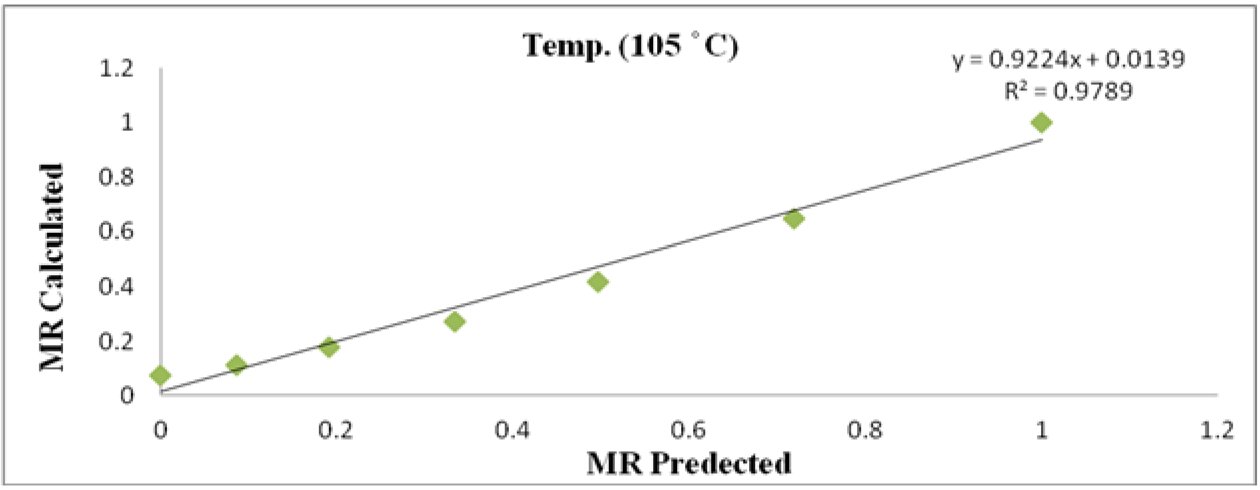


Fig. 8. The observed and the calculated values of flaxseeds moisture ratio at 105 ºC , rotation speed 15 r.p.m. and feeding rate 2 kg/patch.
Source: Authors' determination.

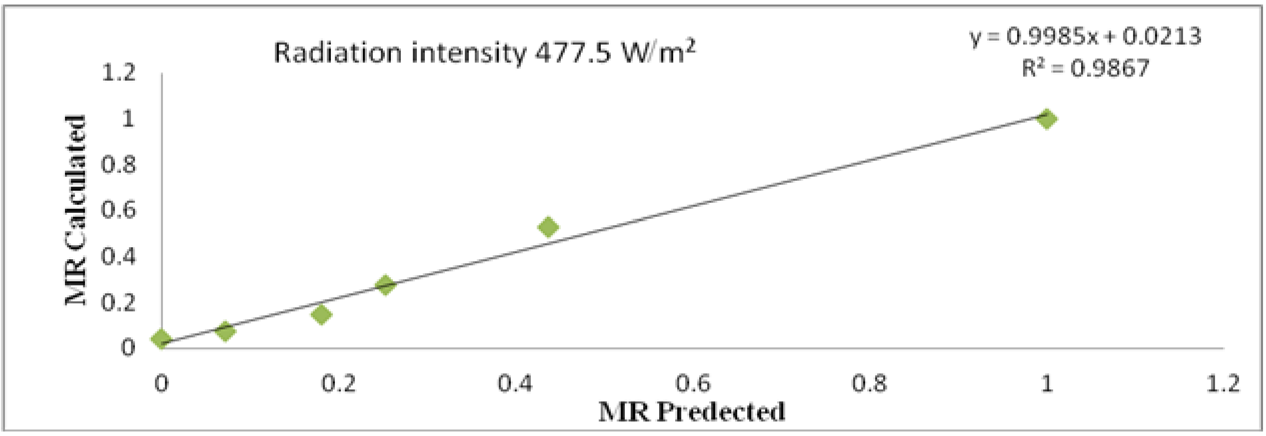


Fig. 9. The observed and the calculated values of flaxseeds moisture ratio at radiation intensity 477.5 W/m^2, rotation speed 15 r.p.m. and feeding rate 2 kg/patch.
Source: Authors' determination.

