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THESIS

DEVELOPMENT AND EVALUATION OF A CORN ROASTING MACHINE FOR A SMALL SCALE PRODUCTION OF CORNRFLAKE (TENGMA) IN BHUTAN

SANGAY LHENDUP

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Engineering (Agricultural Engineering)
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Corn roasting machine is one of the necessity typical machine to roast the corn in Bhutan. The roasted kernels were pounded instantaneously to produce a peculiar cornflake. In this research, the corn roaster using an electric heater (2750W) as the source of heat energy was developed for a small scale production. Stainless steel was used for roasting chamber and agitation unit. Similarly, insulation cover and frame were fabricated from the mild steel. The other prominent machine components used were thermostat, overload relay, insulation and unloading mechanism. Performance of the roaster was evaluated by roasting at three weight levels of 500, 1000 and 2000 g with combination of four temperature levels of 176, 210, 250 and 260ºC (average thermocouple temperature in the mid loci of roasting chamber) respectively. It was a factorial experiment of completely randomized design and statistical analysis of the collected data was performed by using analysis of variance (ANOVA) at the significance level of 0.05.

Performance evaluation results of the developed roasting machine showed that the mean optimum machine capacity was 6.08 kg/h and the mean maximum power efficiency was 52.33%. It required only one operator and the minimum mean electric power consumption was 0.20 kW-h/kg. Subsequently, other performance was characterized by the mean percentage of weight lost after roasted as 25.35%. Furthermore, the performance evaluation and the visual examination were found out that 79.01 % of the mean roasting efficiency, 13 minutes of the most appropriate time and 260°C of the best temperature level corresponding to weight level of 1000 g. These perhaps suggested a choice for the best treatment combination of the developed corn roaster.

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Sangay Lhendup

April 2009

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DEVELOPMENT AND EVALUATION OF A CORN ROASTING MACHINE FOR A SMALL SCALE PRODUCTION OF CORNFLAKE (TENGMA) IN BHUTAN

INTRODUCTION

Roasting is the most important operation to obtain the degree of roast in a post harvest process. The perfect roast depends on visual examination and complimented with audible clues. The degree of roast was accountable with appearance of grain or legumes such as become darker, crack and aromas. Visual examination was one of the technique to judge the roasting stage or image and it was widely adopted by farmers and even in industrious. First and second crack of roasting corn can be perceived by audible while roasting. However, it was very hard to judge the median colour of the batch to determine the degree of roast.

World production of maize is lower than rice and wheat crops. Maize also referred as a corn in U.S.A and member of the grass family. It is now spread all over the world as a staple food crop. Worldwide figure of corn production projected that U.S.A with 41.21%, China 19.01% and 38.78% other countries were the major corn growing countries. The corn cultivation was projected of 158.69 million hectares with a total production of 767.96 million tons in the world (United States Department of Agriculture, 2008). In the western countries, most of the corn products are fed to animals. However, almost the entire productions are used for human consumption in Asia and Africa.

Maize is a major food crop in Bhutan. It was cultivated across the country and high potential in terms of area and production of food crop. An area of 21,828 hectare was under maize cultivation producing 90,566 tons of maize grain in the year of 2004. The yield of the maize was increased from 2.47 ton per hectare in 2000 to 4.12 ton per hectare in 2004 (Department of Agriculture, 2006). Over 70% of the households cultivated maize mainly for the subsistence and food crop plays a vital role in achieving household food security.

Thus, for higher yields and quality; the maize improvement programme was adequately reviewed in the world by botanical technology, production technology and genetic improvement. The corns were obtained as feeding, food processing, chemical composition and nutritive value. As a human food, it was edible as fresh corn, canned, frozen and sometime converted into cornflake product. However, it was major food in many parts of the world but it was inferior to other cereals in nutritional value. The study on maize structure (kernel) is also a significant factor for the adoption of maize improvement on yield and quality.

Inedible parts of the maize plant were especially used in industries like stalks for paper and wallboard; husk for filling up materials; folk arts of object by woven amulets and even to cornhusk dolls; cob and stover for fuel and sometimes it was used instead of charcoal. The edible corn products for human consumption were hominy, mush, grits, starch, sugar and even oil are also extracted from it. The classifications of maize were based on endosperm characteristics such as physical properties: colour, size, shape and hardness. The seven different subspecies were; dent corn, flint corn, sweet corn, flour corn, pop corn, waxy corn and pod corn (Park, 1999).

Although the pounded maize (Tengma) making machines are supplied by the Agriculture Machinery Centre (AMC) in Bhutan and have been widely adopted. However, roasting machine has never been available. At present, technology of roasting mechanism to roast the corn became as basic needs to produce a corn flake product. Perhaps trial development of manually roasting machine and other post harvest machines has been carried out at Research and Development Centre in AMC. Nevertheless, the particular developed roaster was not feasible or not commercialized in the market because the source of heat was firewood which is not environmentally friendly as well as machine capacity was equivalent to human roasting.

Everywhere in Bhutan, farmers were entirely dependent on subsistence farming; their daily lives were involved most of the time in agricultural activities. In current situation, the farmers were constrained with lack of farming technology and shortage of farm labour. Farming in Bhutan was associated with drudgery, hardship and adversity. To constitute the primary beneficiary of the Bhutanese farmer's living standard, AMC has collaborated with them to choose, create, innovation of agricultural technologies and develop farming technologies to suit with local environmental condition in Bhutan. This is an indication of the benefits translating directly into enhanced income for the farmers.

The main intension development of a corn roasting machine was to reduce drudgery, save costs and enhance the production capacity through easily accessible energy resource input (electrical energy). Basically, around seven women were traditionally or manually roasting corn with rudimentary of roasting mechanism. Traditionally, roasting was also physically demanding job as it was usually carried out in direct heat transfer from open burner for a long duration. Not only was this method physically exhausting but also substantial amount of corn was lost in the process of operation. Hence, traditionally operation characterized was by backbreaking and hard work with low productivity.

With this machine, the work will be done with better performance and substitute a hardship faced by a roaster. The physical demand will be alleviated. Moreover, the corn loss in the roasting process may be significantly reduced. The adoption of this machine will not only enhance cornflake production capacity, it also makes agriculture a commercially viable enterprise. The particular postharvest processing machine focused to promote the technology in the rural regions. The application of the technology also renders agriculture more attractive for farming practices.

Corn was consumed in Bhutan mainly in the form of grits (Kharang), roasted and pounded maize (Tengma), and pop corn (local name called Ashom Mungnang). Moreover, it was also processed into local liquor (alcohol called Ara) from the residual corn. Cornflake products or roasted and pounded corn were rapidly increasing in productions; which were marketed in country as well as many entrepreneurs also aimed to export the product to other countries as packaged product and surplus cornflake were consumed in domestic itself as a light breakfast and snacks.

Therefore, this research was intended to develop and evaluate a unique corn roasting machine for a small scale production of typical cornflake product in Bhutan. A prototype machine was invented as heat source from electric heater of single phase and tested in a laboratory condition to determine its performance.

OBJECTIVES

The overall objective of this thesis research was to develop and evaluate a corn roasting machine for small scale production of corn flake products. The specific objectives are listed below.

1) Develop a corn roasting machine in which heat source is from electric heater, single phase supply.

2) Test the performance and evaluate the developed roasting machine under laboratory condition.

LITERATURE REVIEW

Corn roasting has become popular postharvest operation to obtain highly commercial agricultural products and preserve the products for longer self-life (Yang, 2005). The performances of roaster for different cereal crops were tested at various parameters and studied the characteristics of corn (Bennett *et al.*, 2007; Bhattacharya, 1994; Butkarrev, 2007; Jha, 2005; Ojolo, 2007 and Perren, n.d). A number of the research work about properties, compositions and effect of roasting corn at different temperatures have been reported (Costa, 1977; Emmanuel, 2007; Felsman, 1976; Karababa, 2006; Laria, 2004; Sacchetti, 2009; Tonroy and Perry, 1974). The moisture content and harvesting stage of the corn, moisture distribution due to drying have been described (Marton *et al.*, 2001; Salunkhe *et al.*, 1985 and Zeleny, 1951). The principles of heat transfer are based on the energy sources and mode of transportation heat to the system (Gupta, 2003).

1. Studies on some characteristics of corn

Maize (*Zea mays L.*) is defined as a cereal grass widely grown for food and livestock fodder. In the late 15th century and early 16th century, maize spread to the rest of the world after it was originated from European country and America. Maize ranks with wheat and rice as one of the world's chief grain crops. Encarta (1993) studied and reported that the maize plant consist of rigid stem, rather than hallow one like most other grasses. The average height was 2.4 m and the leaves, which grow alternatively, were long and narrow. The main stem is composed of a staminate (male) inflorescence, or tassel. The tassel was made up of many small flowers termed spikelets and each spikelet bears three small anthers, which produce the pollen grains, or male gametes. The pistillate (female) inflorescence, or ear, was a unique structure with up to 1,000 seeds borne on a hard core called cob. The ear was enclosed in modified leaves called husks. The individual silk fibers that protrude from the tip of the ear were elongated and each attached to an individual ovary. Pollen from the tassels was carried by wind and falls on to the silk, where it germinates and grown down through the silk until it reaches the ovary. Each fertilized ovary grows and develops into kernels.

