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Design, Construction, and Performance Evaluation of an Innovative Hybrid Fluidized Bed-Infrared Chickpea Roaster

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ABSTRACT: Traditional roasting of chickpea is an arduous and intricate unit operation for processors. It is highly labor intensive, tedious, unhygienic, and productivity is often too low to justify labor and investment time. The aim of this study was thus to design and fabricate a chickpea roaster and evaluate its performance. Raw chickpea of different moisture content (7.92, 8.37 and 9.16%) were roasted at different roasting temperatures (110, 120 and 130°C) and performance characteristics including, roasting time, percentage material loss, functional efficiency, throughput, and machine capacity were evaluated. Results obtained indicated that roasting chickpea of 7.92% at 120°C yielded the best roasting conditions, as it had the least material loss of 1.47% best throughput capacity and functional efficiency of 18.13kg/h and 97.72%, respectively. The fabricated chickpea roaster does not require skilled labor and can effectively address the challenges associated with chickpea roasting.

Practical application: The fabricated roaster is relevant to the roasting chickpea to produce roasted chickpea (called Nokhodchi). This will practically address the impending challenges associated with chickpea roasting especially in the Mamaghan and rural areas. This roaster will further ensure production of quality chickpea to its teeming consumers, thereby contributing to food security.

Keywords: chickpea, roasting, Nokhodchi, fluidized-bed, infrared, performance evaluation

INTRODUCTION

Chickpea (*Cicer arietinum* Linn.) is one of the oldest and most consumed legumes in the world and in the Mediterranean regions of Asia, Africa and Europe. In addition to its high content in proteins, it contains an important amount of polyphenols and it is considered to be among the richest legumes (Mrad, Rouphael, Maroun, & Louka, 2014). Chickpea is one of the most important beans in Iran, India, Turkey and Australia (Kaur, Singh, & Sodhi, 2005).

Processing of chickpea into Nokhodchi (roasted chickpea), involves a number of unit operations including cleaning, grading, roasting, resting, moisturizing, dehulling, cleaning and grading again. Of all the processing steps, the most critical and vital, that determines the final quality of chickpea are the roasting and moisturizing operations (Coskuner & Karababa, 2004; Iyer, 1997).

Roasting and puffing are ancient methods of processing pulses and have not been modernized or automated, although some degree of mechanization has occurred recently. Graded seeds are heated in a pan to about 80°C, cooled overnight, and sprinkled with fresh or salt water (Coskuner & Karababa, 2004; Iyer, 1997).

Roasting is a very labor intensive, high energy and time-consuming operation. Roasting is a process by which the food product are subjected to thermal and irreversible structural changes accompanied by reduction of moisture contents purposely to enhance digestible content for human consumption(Fellows, 2009). Transfer of heat can be determined by the property of matter and temperature. It is governed by the second law of thermodynamics which dictates that a free flow of heat is possible only from a body of higher temperature to a lower temperature.

Three mechanisms modes of heat transfer are conduction, convection and radiation (Rathore & Kapuno, 2011). Thermal radiation is one of the basic mechanisms for energy transfer between regions of two or more different temperatures by which heat is conveyed from one place to another without heating the intervening medium. It involves the emission of heat rays through spaces and roasting will be successfully obtained in the exposure of raw chickpea to the radiant heat emitted from infrared lamps contained inside an enclosure chamber (Pan & Atungulu, 2010). Therefore, this research work was carried out to construct a hybrid fluidized bed- infrared roasting machine in Iran.

Chickpea are either consumed fresh or processed into a variety of products. There are a variety of traditional chickpea preparation and processing methods that include soaking, decortication, grinding, sprouting, fermentation, boiling, mashing, roasting, parching, frying, and steaming treatments (Deshpande & Damodaran, 1990). Among these, the roasted chickpea is the most popular. It is a traditional snack food, which is eaten in Iran and other Middle Eastern countries.

In Turkey nearly 20% of total chickpea production is used to produce leblebi. As a generic word, leblebi originated from the Persian word "lebleb," and it means roasted chickpea (Bilgir, 1976; Coskuner & Karababa, 2004). Roasted chickpea in Turkey is called leblebi (a word with Persian root) and in Iran has known as Nokhodchi. Nokhodchi is also has a long shelf life due to its low moisture content, and can be stored for six to12 months, depending on the packaging materials used.

Today, there is no large-scale industrial production of leblebi. Leblebi is produced traditionally at some small-scale family plants in Turkey. The scientific literature related to leblebi production and quality is very limited (Bilgir, 1976; Coskuner & Karababa, 2004; Köksel, Sivri, Scanlon, & Bushuk, 1998).