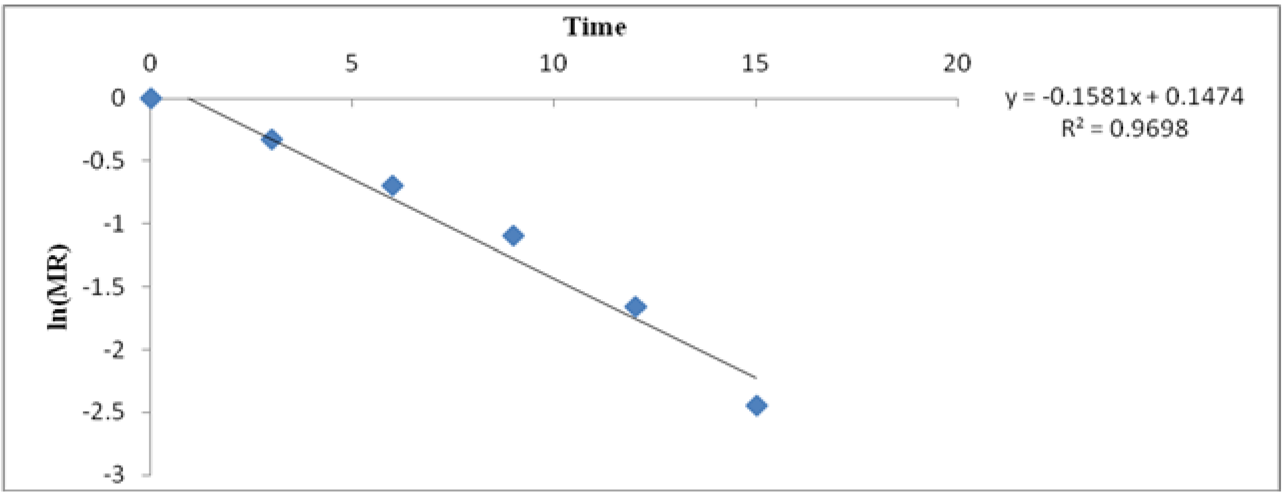


Fig. 10. Drying constant ((K_H)) of Henderson and Pabis's model at rotation speed of 15 r.p.m, surface cylinder temperature of 105^{0}C and 2kg feeding rate.
Source: Authors' determination.