Marton and Peter (n.d.) reviewed and revealed that varieties of maize showed widely differing characteristics. Some varieties mature in 2 months; other take as long as 11 months. The foliage is varies in intensity of colour from light to dark green and brown, red, or purple pigments may modify of it. The number of row of kernels ranges from 8 to 36 or more. Six general groups of varieties were differentiated by the characteristics of kernel.

Park (1999) described the various types of corns firstly,

(a) Dent corn was the leading type of maize grown in United States farms. The sides of the kernel consist of hard called horny starch and the crown contains soft starch. As the grain matures, this soft starch shrinks, forming the characteristic dent.

(b) Flint corn, the horny starch extends over the top of the kernel, so that there was no denting. Some varieties of flint corn were favored in cold climates because of their ability to germinate at low temperatures, or in tropical climate because of their resistance to weevils.

(c) Pop corn was a variant of flint corn with small kernels of great hardness. When heated, the moisture in the kernels expands, causing the kernels to pop open.

(d) Flour corn contains a preponderance of soft or less densely packed starch, and it readily grounded into meal (corn flour). It was grown extensively in the Andean regions of South America. The yellow flour made from the whole grain used to make tortillas, flat breads and polenta.

(e) Sweet corn was the type of maize commonly grown for human consumption as a vegetable. The sugar produced by the sweet corn plant was not converted to starch during growth, as it was in other types. The seeds were characteristically wrinkled when the plant gradually mature.

(f) Pod corn was seldom used as food but was often grown as a decorative plant; each kernel was enclosed in its own set of diminutive husks. Another decorative maize, commonly called Indian corn, consists of multicoloured varieties of flour and flint types

The essentiality of growing corn is for consumption and industrial products. About 20 percent of the annual corn crop is converted into food and chemical, 80 percent used for other purposes in the early 1960s (Steven, 1992). Three main commercial processes are used to convert raw corn into food and industrial products: (a) wet milling, (b) dry milling and (c) alkali processing. To understand the maize characteristics it has been examined the composition and structure of the corn kernel as follows. The corn kernel structures consist of four main parts: germ, pericarp, tip cap and endosperm (Figure 1and 2).

a) The germ is the only living part. It contains the essential genetic information, enzymes, vitamins and mineral for the kernel to sprout into a new corn plant. Corn oil, comprising about 25 percent of the germ, it is the most valuable part of the corn kernel because of its relatively high level of linolenic fatty acid (a desired polyunsaturated fat) and its bland taste.

b) The pericarp is the outer covering that protects the kernel from deterioration by resisting penetration of water and water vapour. In addition, it protects from undesirable microorganisms and insects.

c) The tip cap is the only area of the kernel not covered by the pericarp. It was attachment point of the kernel to the corn cob and is the major path of entry into kernel. During field drying, a black hilar layer forms in the tip cap region to partially block this pathway and thus protect the kernel.

d) The endosperm, approximately 82 percent of the kernel's dry weight, is the source of energy and protein (in the form of starch) for the germination seed. The thick celled that are highly proteinaceous aleurone layer on the outside of the endosperm acts as a semipermeable membrane to restrict the flow of gases and liquid into the endosperm. There are two types of endosperm: soft and hard, in hard endosperm, starch granules are tightly packed together, each held firmly in a protein matrix.

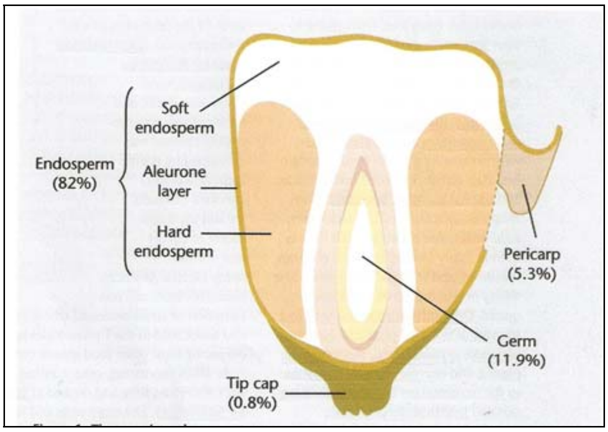


Figure 1 The kernel structure of corn.

Source: Steven (1992)

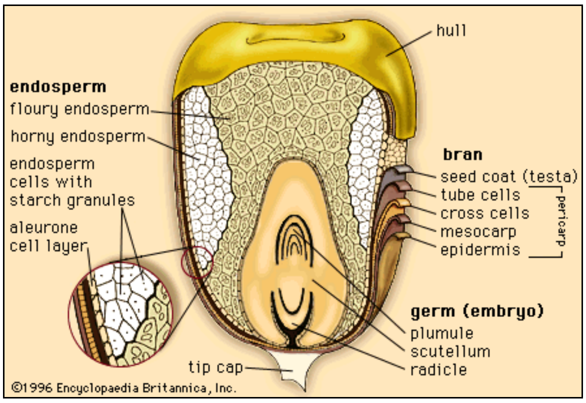


Figure 2 Elaborate structure of corn kernel.

Source: Steven (1992)

2. Studies on similar to corn roasting machine

Starting from 1864, roasting equipment/roasters manufactured on an industrial scale for the first time in the world. Von Gimborn (1868) invented over the design and construction on an industrial basis from which the Emmerich spherical roaster for capacities from 2.5 to 120 kg and became legendary. The spherical roaster was called Emmerich high-speed roaster that was patented in 1884. In addition, revolutionized coffee roasting technology was another roaster which was fully automatic roasting plants in the first half of the twentieth century. These also give an insight into modern roasting systems with hourly capacities up to 5000 kg and more per line, which are delivered to large-scale roasting plants in Germany and abroad.

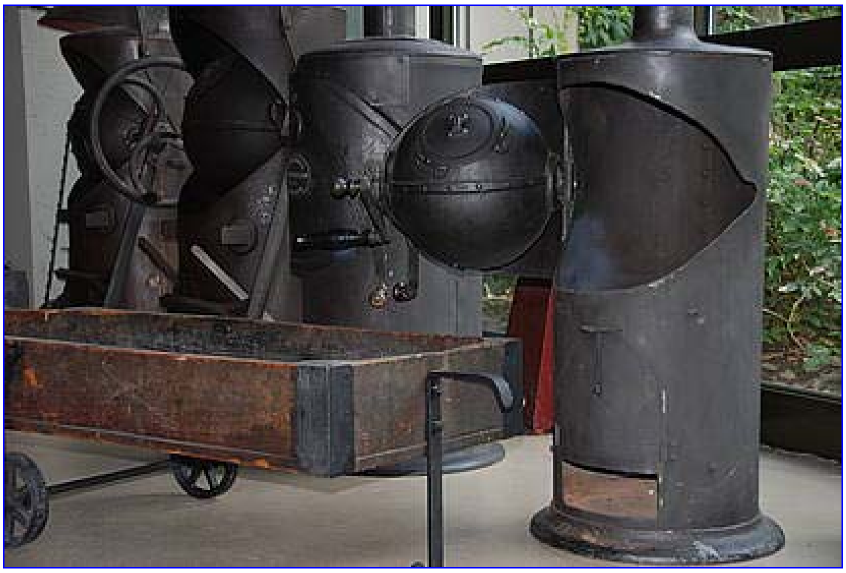


Figure 3 Emmerich spherical roaster for coffee roasting technology (charcoal as a source of heat)

Source: Gimborn (1868)

Roasting process involves the application of dry heat to legume seeds using a hot pan or dryer at a temperature of 150ºC to 200ºC for short time, depending on the legume or the recipe to be made. Roasting produces a better product as far as protein quality is concerned than one produced by common wet cooking under pressure. A several food crops which need roasting before to consumption such as coffee, peanut and other legumes. Coffee roasting revealed that all coffee starts as green (unroasted) beans, which are the seeds of the coffee fruit. Taking those seeds from the plant to the coffee pot involves roasting them for several minutes between 205ºC to 260ºC. During the first few minutes of roasting, green beans begin to turn yellow and develop a vaguely grassy or grainy smell as their water content causes them to steam from within the coffee. As the internal temperature of the beans rises, the coffee gives off a fragrant smoke and begins to make a crackling noise as the sugar caramelize and the essential oils released. The beans puff up to almost double their size the roast becomes darker until a second more volatile phase of cracking begins. At this point, the beans are done, or can be roasted further for a "dark roast" variety.

Perren (2005) pointed out that besides structure resistance forces, driving forces are required in order to achieve a volume expansion. During roasting, a considerable quantity of moisture and dry mass is evolved. The quantity of carbon dioxide and moisture evolved during High-Temperature-Short-Time (260ºC, 170 s) and Low-Temperature-Long-Time (228ºC, 720 s) roasting process was determined using Near-Infrared-Absorption technique (NIR). In both processes, a maximal moisture evaporation rate caused by the evaporation of initially present moisture was observed before the roasting process was stopped. Under HTST conditions, carbon dioxide evolution rate increased exponentially at temperatures above 180 - 200°C, whereas under LTLT conditions, carbon dioxide evolution rate was rather constant above 180 - 200°C until the end of the roasting process. Finally, the weight ratio of carbon dioxide and moisture in the total roast loss were calculated and a mass balance for the roasting process was developed.

Bressani (1993a) reported that pressure cooking black beans for 10 to 30 min at 121ºC improved the utilization of black bean, as compared to raw beans. Bressani (1993b) also reported that the in vitro digestibility of navy beans was improved by mild heat treatment. Excessive heating reduced the nutritive value of beans due to the destruction or in activation of certain essential amino acids.