Based on seed color and geographic distribution, chickpea is grouped into two types-desi (Indian origin) and kabuli (Mediterranean and Middle Eastern origin). The seeds of kabuli cultivars are large with white to cream colored seed coat. The seeds of desi cultivars are small, wrinkled with brown, black or green color. The bold seeded cultivars of desi type are often used for roasting. Significant differences in these two groups have been observed with regard to their seed coat %, crude fiber content, mineral and trace element composition, polyphenolic content and in vitro digestibility by several workers (Chavan, Kadam, Salunkhe, & Beuchat, 1987; Jambunathan & Singh, 1981; Singh & Jambunathan, 1981).

Chickpeas that are used for leblebi processing must conform to some important quality criteria such as shape, size, color, and harvesting time. The shape, size, and color of chickpeas vary according to cultivars. Generally, large-seeded (8-9mm in diameter and 30.0-50.0 g of 100 kernel weight), lighter-colored, round, and smooth surface kabuli chickpeas are preferred and appropriate for leblebi processing. Also, the chickpea must have a thick seed coat and the hull must be easy to remove from kernels during leblebi processing (Coskuner & Karababa, 2004).

Although the source of the production of roasted chickpea is Turkey, but even in this country there are few scientific articles and available resources on the literature about processing, characteristics, nutritional value and processing stages (Barrón, González, Albar, & Tirado, 1992; Coskuner & Karababa, 2004). Currently, processing of roasted chickpea in the world is only done in the three Asian countries of India, Iran and Turkey. In Iran, the processing of this product is mainly carried out only in the Mamaghan which is a part of the city of Azarshahr. This sector, alone processes 40% of the whole country's roasted chickpeas (called Nokhodchi) production in a traditional method, and supplies about 90% of the Nokhodchi used in the country. At present, 1,300 active production units in the Mamaghan, annually supply about 220000 tons of roasted chickpea and deliver them to domestic and overseas markets. So far, the chickpea industry in this region has led to the realization of job creation for 10,000 people (Student News Agency of Iran, ISNA, Azerbaijan Agency. 2013. News Code: 92060603895-www.isna.ir).

Nokhodchi is a ready to eat snack food (usually consumes as a nuts) in different regions of Iran and many countries of the world. This type of processed chickpea is consumed in the most provinces of Iran. Like other grains, Nokhodchi are only made from raw chickpeas. Chickpea is a good food product that contains digestible essential food ingredients. Chickpea roasting is a very old and commonly used technology in the home-grown workshops of Mamaghan.

The most critical unit operation that determines the quality of final product in Nokhodchi production, is the roasting operation. It has been quite difficult to mechanize this operation correctly and rightly because this operation was not well understood by many designers and manufactures. Currently, the process of chickpea roasting in Mamaghan is carried out in a traditional method. Using the available technology for chickpea processing has caused that this method to be a serious and harmful process and produce a product with low or moderate quality.

Therefore, changing the technology and mechanizing the heating and roasting process is necessary to improve the health of the people working in this field, as well as to improve the quality of the finished product. Field studies and surveys showed that the enhancement of technology in chickpea roasting is one of the essential and important research and study priorities. In traditional technology, the heating of raw chickpeas is done in a horizontal rotating-drum roasters. This system causes non-uniform heating of the product. This problem affects the qualitative and apparent qualities of the roasted chickpeas resulting from this process. Also considering the adverse effect of traditional roasting method on human health and food security, there is need for the evolvement, development, and construction of the machine on a laboratory scale (at first) to address this prevalent issue and eliminate this drudgery. Therefore, this research was conducted with the aim of changing and modernizing the existing roasting method with a new technology by designing, construction and evaluating a new roasting machine In order to enhance the qualitative properties of the product.

It was envisaged that the constructed roaster would deliver the desired and safe Nokhodchi (roasted chickpea) for its intended consumers, reduce drudgery and save time and labor.

MATERIALS AND METHODS

A. Materials

The main materials used in the execution of the research work, was 300 kg of representative sample of local chickpea cultivar from 2016 harvest, were purchased from the Khalifan village (36.5°N, 45.79°E) around the Bukan city in West Azarbaijan province of Iran. The cultivar was kabuli type raw chickpea grain. Raw chickpeas were respectively processed into final product (Nokhodchi) using the unit operations shown in Fig. 1.

Chickpea
↓
Cleaning and grading
↓
Roasting in a hybrid fluidized bed-infrared machine (in different temperature-time combinations)
↓
First resting (For 24 hours in thick hemp sack)
↓
Moisturizing and soaking (About 10% of the weight of the chickpeas)
↓
Second resting (For 12 hours inside double layer and thick plastic sacks)
↓
Batch type chickpea dehulling in cast iron pans (3kg/batch)
↓
Cleaning and grading (separation of hulls from kernels in each batch)
↓
Yellow roasted and puffed chickpeas

Fig. 1. Flow chart showing unit operations involved in obtaining the Nokhodchi.