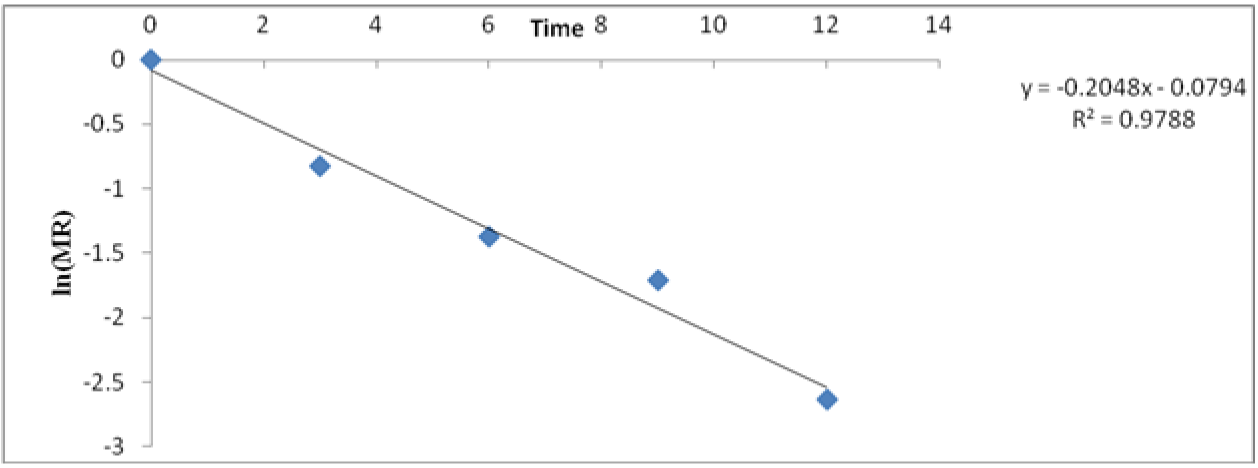


Fig. 11. Drying constant (K_H) of Henderson and Pabis's model at rotation speed of 15 r.p.m, infrared intensity 477.5 W/m^2 and 2 kg feeding rate.
Source: Authors' determination.

Table 3. The values of heating constants K_H for both conduction and infrared heating methods

Temperature, °C	Feed rate, kg	Rotational speed, 15 r.p.m
90	2	0.1440
105		0.1581
120		0.1601
135		0.1652
Infrared intensity, W/m2		
53.1		0.1779
331.6		0.2013
477.5		0.2048
848.9		0.2196
1,326.4		0.2517

Source: Authors' determination.

Analysis of flax seeds drying using Henderson and Pabis's model [6] to calculated constant (A_H)

Figures 12 and 13 present the exponential relationship at surface cylinder temperatures of 105°C at rotation speed of 15 r.p.m and 2 kg feeding rate for conduction heating method and radiation intensity 477.5 W/m^2 at rotation speed of 15 r.p.m and 2 kg feeding rate for infrared heating.

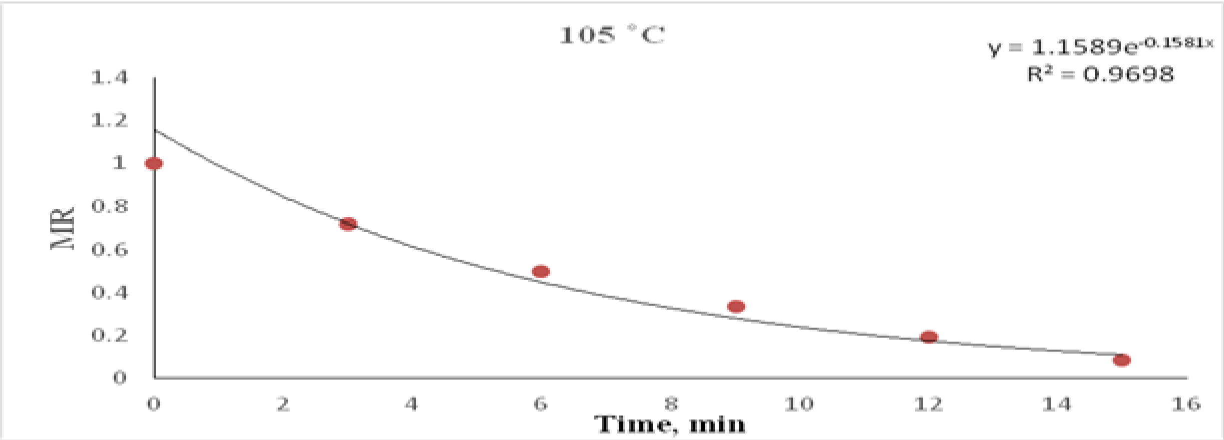


Fig. 12. The exponential relationship between MR and time at cylinder surface temperatures of 105 °C at rotation speed of 15 r.p.m and feed rate 2 kg.
Source: Authors' determinations.