3. Moisture Content

Moisture content is perhaps the most critical factor in the harvesting, drying, storing, roasting and marketing of cereal crops. According to Thompson and Mutters (2001) marketing, storage as well as process operation like roasting are the distinct aspects of grain handling in which moisture plays an important roles. In market, the average moisture content of the grain of the bulk being bought and sold is important. For example, a cargo of 25,000 tons with 14% moisture represents 3,500 tons of water. If 13.5% moisture is in the cargo then the moisture content has reduced to 3,375 tons of water. Both stakeholders have to determined the expensiveness due to contain of water in the grain. For storage, if it contains moisture in the grain then it is desirable, one has to determine of what extent and how fast storage fungi will develop and damage the grain. Freshly matured harvested shelled corn had moisture content in the range of 20 to 30%, which is relatively high compare to other cereals (Salunkhe *et al.*, 1985). However, drying or dehydration is also the process of removal of moisture until the moisture content of the product is in equilibrium with surrounding air. The high and low moisture content in the corn is one of the main effects while roasting. The dried cereal crops usually have in the range of 12 to 14% moisture on the wet basis. The moisture content of grains depend on several factors such as early harvesting, late harvesting, hybrids, weather condition (warm, rain, cool, wet) and maturity. Instead of harvesting grain in September, it was harvested in late November, then revealed that almost 4% of moisture content was reduced (Marton *et al.*, 2001). Generally, it is an important aspect to maintain a uniform moisture and temperature for better quality of products and preserve safely at longer duration.

Brooker *et al.* (1992) described that the two general methods used to determine the moisture content of cereal crops such as direct methods and indirect methods. Direct methods are called air oven, water oven and distillation system. The indirect methods of moisture content is determined by measuring of grain or cereal crops such as mechanical, electrical or thermal property, which are related to moisture content and usually expressed on wet basis.

Determination of moisture content of cereal crops can be estimated by two methods: - 1) wet basis and 2) dry basis. In the wet basis, moisture content in the corn after roasting can be defined as weight of water remove from corn by the weight of corn before roasting. Determination of moisture content on the dry basis is also the weight of water remove by the weight of corn after roasting.

It is expressed in the percentage as:

a) $$MC_{wb} = \frac{W_w - W_d}{W_w} \text{ x } 100\ (\%) \qquad \text{---(1)}$$

b) $$MC_{db} = \frac{W_w - W_d}{W_d} \text{ x } 100\ (\%) \qquad \text{--- (2)}$$

where MC_{wb} = moisture content (%), wet basis.

MC_{db} = moisture content (%), dry basis.

W_w = weight of corn before roasting (g)

W_d = weight of corn after roasting (g)

It has an inter-relationship such as from wet basis to dry basis or vice versa and usually expressed by:

c) $$MC_{wb} = \frac{MC_{db}}{100 + MC_{db}} \text{ x } 100\ (\%) \qquad \text{--- (3)}$$

d) $$MC_{db} = \frac{MC_{wb}}{100 - MC_{wb}} \text{ x } 100\ (\%) \qquad \text{--- (4)}$$

The moisture content expressed on the dry basis is always larger than the wet basis. Researcher estimate of water removal on dry basis especially for the drying postharvest operation and determines most of moisture content on food products.

Other convenient method to determine the moisture content is the conversion chart. The moisture content is able to convert from one basis to the other. Such as moisture content conversion scale will be able to convert the moisture content of dry basis to wet basis or vice versa. To determine the amount of water remove from product is estimated base on formula of wet basis and dry basis methods that are mentioned above.

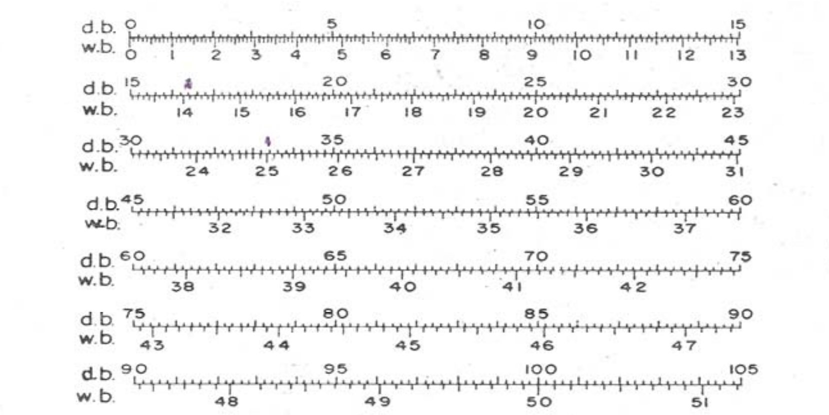


Figure 4 Moisture content representation on dry basis and wet basis.

Source: Hall (1980)

To evaluate the moisture content on either wet basis or dry basis using a conversion chart, the formulae are mentioned below. Freshly harvested corn usually content the moisture in the range of 20 to 30% and has to remove the moisture until its amount is equivalent to 14 - 12% by drying or any methods.

To determine the initial and final amount of water in product on wet basis:

a) $MC_{initial} \text{ x } Wtp_{initial} = Wt_w$ Before drying --- (5)

b) $Wt\ p_{ww} \text{ x } \dfrac{100}{100 - MC_{final}} = Wt_p$ After drying --- (6)

c) Amount of water remove = $Wtp_{initial} - Wt_p$ --- (7)

where $MC_{initial}$ = initial moisture content on the product (%), wet basis

MC_{finial} = final moisture content on the product after drying

$Wtp_{initial}$ = weight of product (g) before drying

Wt_w = weight of water in the product (g) before drying.

Wtp_{ww} = weight of product without water (g) before drying

Wt_p = weight of product (g) after drying

Using moisture content conversion chart and determination of water removed on dry basis is as follow:

$$\text{d) } Wtp_{ww} \times \frac{MCdb_{initial} - MC\ db_{final}}{100} = \text{weight of water removed} \quad \text{--- (8)}$$

4. Heat Transfer

Transfer of heat can be determined by the property of matter and temperature. It is governed by the second law of thermodynamic, which dictates that for a free flow of heat is possibly only from a body of higher temperature to a lower temperature (Gupta, 2003). The principles of heat transfer are based on the energy sources and the heat energy transportation to the system (movement of molecules within fluids). Fluids are consists of liquids, gases and rheids. The three mechanisms modes of heat transfer are conduction, convection and radiation. The heat energy transfers between a solid and a fluid when there is a temperature difference between the fluid and the solid. This is known as "convection heat transfer". Generally, convection heat transfer cannot be ignored when there is a significant fluid motion around the solid. However, convection is one of the major modes of heat transfer and mass transfer. In fluids, both convective heat and mass transfer take place through diffusion. A common use of the term convection leaves out the words “heat” but nevertheless refers to heat convection: that is the case in which heat is the entity of interest being advected (carried) and diffused (dispersed). In one of the two major types of heat convection, the heat may be carried passively by fluid motion, which would occur without heating process (a heat transfer process termed loosely as “force convection”). In the other major type of heat convection, heating itself may cause the fluid motion (via expansion and buoyancy force), at the same time cause heat to transport by this motion of the fluid (a process known loosely as natural convection, or “free convection”).

According to Frank *et al.*, (1990) the temperature of the solid due to an external field such as fluid buoyancy can induce a fluid motion. This is known as "natural convection or free convection" and it is a strong function of the temperature difference between the solid and the fluid. Blowing air over the solid by using external devices such as fan and pump can also generate a fluid motion, which is known as "forced convection".

Henderson *et al.*, (1970) revealed that fluid mechanics plays a major role in determining convection heat transfer. For each kind of convection heat transfer, the fluid flow can be either laminar or turbulent. Laminar flow generally occurs in relatively low velocities in a smooth laminar boundary layer over smooth small objects, while turbulent flow forms when the boundary layer is shedding or breaking due to higher velocities or rough geometries. The principal resistance to heat transfer is found in a relatively stagnant laminar layer and an adjacent turbulent zone of fluid at the solid-fluid interface. Heat must pass through the laminar layer by conduction in the fluid. The heat rate is proportional to the difference in temperature between the surface and the main bulk of fluid and to the surface area times the proportional constant h_c. This particular h_c is called the unit surface thermal conductance for convection (popularly known as heat transfer coefficient). It is determined by the properties of the fluid, the nature of the surface, the manner of the fluid flow and velocity of the fluid flow past the surface. It can be regarded as the conductance k/x_f of a layer of the fluid of fictitious thickness x_f through which heat can pass only by conduction. It can be expressed as follows.