All of materials other than chickpea grains (MOG), including chickpea pods, broken stalks, soil, weeds and pebbles were separated by a circular slot rotary sieve. The grains were graded in homogeneous sizes in addition to cleaning by the sieve. The remaining probabilistic impurities were manually separated. In the next steps, operations including roasting, resting, moisturizing, dehulling, cleaning and grading were performed on the chickpea samples.

B. Geometric Mean Diameter (GMD)

The geometric mean diameter of raw and roasted chickpea samples was measured by using electronic digital caliper with least count of 0.02 mm. Geometric mean of the spatial dimensions (length, breadth and thickness) was calculated as equivalent diameter:

$$D_e = (L \times B \times T)^{1/3} \quad (1)$$

D_e= The equivalent diameter of grain, mm. L = The length of grain, mm. B = The breadth (width) of grain, mm and T= The thickness of grain, mm.

Graded chickpeas with a geometric mean diameter of 8.054 mm, were used for this study.

C. Moisture Content

Initial moisture content (M_C) of samples was determined by using oven method at 105°C for 24h (Esref & Hulya, 2008; In, 2005). Oven, glass plate, Digital scale with a precision of 0.01, Desiccator and clamp were used to calculate the moisture content of samples. The oven specification used to determine the moisture content was Memmert, Germany, D 06062, model 600.

The digital scale used in this experiment was KERN 470 with a precision of 0.01, 1 gram error (e = 1 g), deviation of 0.1 gram (d = 0.1 g), maximum and minimum capacity of 5,000 and 5 grams, respectively. The following equation was used to calculate the moisture content of the samples:

$$M_c = \frac{M_1 - M_2}{M_1} \times 100$$

M_c= Moisture content (wet basis), %
M_1= Weight of wet chickpea, kg
M_2= Weight of dry chickpea, kg

D. Methods

The analytical aspects in the design are to determine reliable parameters by which the system is constructed to achieve safe and reliable operations while achieving the design objective. The details analysis of each section in the logical sequence of construction are presented below. Machine elements were designed base on the thermal furnace of the burner and hot air tank design, the fan and burner selection design.

Material Selection Design. The selection of suitable material for use after careful analysis and design consideration is based on various properties of engineering material such as strength, hardness, ductility, machinability and dimensional stability at high temperature (creep).

Design consideration. In designing this equipment, factors considered included: (1) availability of raw materials for construction; (2) safety; (3) costs; (4) thermal compatibility; (5)simplicity of fabrication and dismantling; (6) corrosion resistance; (7) mechanical properties of the material (e.g., stress, creep, and fatigue); and (8) strength and reliability (Ikechukwu & Maduabum, 2012; Sobowale, Adebiyi, & Adebo, 2016). Furthermore, basic requirements and features of a chickpea roaster were also considered. This includes, a batch type operation that would lead to the production of moderate mass capacity of roasted chickpea, a regulated mechanism that ensures batch roasting and heating to a desired and constant temperature (Akinnuli, Osueke, Agboola, & Adediran, 2015; Igbeka, 1995).

Design computations. Further to earlier stated design considerations, basic chickpea roasting techniques, properties of the chickpea and effective simulation of the roasting process guided the design computations. This included continuous agitation by fluidization to prevent the formation of lumps and accumulation of chickpeas, as experienced during the traditional roasting process. Consideration was given to the design for volume of the roasting chamber, volume of the furnace of burner, volume of the hot air tank, air velocity in different degrees of open air inlet to the blower, length and diameter of the interface pipes, General shape, height and other dimensions of the fluidized bed tank, volume, position and dimensions of the air relaxation chamber and Infrared bulb enclosure, position and specifications. Estimated heat required for roasting and the estimated convective and radiation heat transfer rate. Equations 1- 6 were used to compute some of the parameters for the components of the chickpea roaster.