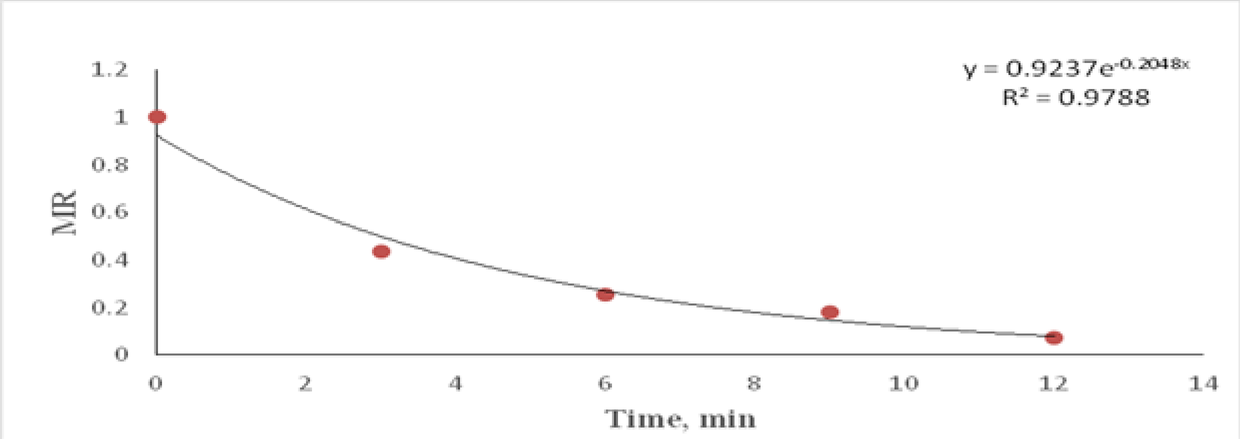


Fig. 13. The exponential relationship between MR and time at infrared intenisity of 477.5 W/m^2 at rotation speed of 15 r.p.m and feed rate 2 kg.
Source: Authors' determination.

The values of constant (A_H) for both conduction and infrared heating methods are listed in Table 4.

Table 4. The values of constant A for both conduction and infrared heating methods

Temperature, °C	Feed rate, kg	Rotational speed, 15 r.p.m
90	2	1.1276
105		1.1589
120		1.1360
135		1.1603
Infrared intensity, W/m2		
53.1		0.8837
331.6		0.9615
477.5		0.9237
848.9		1.0405
1,326.4		1.2190

Source: Authors' determination.

The applicability of Henderson and Pabis's model in simulating the drying data

Figures 14 and 15 show the observed and the calculated values of flaxseeds moisture ratio at at 105°C , rotation speed 15 r.p.m. and feeding rate 2 kg/patch for conduction heating and radiation intensity of 477.5 W/m^2, rotation speed 15 r.p.m. and feeding rate 2 kg/patch for infrared heating.

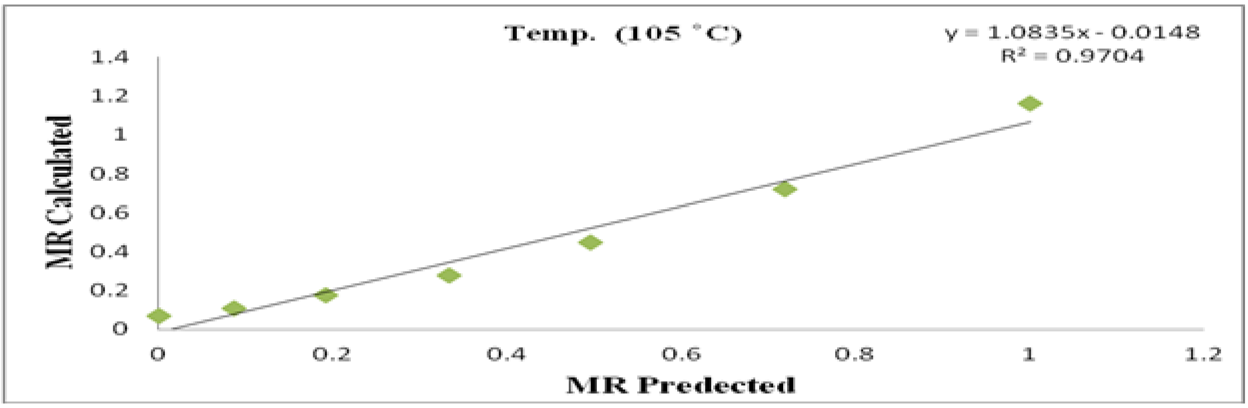


Fig. 14. The observed and the calculated values of flaxseeds moisture ratio at 105 ºC , rotation speed 15 r.p.m. and feeding rate 2 kg/patch.
Source: Authors' determination.