Conduction mode of heat transfer:

$$q = - kA\,(dt/dx) \qquad \text{--- (9)}$$

where q = heat transfer rate (watt or J/sec)

k = Thermal conductivity (W/m * K)

A = cross-sectional area of flow path (m^2)

t = temperature (°C)

x = distance through conducting medium (m)

Convection mode of heat transfer:

$$q = h_c A (t_s - t_f) \quad \text{--- (10)}$$

where q = heat transfer rate (watt or J/sec)

h_c = convective heat transfer coefficient (W/m^2*K)

A= surface area (m^2)

t_s = surface temperature (°C)

t_f = main bulk fluid temperature (°C)

5. Roasting of other crops similar to corn

The main crops or grains that need roasting in the worldwide are coffee, peanut and other legumes. The mechanism of coffee roasting revealed that all coffee starts as freshly harvested as green (unroasted) beans. Prior to consumption, it has to roast for several minutes with the temperature between 205 to 260°C but the time and temperature has to differ according to variety of grains. This could be operated in conventional method or modern technology. In general, the roasting is achieved with different stages such as begin to turn yellow, develop an aroma or grainy smell and remove the water or oil from the grain. As the internal temperature of the grain rises, the grain gives off a fragrant smoke and begins to make a crackling noise as the sugars caramelize and the essential oils are released. Again, after a few seconds, the grain become darker and volatile phase of cracking begins. Then some grains puff up almost double their size. Finally, it become a dark roast and can process for further operation or consumption. The advantages of roasting for several crops were as follows:

5.1 Roasted barley

It is easier to grind as the roasting rupture the kernel. According to one of the commercial miller stated, “Grinding roasted barley is 25% faster than raw barley.” This saves time and grinding costs. For better quality, usually roasting protects the enzymes as no need to add enzymes to the processing food. It helps to increase digestibility as the roasting process breaks down the cell structure within the grain, making the nutrients readily available to the animal. McNivin (1994) reported that the digestion raise the net energy lactation value of 0.79 for raw barley to 0.82 for roasted barley as a result, the milk production increased 6.6lb with roasted barley. It becomes more palatable and sweet aroma if molasses has added. Roasting helps to increase bypass protein and bypass starch such as raw barley is 58.07 but roasting enhances it to 72.83; making more protein available in the intestinal tract of the dairy cow.

5.2 Roasted corn

Roasting corn increases the speed of starch availability. The starch becomes more soluble and more available resulting in a higher energy value. Starch availability from raw corn is 22% compared to 49% in roasted corn. Roasting corn has raise the energy level 10% and making room for more forage in the diet. It also reduces the amount of the corn required for consumption compared to raw/fresh corn. Roasting corn through an open flame dries away moisture and burn off the mold spores from each kernel of corn. It provides a feasible mechanism for reducing the mycotoxin concentration at least 40 – 80%. Because of this puffing effect, the dairy and cattle feeder can experience lower vet bills, better breeding, less abortions and less physical stress on the animal for more production of milk and meat. During hot, humid weather, feed mills can experience more than double the shelf life in roasted flaked corn, raw corn and other forms of processing.

The roasted corn is important in diary and cattle feeding in order to meet the demand of energy. It supports better breeding, improve butterfat as well as protein and maintain body weight during peak production, resulting in a higher and longer peak level.

5.3 Roasted soybean

The trypsin inhibitors in raw soyabeans prevent normal digestion of protein in the gut of poultry and swine. The amino acids, methionene and cystine are less available to poultry and swine as well as it retains a bitter taste, which inhibits normal feed consumption. Research trials show that swine fed roasted beans gain 9% faster on 9% less feed. Roasted beans also helps reduce dust levels in the facility. Microbes in the cows' stomachs break down raw beans quickly, but roasted soyabeans have delayed the microbial action, allowing the "undegraded" protein to pass into the cows intestines where it can pass directly into the cow's bloodstream. That 'bypass' effect of protein can rise to an optimum of 6.5% and will provide extra milk in the bulk tank. Whole soyabeans contain about 18% oil. Feeding raw soyabeans, the oil is not digestible therefore, the energy is not available, but when soyabeans are roasted, the oil becomes an available energy source and is 2.25 times as much energy as a carbohydrate without increasing the starch content. Roasted beans even guards against oxidative rancidity.

5.4 Roasted wheat

Roasting denatures the flour within the wheat preventing dough balling in the rumen causing the animal to lose appetite. Instead, the flour becomes crunchy and continues to move through the digestive system. Rather than feeding 20% wheat, one can feed 40 to 45 % in the diet. Roasted wheat has a higher bypass starch releasing a lower amount in the rumen and a greater amount in the intestinal tract. In the other hand, wheat can be salvaged by roasting it, which will destroy powdery mildew, eliminate mold and eradicate fungus.

6. Test Procedure

RNAM (1983) prescribed that the preparation of general guideline of tests and procedures for farm machinery. It is also pointed out that how much important for experimenters to get acquainted with the construction and operational features of a machine before tests are started in order to asses the real performance and evaluate its suitability in view of limitations of time, fields, materials and manpower. In general, the persons who conduct an experiment on the industrial exported or imported machinery should look through all available information and required detailed information such as manufacturing drawings, etc., if necessary. The experimenter should make all required adjustments as per manufacture's recommendation and conduct some preliminary field trials so that the machine can be kept at its best working condition during the test. Other factors are how to perform an accuracy of data. These are mainly based on the objective and to select appropriate measuring instruments before tests. Usually excellent accuracy needs expensive instruments and skillful technicians. On the other hand, measurement with low accuracy invites the question of effectiveness of measured value. Measuring instrument should be calibrated at periodic intervals and after long rest. It is also recommended that each research and testing institution have appropriate equipment for calibration. The measured values and those induced from them in a test report should be properly rounded off. In case of multiplication and division between or among measured values, computed result must be rounded off such that it contains no more significant digits than are contained in the least precise value. In test related to agricultural machinery, there are several variables, which effect the test data. In order to control the influences of these variations, replications are necessary. Statistical analysis should be carried out for the evaluation of the data obtained through replications. Prior to test the statistical design should be prepared.

In RNAM, it is consisting of outline of test code and procedure as follows:

a) Definition of terms;
b) Specification of the machine;

c) Laboratory test;

d) Test conditions;

e) Performance test;

f) Practical field test;

g) Criteria for evaluation;

h) Test report format.

These codes and procedures for farm machinery prescribed that the items to be measured and examined for evaluation of performance, working capacity and adaptability of machines or implements to a local environment conditions, in comparison with indigenous technology.

Roasting is the postharvest operation for reducing the moisture content of grain. It is generally laborious and drudgery to roast on the open-hearth fire. The important terms have to consider as roasting capacity, roasting efficiency, power efficiency, optimum temperature, percentage of weight loss after roasting and power consumption per unit. The conditions of crop like varieties, sizes and percentage of moisture content on the kernel are the significant aspect. The other conditions could be a machine performance, systematic operation and skill operator or experience. The additional factors are feeding method, unloading, adjustment and revolution per minute of agitation. Measurement of performance is one of the primary importance and must be carried out under controlled conditions to obtain reliable data.

According to RNAM test code, the performance evaluations of the power thresher were output capacity, threshing recovery, threshing efficiency, cleaning efficiency and other terms. Threshing is defined as grain received at all outlets with respect to total grain input expressed as percent by weight. Similarly, cleaning efficiency also defined as the whole grain with respect to grain mixture at main grain outlet expressed in percent by weight. The items to be measured and observed are:

1) Weight of whole grain, damaged grain, unthreshed grain and foreign matter in the samples from all outlets;

2) Feed rate;

3) Power required or fuel consumption at no load and load;

4) Revolution speed of main shaft;

5) Labour requirement;

6) Ease of handling and operating

From the analysis of samples and sampling time, feed rate, threshing recovery, threshing efficiency, cleaning efficiency of main outlet, rate of damaged grain, loss of grain are calculated as follows:

Total grain input:

$$A = B + C + D \qquad \text{--- (11)}$$

where A = Total grain input per unit time by weight

B = Weight of threshed grain (whole and damaged grain) per unit time collected at the main grain outlet.

C = Weight of threshed grain (whole and damaged grain) per time collected at all outlets except for main grain outlet.

D = Weight of unthreshed grain from all outlets per unit time.

Percentage of damaged grain at all outlets:

$$\text{Damage percentage} = \frac{E}{A} \text{ x } 100\ (\%) \qquad \text{--- (12)}$$

E = Quantity of damaged grain collected at all outlets per unit time

Percentage of blown grain:

$$\text{Blown percentage} = \frac{F}{A} \text{ x } 100\ (\%) \qquad \text{--- (13)}$$

F = Quantity of whole grain collected at chaffed straw outlet per unit time.

Percentage of grain loss:

$$\text{Loss percentage} = \frac{G}{A} \text{ x } 100\ (\%) \qquad \text{--- (14)}$$

G = Weight of whole grain, damaged grain and unthreshed grain per unit time at chaff outlet and straw outlet (hold-on) or chaffed-straw outlet (throw-in) and scattered grain per unit time.

Percentage of unthreshed grain:

$$\text{Unthreshed percentage} = \frac{H}{A} \text{ x } 100(\%) \qquad \text{--- (15)}$$

H = Weight of unthreshed grain per unit time at all outlets

$$\text{Threshing efficiency} = (100 - \text{Unthreshed percentage})\ (\%) \qquad \text{--- (16)}$$

$$\text{Cleaning efficiency} = \frac{I}{J} \text{ x } 100\ (\%) \qquad \text{--- (17)}$$

I = weight of whole grain per unit time at the main grain outlet.
J = weight of whole material per unit time at the main outlet.

$$\text{Threshing recovery} = \frac{B}{A} \text{ x } 100\ (\%) \qquad \text{--- (18)}$$

Test procedure of the power thresher was an example and modified to be used for the developed corn roaster.