$V_i = \pi r_i^2 h_i$ Where index i = *rc, fb, hat* and *art* (1)

$$V_{hat} = \pi r_{hat}^2 h_{hat} + \frac{\pi}{12} h_{ic}(D^2 + Dd + d^2) \quad (2)$$

$$M = V_{rc} \times \rho \quad (3)$$

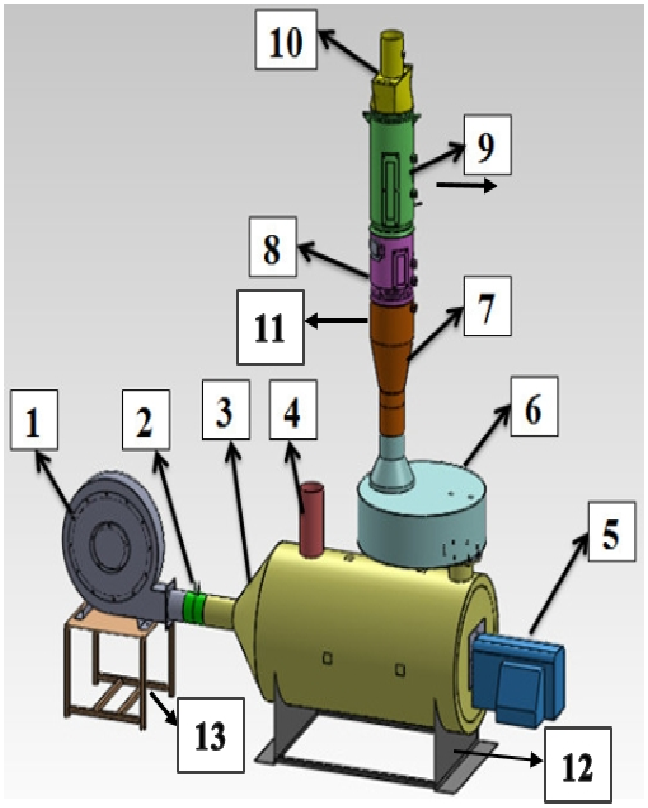
$$V_c = \frac{\pi D_e^3}{6} \quad (4)$$

$$Q = MC_p \Delta T \quad (5)$$

$$Q_c = h_c A \Delta T \quad (6)$$

In the equation (1), V is the volume (m^3) and the index i, displays the parts under design and calculation, including the roasting chamber (V_{rc}), the furnace of burner (V_{fb}), the hot air tank (V_{hat}) and the air relaxation chamber (V_{arc}). π = 3.142, r_i and h_i are the radius and height of the relevant parts (m) respectively; M is the mass of chickpea in the roasting chamber (kg); ρ is the density of chickpea = 769 kg/m^3 (Konak, Carman, & Aydin, 2002); V_c is the chickpea seed volume. Q is the estimated heat required for roasting (W); C_p is the specific heat capacity of the chickpea = 1.146 kJ/kg^{o}K (Sabapathy & Tabil, 2004). ΔT is the change in temperature, Q_C is the estimated convective heat transfer rate (W), h_C is the thermal conductivity or convective heat transfer coefficient = 0.171 W/m^{o}C (Sabapathy & Tabil, 2004). A is the surface area of the roasting chamber (m^2). From the design calculations, the 7.86 × 10^{-3}m^3 roasting chamber can effectively hold 6.044 kg of chickpea. The calculated heat required for roasting was 694.9 (W/h), while the estimated convective heat transfer rate was 2.84 W.

Description of the constructed roasting machine. As shown in Fig. 2, the equipment consist of a high volume centrifugal fan with forward curved blades, with inlet and outlet diameter of 150 mm and 112 mm respectively(1). An electric motor with specifications including: Milano manufacturing company, production date 2013-09, 1 Phase, 220 V, 50 Hz, 1.5 HP/1.1 KW, 7.2A and 2800 RPM, was used to operate the fan. The fan by the pipes with 112mm diameter and 2mm thickness was connected to a hot air tank. A concentric orifice meter which was designed and constructed during this research, was placed in the middle of the fan connecting pipe to the hot air tank to measure the fluid flow in accordance with Bernoulli's principle (2).



ITEM	**PART NAME**
1	Fan
2	Orifice Meter
3	Hot Air Tank
4	Furnace
5	Gas Burner
6	Air Relaxation Chamber
7	Diffuser
8	Chickpea Roasting Chamber
9	Fluidization Crate Of Chickpea Grains
10	Infrared Bulb Enclosure
11	Air Rectifier System
12	Base of Equipment
13	Base of Fan

Fig. 2. Three-dimensional view of chickpea roasting machine and its components.