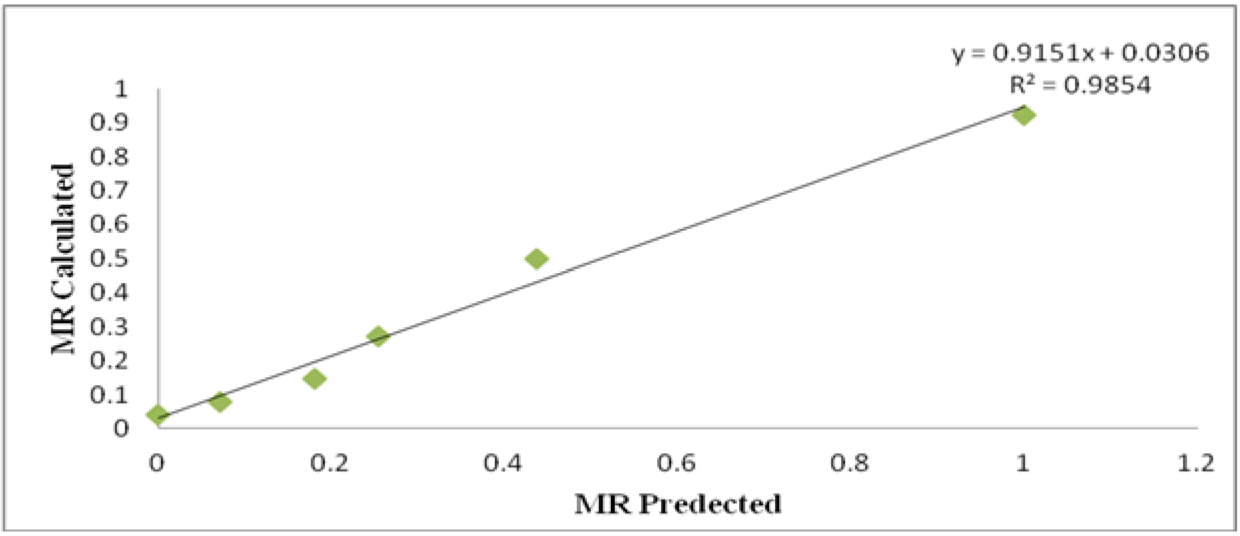


Fig. 15. The observed and the calculated values of flaxseeds moisture ratio at radiation intensity 477.5 W/m^2, rotation speed 15 r.p.m. and feeding rate 2 kg/patch.
Source: Authors' determination.

The results indicated that, Henderson and Pabis's model [6] can satisfactorily describe the moisture behaviour of the flaxseeds conduction heating and infrared heating processes.

Fungi inactivation during conduction and infrared heating

Table 5 presents the change in fungal mortality levels as related to the exposure time and the heating surface temperature for the conduction heating method and the radiation intensity for the infrared heating method. The results showed that, the high values of temperature in conduction heating and the high values of radiation intensity in infrared heating reduced the fungal load in an effective manner. Also, longer exposure time in both conduction and infrared heating methods resulted in more fungal load reduction. As shown in the table, the initial fungal count for flaxseeds was 2013 colonies/g, and they were decreased to a variedlevels depending upon the heating surface temperature, infrared intensity and the exposure time.