MATERIALS AND METHODS

Materials

The materials, parts, equipments and manufacturing machines used in the research project are as follows:

1. The specific materials required for a development of roasting machine.

1.1 Stainless steel sheet – Grade 304 (1.2 mm thickness)
1.2 Stainless steel plate – Grade 304 (50 mm width x 4 mm thickness)
1.3 Stainless steel rod – Grade 316 (dia. 12.54 mm and dia. 5 mm)
1.4 Stainless steel bolts and nuts – Grade 316 (M8 x 1.25 mm)
1.5 Mild steel sheet (0.8 mm thickness)
1.6 Mild steel tube (25 x 25 mm)
1.7 Mild steel angle (25 x 25 x 3 mm)
1.8 Electrode
1.9 Fine grade sand paper

2. Readily available parts purchased from commercial market and assembled in the roasting machine were:

2.1 Electric heaters (2000 and 750 watts)
2.2 Electric motor (186 watts)
2.3 Impeller
2.4 Platinum coated safe guard
2.5 Electric wire/cable (2 x 2.5 sq.mm, 300/500V, 70°C)
2.6 Indicator for heat and power
2.7 Ball bearings with saddle housing
2.8 Nuts and bolts
2.9 V pulley and V belt (dia. 2 inches, B54)
2.10 Insulation (fiber glass wool, heat resistance of 1000°C)

3. Equipments required were listed below

3.1 Thermostat (range: 50 - 300°C)

3.2 Overload relay (18A, single phase)

3.3 Motor reducer (ratio 1:60)

3.4 Electric motor (248 watts, 220 V, 50 Hz)

4. Measuring instruments used for machine performance test in laboratory

4.1 Thermocouple (FLUKE, 52 K/J, USA)

4.2 Digital type stop watch (CITIZEN/CASIO, HS20, Japan)

4.3 Anemometer or air flow meter (EXTECH, 407123, USA)

4.4 Balance (Digital type, 0.1 g resolution) (SATORIUS, S600, Japan)

4.5 Digital temperature gun meter (RAYTEK, ST20, USA)

4.6 Voltmeter's digital type (METRIX, ITT, MX44, France)

4.7 Ammeter's digital type (KYORITSU, KEWSNAP 200, Japan)

4.8 Moisture meter's digital type (Grain Moisture Tester, PM400, Japan)

4.9 Data logger (MUA/USEEP, A046915, USA)

4.9 Buckets

5. Tools used for development of roasting machine

5.1 Vernier caliper

5.2 Measuring tape (POLO 3.5 m, power return)

5.3 Try square

5.4 Ball peen hammer

5.5 Die plate

5.6 Spanner set

5.7 Socket wrench set

5.8 Combination plier

5.9 Slide wrench

5.10 C-clamp

6. Machines used for development of machine

6.1 Arc welding machine

6.2 MIG welding machine

6.3 Gas welding machine

6.4 Automatic lathe machine

6.5 Gallatin machine or shearing machine

6.6 Universal drilling machine

6.7 Hand drill machine

6.8 Hand grinding machine

6.9 Portable cutting machine

7. Raw materials

7.1 Flint corn (Experiment specimen and preliminary test)

7.2 Sweet corn (preliminary test)

7.3 Lubricant

7.4 Paints

Methods

1. Design and fabrication of the roasting machine

The basic principle of design should be decided before the overall configuration of corn roasting machine. A numerous literature search were made to investigate similar to corn roasting machine and for a small scale production or individual farmers. After taking into accounts the energy source as electrically heating element, it was decided that electric heater of single phase, 220 – 240V with around 3000 watts as heat energy source should be developed. The detail developments of machine were considered on basic needs of configuration and for household levels. Considerations of criteria established while designing individual components of the corn roasting machine. A description of individual parts used in the development of the machine is included.

1.1 Basic design configuration

The basic design which was considered for the development of a corn roaster in the process of pounding into cornflake. The basic principle of configuration and heat dissipation are shown in the Figure 5 and Figure 6.

1.2 Design criteria

After the basic design principle was finalized, it was necessary to decide certain design criteria before the actual fabrication of the machine could have been started. For this purpose, following criteria were selected

1) Almost entire machine parts should be detachabled for easy repair, maintenance and interchangeable.

2) The machine parts should be constructed from stainless steel since it is a food processing machine.

3) Use of local materials wherever possible
4) Should not displace labour
5) Should have low operating cost
6) Acceptable to the farmers
7) Effectively useful for individual farmer upon the production of small scale
8) The machine should be low in capital cost.
9) Flexible design to use under varying circumstances

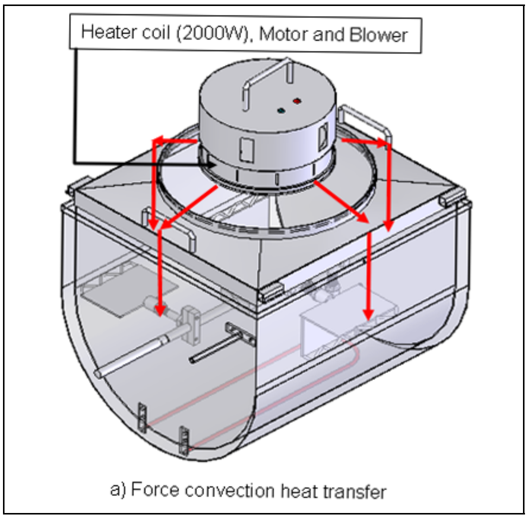


Figure 5 The basic principle of heat dissipation (Forced convection heat dissipation).

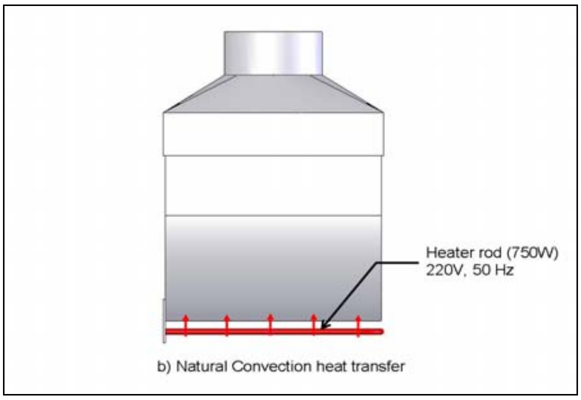


Figure 6 The basic principle of heat dissipation to the roasting chamber (Natural convection heat dissipation).

1.3 Design parameters

The factors that might influence the machine capacity and power efficiency identified were mentioned below:

a) Temperature factor
b) Loaded weight factor
c) Corn variety
d) Duration of corn soaking
e) Moisture content of soaked corn

The moisture content of soaked corn parameters also play important role in the roasting operation. Usually, the soaked corn moisture content are not controllable. Measurement of roasted corn parameters and use of an appropriate experimentation are necessary.

1.4 Detailed parts of roasting machine development

Based on the preliminary design criteria and the different functions that are expected to be performed by the machine, following different components of the machine were prominent parts.

a) Roasting chamber with lid
b) Agitation fins
c) Heating elements
d) Over load relay
e) Thermostat to regulate the temperature
f) Power drive

1.4 a) Roasting chamber with lid

The roasting chamber was an important component in the machine. It was fabricated from 1.2 mm thickness stainless steel with dimensions of radius 190 mm and other dimensions of height and width were 380 x 410mm. It was mounted on shaft (SS). The thickness of chamber was decided on consideration of temperature attained on it. It has to resist the roasting temperature in order to avoid from crumble and melting down. Since it was made from stainless steel, it is suitable to handle the food products with hygienic. The applications of mild steel are able to resist the heat at the process temperature range of 400 - 500°C and stainless steel can resist heat or melting temperature in the range of 800 - 1000°C (Ullman, 1944).

1.4 b) Agitation fins

Four numbers of V shaped (SS rod dia. 5mm) at the tip of detachable fins were designed to stir the corn in the chamber during roasting. It was also made out from the stainless steel and attached to shaft (SS) by welding. It served to agitate the corn thoroughly in the roasting chamber. The clearance gap between tip of fins and interior chamber surface was limited to 1 to 3 mm in order to avoid from the struck or damage the corn. The particular figure (agitation mechanism) was displayed in the Figure 8.

Figure 7 Fabrication of chamber and lid.

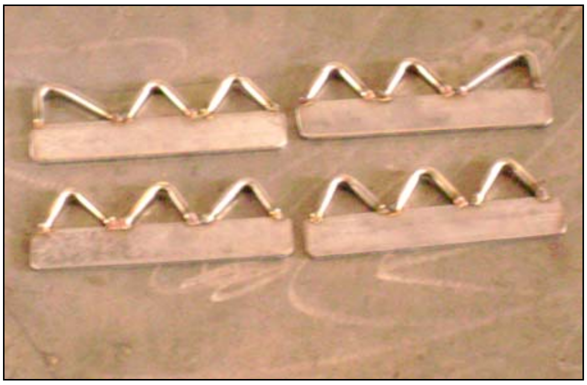


Figure 8 Fabrication of agitation fins.