Pressure transducers were installed in the upstream and downstream parts of the orifice to measure pressure variations. On the other hand, a gas burner was used to generate required heat (5). The burner specifications were: made in Iran, model "JGN 80/2", thermal capacity of 60-260 KW, gas pressure range of 15-40 mbar, fuel of natural gas and 1 ~/ 220V/50 Hz. The thermal furnace of the gas burner and hot air tank had cylindrical shape. The radius of lateral walls of the furnace and air tank were 250 mm and 290 mm. in addition, their length were 900 mm and 1000 mm which were made entirely from 3 mm and 2 mm thick steel sheets, respectively. The furnace was coaxially located inside the hot air tank (4). The edge of holes (with the diameter of 120 mm) in the center of lateral walls of the furnace and hot air tank were welded at the entrance point of burner to the furnace. The pipe with outside diameter of 112 mm, at the distance of 20 mm from the end and the highest point of the furnace surface, was welded to the created hole at this point. The pipe passes through the space between the furnace and the hot air tank and leaves it from its opposite hole in the air tank surface. The pipe was extended to the free space in the outside of laboratory to act so as a chimney and the products resulting from the combustion of natural gas in the furnace were transferred to the free air. On the other side, the pipe with 112 mm in diameter, was welded to the created hole with the inner diameter of the pipe, at a distance of 20 mm from the edge of end wall and at the highest point of the surface of the hot air tank. This pipe is connected to the air relaxation chamber by flange, screw, and other interconnecting pipe. In order to prevent turbulence and to create air flow uniformity throughout the cross-section of the fluidized bed in chickpea roasting chamber, an air relaxation chamber was designed and constructed (6). The air relaxation chamber is a 600 mm in diameter metal cylinder, with the height of 200 mm and thickness of 3 mm. Two holes were created, the first with the diameter of 108 mm at the lower base of the relaxation chamber for air entering, and another with the diameter of 200 mm at the upper base for exhaust air. A pipe with an internal diameter of 108 and an outer diameter of 112 mm, to the bottom and a conversion of 200 to 108 mm, to the top of the relaxation chamber was welded. The top view and final geometry of the relaxation chamber with related connections was shown in the figures 3, 4.

After the air relaxation chamber, due to the high flow rate of the air, a diffuser was designed and constructed to reduce air velocity (7). Diffuser causes expansion of the air flow, reducing air velocity and therefore static pressure increases (Fuss, Subic, & Mehta, 2013; R. Mehta, 1979; R. D. Mehta, 1985; R. D. Mehta & Bradshaw, 1979). The diffuser was made from 304 stainless steel sheet (SS. 304) with thickness of 0.5 mm. Diffuser has a circular cross section, an inlet diameter of 112.5 mm, a height of 200 mm and an approximate angle of 25°.

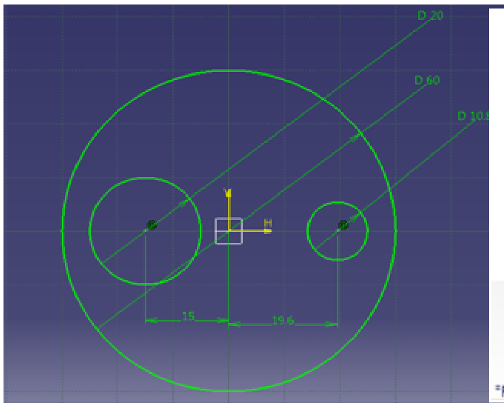


Fig. 3. The top view of relaxation chamber.

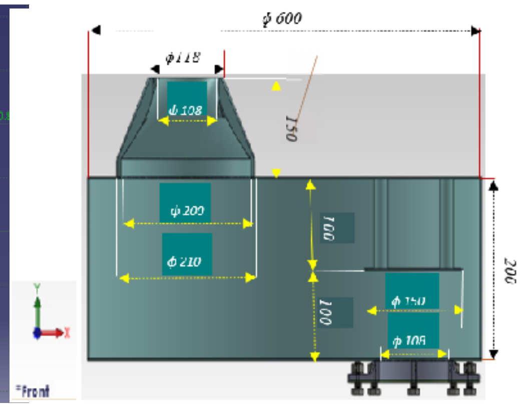
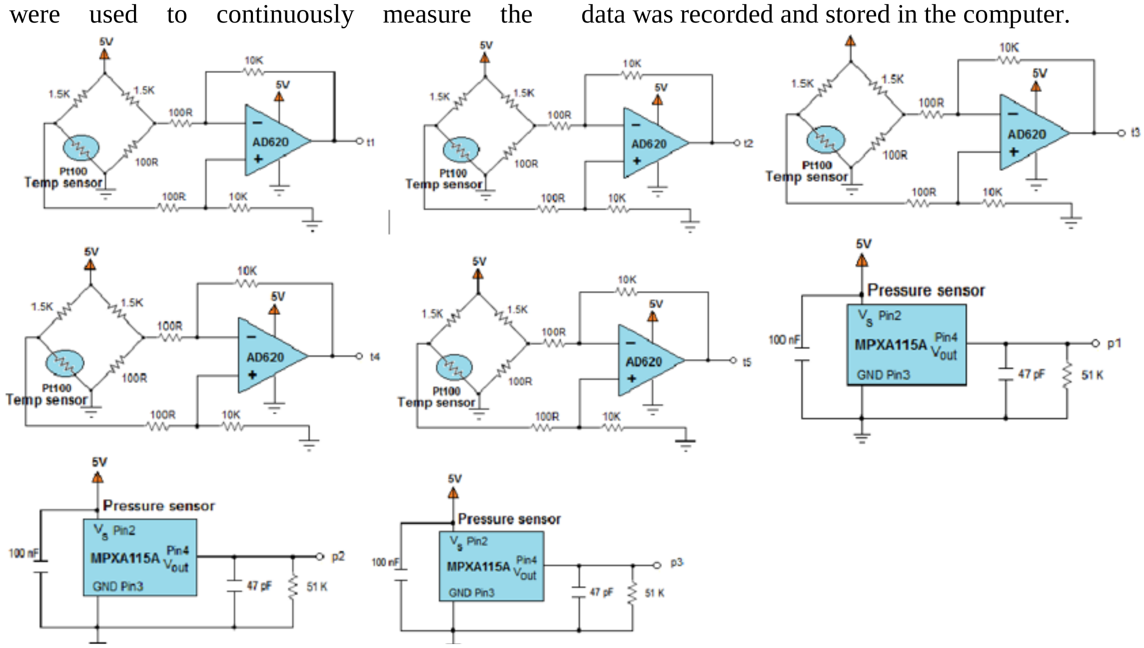