Table 5. The exposure time and the heating surface temperature for the conduction heating method and the radiation intensity for the infrared heating method

Heating temperature, °C	**Exposure time, min**						
	0	3	6	9	12	15	18
90	2,013	1,230	1,099	978	845	701	557
105	2,013	1,081	980	858	708	584	431
120	2,013	1,015	845	734	589	468	304
135	2,013	900	712	620	464	337	178
Radiation intensity, W/m2							
331.6	2,013	1,105	987	906	765	612	
477.5	2,013	980	773	694	548	391	
848.9	2,013	720	591	476	312	170	
1,326.4	2,013	576	407	245	91	13	

Source: Authors' determination.

In general, it can be said that, the accelerated heating using the conduction heating and infrared heating techniques could be considered as an effective procedure for fungal inactivation, however the infrared heating method was more effective in comparison with the conduction heating method. This would be very beneficial for flaxseeds which deteriorate in a short time after harvesting due to actions of both higher moisture content and higher fungal load.

Free Fatty Acids (FFA%) in the extracted oil

The percentage of lipase enzyme in flaxseeds oil hydrolysis it into free fatty acids. Also oxidation for free fatty acids leads to produce various off odor compounds such as aldehydes and kentons. The free fatty acids tests were conducted after seeds storage in traditional storage system (burlap bags under ambient condition) only for the samples which approached the safe storage moisture content of flaxseeds in the range of (5-7% w.b). Table 6 illustrates the change in percent free fatty acids in relation to heating surface temperature and exposure time.

Table 6. Free fatty acids, oil, acid value and peroxide value as related to heating surface temperature and exposure time

Heating surface temperature, ºC	Heating time, min	Seeds bulk temperature, ºC	Moisture content (w.b. %)	F.F.A., %	Acidity (as oleic acid) %	Peroxide value (MeqO²/kg oil)
Ambient	0	26	10.1	0.4	0.79	3.31
90	18	85	4.7	0.29	0.58	4.94
105	12	87	5.6	0.3	0.60	2.82
105	18	100	4.5	0.32	0.63	2.76
120	9	89	6.2	0.32	0.63	3.16
120	15	105	4.8	0.37	0.73	3.25
135	9	96	5.9	0.34	0.68	5.68
135	15	112	4.4	0.42	0.83	11.62
Radiation denisity, w/m²	**Heating time, min**	**Seeds bulk temperature, ºC**	**Moisture content (w.b. %)**	**F.F.A., %**	**Acidity (as oleic acid) %**	**Peroxide value (MeqO²/kg oil)**
331.6	15	39.1	8.7	0.56±0.02	1.11	1±0.02
477.5	12	53.9	8.7	0.53±0.03	1.05	1±0.01
848.9	6	48.9	9.1	0.64±0.04	1.27	3±0.05
1,326.4	9	77.8	8.3	0.84±0.02	1.67	5±0.03

Source: Authors' determination.

As shown in Table 6, both studied methods of conduction and infrared heating could keep lower levels free fatty acids of the extracted oil. This was clear in which free fatty acid of all samples were less than 5 % which indicate no rancidity after 3 months of storage on burlap bags under traditional storage condition.

CONCLUSIONS

Seeds bulk temperature increased with the increase of exposure time and approached levels lower than that of the heating surface temperature.

Rapid moisture removal from seeds was clear in all experiments particularly at higher heating surface temperature and radiation intensity and longer exposure duration.

Both the simple and modified exponential drying equations satisfactorily described the heating behavior of flax seeds. However, for more simplified application, the simple exponential equation may be used with clear accuracy.

The accelerated heating using the conduction and infrared heating technique considerably decreased the percentage of free fatty acids and the peroxide value.

Heating surface temperature of 105ºC and the exposure time of 12 min for conduction heating and radiation density 331.6 W/m² and the exposure time of 15 min for infrared heating are recommended to decrease the moisture content of flaxseeds to the safe level and the percentage of free fatty acids at the range of 0.3 and 0.56±0.02 respectively, and peroxide value at the range of 2.82 and 1±0.02 respectively.

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