1.4 c) Heating element

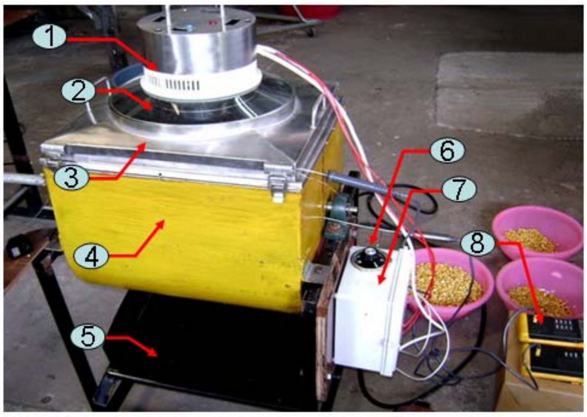
The source of heat was from the electric heater coil of 2750 watts, 11.50 amperes, 220 volts (single-phase supply). The shape and size of heaters was spiral coil type and heater rod (U shape) with diameter of 6 mm for both cases. The dimension of the U shape heater was length of 380 mm (U shape length only) and the distance between U shape rods was 73 mm. These electric heaters system assembled on top of the chamber and 1-3 mm below exterior surface of the corn roasting chamber. The force convection heat from top of the chamber was drawn with the aid of centrifugal fan. In this research, transfer of heat was convection where the transportation of heated fluid from electric heater to roasting chamber to roast the product. The transportation of fluid was adopted the forced convection as well as free or buoyancy convection system.

1.4 d) Overload relay

Overload relay (MSO – N10/N11) is suitable only if a circuit is capable of delivery not more than 5,000 rms symmetrical amperes. It was mainly consist of adjustable magnetic switch, compensator, trip off relay, 600 volts maximum and fuses of rated 30 amps (maximum). Set the temperature dial (thermostat) in the position as per the experimental design and attached the heat sensor in the roasting chamber. The switch was trip off when it reaches to full loaded temperature and reset it automatically by overload relay. It was even control the electric motor. The control circuit wiring was an important to consider because if the wiring is too long the circuit may not open even when the excitation released due to a floating capacity. At that particular time, never manually operate the product in the live state.

1.4 e) Thermostat to regulate the temperature

To vary the temperature in an experimental was one of the main factors in the evaluation of machine performance. Thermostat consist of a magnetic strip trip off, 8A interlocking, plug connector and back light (indicator). The temperature regulator was in the range of 50 - 300°C (set point) and pertinent accessories as sensor was necessary combination component. It usually cut off power supply when the temperature sensor set point reach to full load on the particular position. The power supply was completely trip off when it reaches to set point. Consequently, the heater coil does not functioned at all until it reaches to lower limit of temperature. The main devices to control the system were the sensor and magnetic switch.



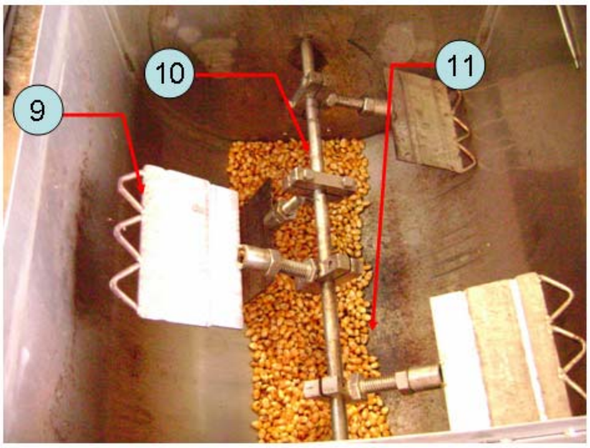


Figure 9 Schematic fabrication and tested figure of typical roasting machine.

1 = Heating elements; 2 = Safe tempered glass; 3 = Stainless steel (SS) lid; 4 = Mild steel cover for Insulation, 5 = Roasted corn receiving tray; 6 = Thermostat (range 50 - 300°C); 7 = Overload relay (18A, 220V, 50Hz); 8 = Thermocouple and its probe placed with thermostat sensor and mid of chamber; 9 = Agitation fins (4 pcs.); 10 = Shaft (SS); 11 = Roasting chamber (SS).

The overall dimensions of the developed corn roaster were 510 x 435 x 1020 mm (L x W x H). Figure 9 showed the all configurations of developed corn roaster and conducted the experiment under laboratory condition.

1.4 f) Power drive

For the power drive, only one motor was used during experimentation. The specification of the electric motor was of 186 watts, single phase and 50 Hz. The motor was attached with centrifugal fan to blow off the heated fluid in the roasting chamber. Other power drive, single phase electric power was supplied to overload relay and bypassed to thermostat, which were further connected with two sources of heater. One of the heaters was mounted on top of the chamber and its heat transfer principle was forced convection system with the aid of blower. Other heat source was adopted on the bottom of roasting chamber and mode of heat transfer was free or buoyancy convection. The block diagram of power supply in the developed prototype is shown in Figure 10.

Table 1 Components consist in the power drive.

S.L (No.)	Item	Quantity
1.	Overload relay	1 set
2.	Thermostat	1 set
3.	Electric motor	2 no.
4.	Motor transformer	1 no.
5.	Centrifugal fan impeller	1 no.
6.	Coil and U shape heater unit	1 each
7.	Manual agitator handle	1 only
8.	Electric motor’s shaft and bush	1 each

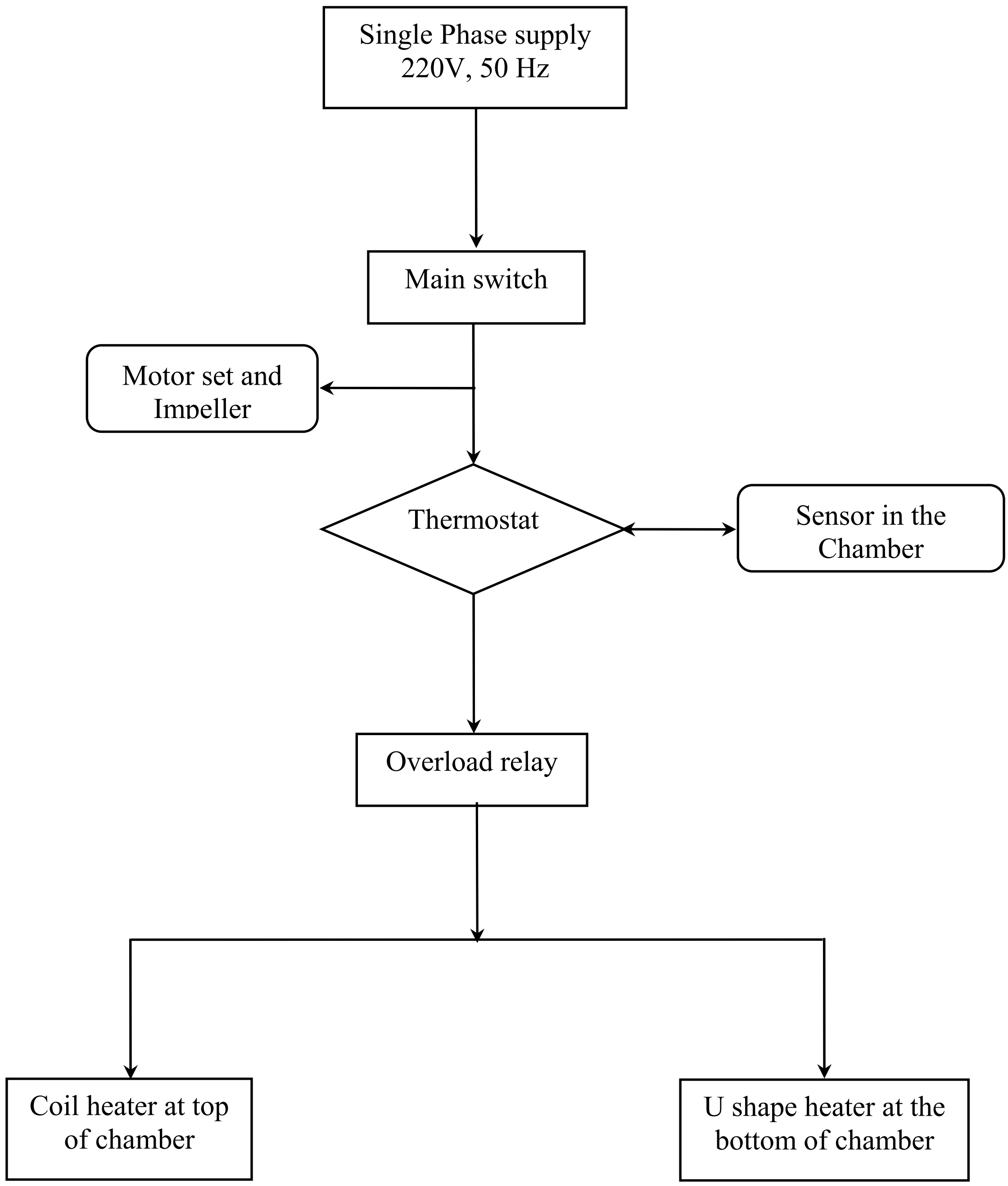


Figure 10 The block diagram of power supply in the developed prototype.

2. Tips and Procedures of roasting corn

Roasting corn is the best to learn with lots of practice. The following tips and procedures listed are just designed guidelines how to process the food roasting operation.

2.1 Safety

a) Safety is the key to success with any roasting machine.
Since this machine was equipped with electric heater on production of high temperature around 260°C and complex electrical circuit. Thereby, trained and skilled operator is recommended.

b) Do not touch the unit without safety appliances while it is in the operation or any other operations.

c) Do not put the product in the roasting chamber or remove the product from it without proper safety precaution.

d) Do not attempt to operate the overload relay while power is ON. Failure to observe this could lead to electric shocks and burns.