Fig. 4. Final geometry of relaxation chamber.

The material of roasting chamber was SS. 304 with thickness of 0.5 mm which was rolled and in the form of a drawer, was attached to the diffuser and relaxation chamber (8). The chickpea roasting chamber had a distributor plate with perforated design in the underside section. The distributor plate had holes with 5 mm in diameter, which chickpea grains were poured on it. Two thermometers, type Pt-100 with insertion length of 100 mm, outside diameter of 10 mm and material of SS. 304, were used to continuously measure the temperature of the air and the surface of the chickpeas during roasting process in the roasting chamber with the hybrid fluidized bed-infrared technology. The temperature data during the chickpea roasting experiments, were recorded by a computer at intervals of 5 seconds. All of temperatures and pressures data at different points of the device, were transferred to the digital electronic circuit by interface wires and then was transmitted to the computer via a USB cable. Then the data was recorded and stored in the computer.



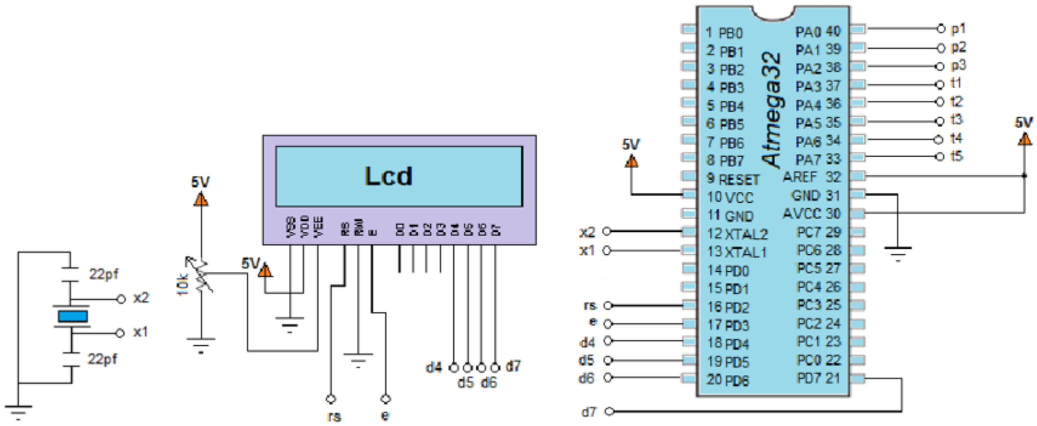


Fig. 5. Electrical panel: Power circuit, electronic circuit of the each of temperature sensors and pressure transducers, the display circuit in the computer or Lcd.

The roasting chamber was made from grade 304 stainless steel sheet with thickness of 0.5 mm. It was rolled and in the form of a drawer, was respectively attached to the diffuser and fluidized bed chamber in the bottom and in the top.

Operation of the constructed chickpea roaster. To achieve a specific temperature, the burner and fan were adjusted according to pre-determined calibration. The burner and 3 minutes later the electric motor of the fan and infrared lamps were turned on. Then the heat control was switched on and waited to bring the air in the roasting chamber to the desired temperatures, which were permanently determined using Pt-100 thermometers and recorded in computer (Ajayi, Olukunle, & Dauda, 2014; Ikechukwu & Maduabum, 2012). When the set temperature was reached, the roasting chamber with a diameter of 200 mm, was filled with approximately 6.044 Kg raw chickpea grains. The hot air with constant temperature was continuously introduced into the roasting chamber through the distributor plate and the chickpea grains were fluidized. Immediately after pouring chickpea into the roasting chamber, a sudden drop in temperature was demonstrated by thermal sensors. The abrupt drop in temperature was due to the significant difference in temperatures between the chickpeas and hot air entering to the roasting chamber. Therefore, at first, the hot air entering to the roasting chamber applies its thermal energy to bring the chickpeas to the equilibrium temperature. At this point, there is heat transfer to the chickpeas with the aid of hot air flow and agitation by fluidization, and roasting process begins. Heat transfer by hot air and radiation emitted from infrared lamps, respectively, are carried out from the surface and the kernel of chickpea grains which are fluidized. Contrary to the traditional chickpea roasting system in the Mamaghan city as well as some other commonly used equipment of roasting for agricultural products in the world, in this machine, agitation of chickpea grains during roasting is done by the proper air flow rate and grain fluidization. Therefore As the moisture content of the chickpea during roasting process reduces, there are not formation of lumps or accumulation which are further broken down by the action of the mechanical agitator by scraping them off the surface and stirring the mall along against the hot surface of roasting chamber. Due to condensation, moisture content may tend to increase in the roasting chamber, hence the upper unit of the roasting chamber was left open for exit of vapor.

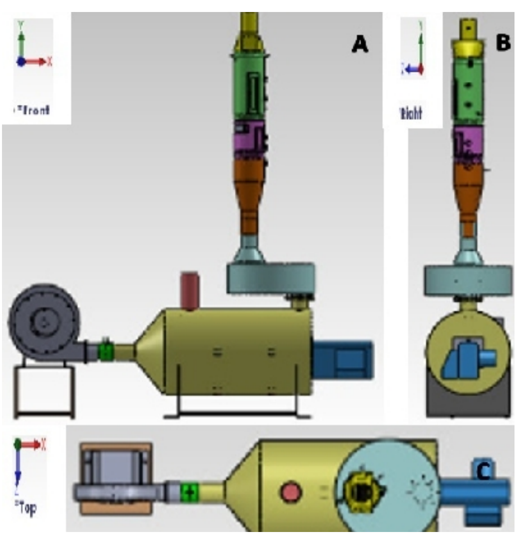


Fig. 6. Different orthographic views of the chickpea roaster: Front(A), End (B), and plan (C).

In simulating the chickpea roasting process, the process was continuously repeated until a uniform fluidization was obtained and a constant moisture content of 2-3%. After about 20 minutes and the completion of the chickpea roasting process, the Nokhodchi (roasted chickpea) was discharged through a chute into a thick hemp sack. Performance evaluation. After construction, performance evaluation tests were carried out on the machine. Two major variables that could determine the quality of the final product (Nokhodchi) were investigated. These are moisture content of the roasted chickpea and the roasting temperature (Table 1).

Table 1: Variables used in the experiment.

Variables	**Values**
Chickpea moisture content, w.b (%)	7.33, 8.61, 9.75
Roasting temperature (^oC)	110, 120, 130
Performance Indicators	Roasting time, throughput capacity, and functional efficiency

Moisture content of the three obtained raw chickpea samples were determined using the method of AOAC (2005).The chickpea roaster was differently fed with an initial known quantity of sieved raw chickpea (M_c) of different moisture contents and the samples were respectively, roasted to Nokhodchi at different temperatures of 110, 120, and 130^{o}C. Through the chickpea roasting process, the respective chickpea were roasted to an approximate moisture content of about 2-3%,the tolerable moisture range and standard for roasted chickpea (Kirse & Karklina, 2014; Medi, 2010; Olga & Dupouy, 2015). Codex standard for certain pulses has expressed that in the case of chickpea sold without their seed coat, the maximum moisture content shall be 2 per cent (absolute) lower in each case. After each chickpea roasting process, the roasted chickpea sample obtained was reweighed (M_o). Using Equations 7–9, the following performance indicators were studied(Lhendup, 2009).

$$M_l = M_c - M_o/M_c \times 100 \quad (7)$$

$$C_t = M_o/t \quad (8)$$

$$E_f = M_o/M_c \times 100 \quad (9)$$

Where M_l is the material loss (%); E_c is the functional efficiency of the machine; M_o is the mass of roasted chickpea (Nokhodchi) obtained (kg); M_c is the mass of raw chickpea fed (kg); C_t is the throughput capacity (kg/hr); and t is the time taken to complete the operation (hr).