2.2 Electric heater unit

a) The electric power of the heater was equipped with 2750 watts in the roasting machine. It was operated by single phase of 220 volts and average currents became 11.50 amperes, which meant it required bigger size of cable compare to 5 amperes and needed to take precaution of electric hazard.

b) The roasting chamber was heated from the top by forced heat convection and bottom by natural heat convection. In this consequence, the vent to escape the heat fluid was provided.

c) The top and bottom exterior surface areas heated around temperature of 40 - 60°C, always be cautious when moving around this area.

2.3 Roasting chamber

a) The roasting chamber was designed in the shape of concave to roast at the maximum of 2 kg corn.

b) The base chamber has to heat up similar to a manual roaster was heated by firewood; thereby the efficiency of heat transfer is increased.

2.4 Agitation unit

The agitation fins were rotated manually at 24 rpm (approximately) in order to mix the roasting kernels thoroughly and to prevent from over burn on the corn bran. The motor drive was not necessary to operate the agitation fins but it was recommended to assemble for completely mechanization system. The power supply from a single-phase motor via a speed reducer was rotated the single main shaft for agitation of the corn kernels. All the components in this drive are easily disconnected since they are meant for detachable. Especially the handle and agitation fins were designed to be removed; these aid for flexible operation and allow the choice in operation with the handle or assembled the motor and speed reducer.

2.5 General basic ideas of procedures and construction of corn roasting

1. Fore most steps, decided the size and capacity of input supply cable (7/22 wire specification) based on the current required by the machine for heaters and motor. Switch ON the main supply.

2. Put ON the overload relay switch. Overload relay (18A) specification also depend on current required for machine (11.50A of the developed roasting machine) and connected via input supply cable to thermostat.

3. Regulate the thermostat dial and set it as per the experimental design of different temperature levels. The attached thermostat in the system is to break off the circuit by overload relay with the aid of sensors placed in the roasting chamber. It was

also connected with heaters parallel to an electric motor on top of the chamber and all components were functions automatically.

4. Attached motor for driving the heated fluid consist of motor winding, impeller and other parts (threaded shaft, bush, washer and other assembled accessories); remember that the threads on main shaft are as such, the counter clockwise to tighten and clockwise to loosen.

5. Roasting chamber dimension was decided based on the subsequence cornflake making machine capacity (500 – 1000 g per operation) which is existing in the Bhutan. The corn was soaked for 12 h. The temperature and weight factors were set up and weighed according to the experimental design.

6. Put the soaked corn in the roasting chamber and needed to roast thoroughly by four agitation fins manually. Agitation fins were mounted on the shaft serially with 90 degree one after another.

7. For the first instance, rotate the shaft handle once or twice manually but after six minutes required to rotate (24 rpm) continuously in order to roast uniformly.

8. Be cautious at this point since operating temperature was increasing gradually (100 - 260°C). Thus, wear the gloves to prevent from accident hazard.

9. After about 10 to 15 minutes, under visual examination with audible clue check whether corn were turned into dark brown through a safe tempered glass. Then if it became dark brown, grab it one from the chamber carefully (avoid accident) and bite it to examine whether turned into gumming state and cook or not.

10. If it turned into gumming state then put off the switch of overload relay and main ac supply switch. After that, top cover of the roasting chamber was removed by detaching the latch and loosens the two wing nuts from the rigid frame to unload the roasted corn on the receiving tray.

11. Subsequently, pound the roasted corn either in the manually pounding or in pounding machine. To produce a typical cornflake, are needed to pound as soon as unloaded from the roasting machine.

12. Finally, produced cornflake was winnowed, segregated and packaged for a human consumption as light breakfast / snack.

3. Laboratory test

There were two sets of laboratory experiments. The first phase experimental was the investigation of the performances of prototype developed roasting machine i.e. machine capacity, throughput capacity, power efficiency, percentage of weight lost after roasted and physical properties of roasted corn. The other further intensive experimental was the determination of roasting efficiency of the developed prototype.

3.1 Machine performance evaluation

The determination of machine performance was based on the following mentioned below.

1. Capacity of the machine:

$$= \frac{\text{Weight of corn before roast}}{\text{time taken to roast}} \text{ (kg/h)} \qquad \text{--- (19)}$$

2. Throughput machine capacity:

$$= \frac{\text{Weight of corn after roast}}{\text{time taken to roast}} \text{ (kg/h)} \qquad \text{--- (20)}$$

3. Percentage of weight loss after roasting:

$$= \frac{\text{Initial weight of corn - Roasted weight of corn}}{\text{Initial weight of corn}} \text{ x } 100 \text{ (\%)} \qquad \text{--- (21)}$$

4. Power consumption:

$$= \frac{\text{P.F. x Power input x Operating time}}{\text{Weight of roasted corn per operation}} \text{(kW - h/kg)} \qquad \text{--- (22)}$$

5. Power efficiency in term of percentage unit

$$= \frac{\text{wt. x } \Delta T \text{ x Cp}}{\text{P. F. x V x I x t}} \text{ x 100 (\%)} \qquad \text{--- (23)}$$

where wt. = Weight of roasted corn (kg) V = Average voltage (220.40V)

ΔT= Change in roasted corn temperature (°C) I = Average ampere (11.50A)

t = Operating time per sample (h) P.F. = Power Factor (0.8) (Commonly in Thailand)

Cp = Specific heat of corn correspond to percentage of weight lost after roasted (Moisture content on wet basis) from the grain's thermal properties of standards table (ASAE, 1994)

6. Roasting efficiency per unit time

$$= \frac{\text{No. of kernels after operation per unit time}}{\text{No. of kernels before operation per unit time}} \text{ x 100 (\%)} \qquad \text{--- (24)}$$

3.2 Experimental design

The experimental design was 3 x 4 x 4 factorial experiment of completely randomized design (CRD). The experiment was conducted with combination of temperature and weight factors. The temperatures were varied from 150 to 300°C by thermostat, which was known as levels or treatments. These treatments designated as 150, 200, 250 and 300°C (T_1, T_2, T_3 and T_4) with four replications. The other treatments were the weight of corn and designated as 500, 1000 and 2000 g (W_1, W_2

and W_3). It was weighed in the digital balance (Satorius S 600, 0.1 g resolution) during the experiments. It was a randomized treatment combination in lieu to obtain reliable data from the experiment. The main aimed was to get the best temperature corresponding to suitable weight from the developed prototype.

Table 2 Experimental design with all treatment combination (CRD)

Weight of corn (g)	Temperature (°C)	Machine Performance (Replication)			
W_1	T_1	W_1T_1	W_1T_1	W_1T_1	W_1T_1
	T_2	W_1T_2	W_1T_2	W_1T_2	W_1T_2
	T_3	W_1T_3	W_1T_3	W_1T_3	W_1T_3
	T_4	W_1T_4	W_1T_4	W_1T_4	W_1T_4
W_2	T_1	W_2T_1	W_2T_1	W_2T_1	W_2T_1
	T_2	W_2T_2	W_2T_2	W_2T_2	W_2T_2
	T_3	W_2T_3	W_2T_3	W_2T_3	W_2T_3
	T_4	W_2T_4	W_2T_4	W_2T_4	W_2T_4
W_3	T_1	W_3T_1	W_3T_1	W_3T_1	W_3T_1
	T_2	W_3T_2	W_3T_2	W_3T_2	W_3T_2
	T_3	W_3T_3	W_3T_3	W_3T_3	W_3T_3
	T_4	W_3T_4	W_3T_4	W_3T_4	W_3T_4

From two pertinent variables, the machine performances obtained in term of machine capacity and optimum value of machine capacity. The significantly different at $P \leq 0.05$ of means value ± STDEV was also obtained by analysis of variance (ANOVA). The analyses of data were a quantitive analysis by using two–ways of univariate analysis of variance (SPSS) and compared by the other programme (STATGRAPHICS Plus, version 3.0) .

3.2.1. First phase experimental design (FPED).

The Table 3 showed that it was a factorial experiment of completely randomized design. It was also known as temperature and weight combination experiment.

Table 3 Assignment of random numbers (R.No) for determination of performance evaluation in the FPED

Temperature (°C)	Replication (No.)	Loaded weight with random number assignment		
		500 g	1000 g	2000 g
150	1	01	06	18
	2	11	04	15
	3	16	14	05
	4	31	17	43
200	1	28	24	45
	2	19	23	03
	3	33	29	26
	4	12	30	20
250	1	02	38	08
	2	39	21	41
	3	22	25	40
	4	10	42	35
300	1	47	44	36
	2	32	13	09
	3	34	48	27
	4	46	37	07

Random numbers were assigned in the experimental design from the statistical table (source: William H. Beyer, Handbook of tables for probability and statistics, 2^{nd} ed., 1968). Raw data were the time taken (minute) to roast the corn at desirable level. The other raw parameters were measured such as hot air velocity, soaked corn moisture content, voltage, product and chamber temperature. Significantly different of mean value, standard deviation and variance were analyzed by using the statistical application.

3.2.2 Further intensive experimental design (FIED)

From first phase experimental, the optimum machine capacity and power efficiency of a developed prototype were evaluated. Further evaluation of the research was prominent to analysis of statistically significant different at significance level of $P \leq 0.05$. In this case, it was assured from FPED based on the performance evaluation and visual examination were found out the most appropriate temperature factors of the machine as 200, 250 and 300°C corresponding to weight factors of 1000 g. Thus, weight of 1000 g was selected for the FIED and varied the mean time into three levels and mean time were selected corresponding from 500 and 1000 g weight levels of grand mean time with all temperature. The third level of time was selected from over all average time of the all temperature and loaded weight treatments. The time and temperature levels were shown in the Table 4 mentioned below. The raw data of time is given in the Appendix Table A1.