RESULTS AND DISCUSSION

A. Roasting time

Results of performance parameters obtained in this study are presented in Table 2. As indicated from the table, roasting time ranged from 15.18 to 20.58 min (0.253-0.343hr). An inversely proportional relationship was however observed between roasting time and roasting temperature. As the heat intensity reduced, roasting time increased and vice versa. The initial moisture content of the raw chickpea also affected the roasting time. At similar roasting temperatures of 110°C, raw chickpea of 9.75% was roasted to Nokhodchi in 0.291 hr, as compared with 0.253 hr of raw chickpea with 7.33% moisture content. Irrespective of the initial chickpea moisture contents, raw chickpea roasted at lesser temperatures of 110°C had the longest roasting times. According to Ajayi *et al.* (2014), heat intensity of the roasting process has a direct relationship on the roasting time, as the rate of reduction in moisture depends on temperature of the roasting pan.

Table 2: Performance of the chickpea roaster under different conditions studied.

Market	**Raw chickpea moisture content, d. b (%)**	**Roasting Temperature (^oC)**	**Roasting time (hr)**	**M_l (%)**	**(C_t) (kg/hr)**
A	7.33	110	0.253 ± 0.06	1.55 ± 0.12	23.88
		120	0.256 ± 0.04	1.56 ± 0.07	23.61
		130	0.261 ± 0.08	1.56 ± 0.06	23.16
B	8.61	110	0.254 ± 0.04	1.56 ± 0.09	23.80
		120	0.253 ± 0.01	1.47 ± 0.09	23.89
		130	0.269 ± 0.05	1.58 ± 0.04	22.49
C	9.75	110	0.291 ± 0.10	1.59 ± 0.01	20.77
		120	0.310 ± 0.03	1.70 ± 0.08	19.50
		130	0.343 ± 0.02	2.30 ± 0.01	17.62

B. Material losses

The material losses during roasting usually is due to the separation of the seed coat in the final stages of the roasting process. As shown in Table 2, percentage material losses ranged from 1.47% to 2.3%. Nokhodchi obtained during roasting operation at 110°C and 9.75% chickpea moisture content recorded the highest material loss of 2.3%, as compared with loss of 1.47%, at roasting temperature of 120°C and chickpea moisture content of 8.61%. This result corroborates reports that Nokhodchi is best roasted at temperatures around 120°C. Furthermore, resident time and roasting temperature of the hot air and the surface of the fluidized bed chamber are the major factors contributing to material losses experienced during chickpea roasting. While an extremely high temperature will burn the chickpea and discolor the final product, roasting at lower temperatures also increases the resident time of the raw chickpea in the roasting chamber.

C. Throughput capacity

As shown in Table 2, the throughput capacity of the roasting machine under these different roasting conditions ranged from 17.62 to 23.89 kg/hr (Table 2). Corroborating the earlier observations of the material losses is the throughput capacity which showed an inverse relationship. The lowest throughput capacity of 17.62 kg/hr corresponded to the highest material loss, while the best throughput capacity recorded was 23.89 kg/hr corresponding to the least material loss. This designed and constructed chickpea roasting machine in the laboratory scale has a better productivity, quantity, and throughput capacity and It also produces high quality Nokhodchi. Most importantly, so far, no one in the world has ever produced the Nokhodchi with such a modern technology.

D. Functional efficiency

The effect of moisture content and roasting temperature on functional efficiency is presented in Fig. 7. Functional efficiency was generally observed to increase with elevated roasting temperatures and decreased with an increase in chickpea moisture content. Nevertheless, the best functional efficiency of 97.72% was observed when raw chickpea of 8.61% moisture content was roasted at 120°C.This also validates initial observations and is in tandem with results obtained under material losses and throughput capacity.

CONCLUTION

Roasting of raw chickpea into Nokhodchi continues to be a tedious operation. To address this, a prototype chickpea roasting machine was designed, constructed and evaluated. The roasting process took a range of 15.18-20.58 min (0.253-0.343hr), while the optimum chickpea roasting conditions were at raw chickpea moisture content and roasting temperature of 8.61% and 120°C, respectively, with a functional efficiency of 97.72%. The drudgery and tediousness associated with chickpea roasting was effectively eliminated and a more wholesome, safer, and good quality product was produced. Furthermore, the operation of this machine does not require manual labor nor does it entail the use of skilled labor. The equipment is of significant importance to the teeming number of local chickpea processors, dwelling mostly in rural communities. The roaster can also be useful in the mass production of Nokhodchi for commercial purposes.

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