Table 4 Assignment of random number for determination of performance evaluation of machine in FIED.

Temperature (°C)	Replication (No.)	Time with random number assignment		
		11 min.	13 min.	15 min.
200	1	07	26	05
	2	06	16	19
	3	18	09	04
250	1	01	23	17
	2	15	10	21
	3	11	08	20
300	1	24	02	14
	2	25	22	27
	3	12	03	13

Statistical tables were also used to assign the random numbers in this experimental design. It was also factorial experiments of 3 x 3 x 3 with completely randomized design for statistical analysis. Weight of roasted corn, roasted corn product temperature and chamber temperature were the raw data of experiment and measured by the balance, thermocouple and temperature gun. For the further evaluation of machine performance, weighed the 100 g from all combinations treatments of a FIED. Then segregated and counts the number of kernels, which were partially roasted (yellow in appearance) and roasted (dark brown in appearance). The roasting efficiency was calculated by applying the Equation 24 to detect the potentiality of the roaster.

4. Specimen preparation

The postharvest process of corn are consist of several processing like harvesting, shelling maize from plant, drying, storing, shelling grain from cob and converted into food product. One of the products, for instance, cornflake was obtained after series of processes such as roasting, pounding and segregating / winnowing.

4.1 A postharvest series process of corn

Growing in the field

↓

Maturity in the field

↓

Harvesting and Inspection

↓

Storage with cobs for short duration

↓

Shelling

↓ Kernel

Sun-drying or dryer

↓

Storage in silo or process into product

↓

Export to market in grain or converted into product.

Figure 11 Flow diagram of corn production.

4.2 Sample preparation

In order to produce a cornflake, the specimens were prepared from two types of corn stages namely freshly harvested and completely dried corns. Fresh corns were usually available right after harvesting where as dried corns have to involve a certain process as follows

4.2.1 Cleaning

Maize grains were sorted and winnowed to remove grain stalk, sticks and remaining cob parts. The grains were further subjected to visual screening to remove foreign particles such as stones. This was followed by washing with water to remove dust, soil particles and any over floats. Damaged, diseased, or discoloured grains as well as immature and sprouted grains were discarded (Ingbian and Adegoke, 2006).

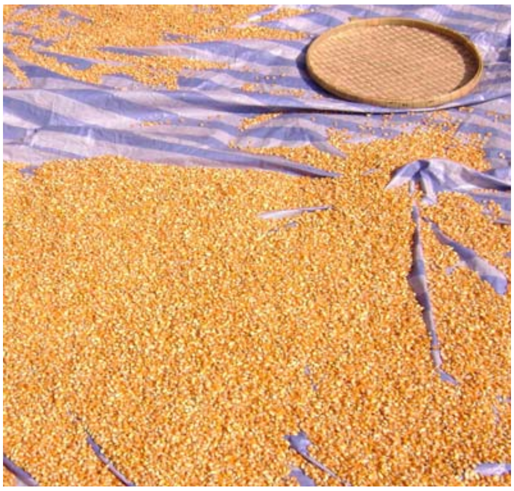


Figure 12 Cleaned, winnowed and sorted the flint corn in the experiment.

Figure 13 Washed and soaked of the specimen.

4.2.2 Soaking

In Bhutan, farmers usually soak corn in the warm water of 30 - 40°C for about one day or overnight. Farmers also expressed that corn soaking in more than 40°C of water does not preferred because while pounding cornflake are converted into tiny pieces or flour. The cleaned maize grains were steeped in water for 12 h, the method described by (Okoli and Adeyemi, 1989). The grains were soaked in water for 12 h. The soaked water was changed after 6 h. The soaked grains were drained and dried for 6 h. The washed and soaked picture is shown in Figure 13.

4.2.3 Roasting

Prepared maize grains roasted in the developed roasting machine in the temperature range of 150 - 300°C until it was roasted. Preliminary test were carried out for several times to conform the reliable data. In the beginning, agitation was not that much necessary but after 6 minutes need to stir continuously in order to prevent from over roast (burn on the bran). Agitation was done manually with 24 ± 3 rpm. Based on the several manual trial of main shaft revolution in a minute have been carried out, it was ensured for selection of the appropriate motor (1Ø, 220V, 50Hz) and speed reducer in which the reducing gears were integral with drive motors.

4.2.4 Pounding

In this research, roasted corns were instantaneously pounded either in manually pounding mechanism or in roller machine and this machine was typically meant for making sunflower powder. At present moment in Bhutan, cornflake making machine with capacity of 60 kg/h are widely adopted and manual pounding mechanism is also still prevail in rural areas.

Figure 14 Conventional manual pounding and cornflake making machine in Bhutan.

Typical corn roasting operation

Corn grains / kernel

↓

Cleaning / washing

↓

Soaking

↓

Drying in open air

↓

Roasting

↓

Instant pounding

↓

Corn Flake Product

Figure 15 Flow diagram of cornflake production.

RESULTS AND DISCUSSION

The machine performance investigations of the developed roasting machine were carried out in this section. The results of these investigations and the discussion thereof are also given in this chapter. The results and discussion presented under these following sections were:

1. Investigation of the optimum machine capacity and throughput capacity of the developed corn roaster

2. Determination of the maximum percentage of weight lost after roasted
3. Identification of the optimum power efficiency and minimum electric power consumption.

4. Determination of the roasting efficiency from the further intensive experiment (FIE)

5. Statistical analysis of the machine performance
6. Discussions on the development of the small scale corn roasting machine
7. Discussions on preliminary data and performance of the corn roaster

1.1 Investigation of the optimum machine capacity

The designed corn roaster and fabricated in this research was supposed to roast the soaked corn with the aid of electric heater (2750 watts) of single phase supply (220.40V, 11.50A, 50Hz). It was therefore, important to evaluate the machine performance in order to detect the optimum prototype capacity. The machine capacity should have to meet the capacity of the subsequence pounding machine for cornflake of 500 to 1000 g per time operation. The detail methods of conducted experiment and evaluations were given in the previous section. Its capacity was evaluated based on the preliminary formula such that initial loaded weight of corn by the time taken in operation. Raw data were the time taken to roast the soaked corn in a desired stage, roasted weights, chamber temperature, sensor temperature and product temperature given in the Appendix A.

Fifty-six kilograms of flint corns (specimen) were roasted in the developed prototype to investigate the machine capacity and other performances of the machine. The machine performance investigation was based on the experimental designed. The time required to roast the sample was observed. With the aid of Equation 19, the machine capacity was calculated. The results given in the Table 5 shows the calculated data obtained for the investigation of machine capacity with different temperatures and weight treatments combination of four replications subsequently.

Table 5 Result of the machine capacity from the developed corn roaster.

Temperature	Replication	Machine capacity (kg/h)		
		Loaded Weight		
° C	No.	500 g	1000 g	2000 g
176	1	2.26	3.73	4.25
	2	2.09	3.58	4.42
	3	2.43	3.47	4.96
	4	2.59	3.30	5.11
	Mean	2.33	3.51	4.66
210	1	2.90	3.67	6.04
	2	2.63	4.28	5.42
	3	2.76	4.40	5.52
	4	2.64	4.56	5.87
	Mean	2.73	4.20	5.70
250	1	2.45	5.44	5.39
	2	3.30	4.88	5.84
	3	3.16	4.50	5.93
	4	2.85	5.38	5.63
	Mean	2.90	5.02	5.69
260	1	3.61	6.19	6.03
	2	3.62	5.76	5.63
	3	3.65	6.07	6.13
	4	3.57	6.35	5.92
	Mean	3.61	6.08	5.92
Over all mean		2.82	4.51	5.44

At 176°C combination with 500, 1000 and 2000 g respectively, the average machine capacities found to be 2.33, 3.51 and 4.66 kg/h. For the temperature 210°C with three experimental weights, the average machine capacities were 2.73, 4.20 and 5.70 kg/h respectively. Subsequently, for 250°C and 260°C with three weights of 500, 1000 and 2000 g respectively, the average machine capacities were found to be 2.90, 5.02, 5.69 kg/h and 3.61, 6.08, 5.92 kg/h respectively. Result from the investigations were determined the machine performance of 6.08 kg/h as the average optimum machine capacity with temperature and weight combination of 260°C corresponding to 1000 g. The average of mean time taken to roast 500 and 1000 g loaded weight were 11 and 13 minutes respectively with all temperature treatments. 15 minutes was the entire average duration to roast the corn with three levels of weight factors corresponding to four levels of temperature factors. These data were cited in the Appendix Table A1. Thus, these investigated times were used in the further intensive experiment (aforementioned in Materials and Methods) for the further characterization of the machine performance.

Therefore, the best combination of the performance was 1000 g of weight to roast at 260°C and consequently this machine performance is suitable to use in cornflake making machine existing in Bhutan.

1.2 Investigation of the throughput capacity from the developed corn roaster

The throughput capacity was evaluated based on Equation 20 stated in the materials and method. The data used for calculation were the roasted weight and time taken to roast.

The results of throughput capacity were also similar to the machine capacity. The optimum mean throughput capacity was also at 260°C with the 1000 g of weight loaded (Table 6). It was the effective capacity of machine during operation. Throughput capacity was always lower than the machine capacity due to water removed (weight decrease) from the product during roasting.

Table 6 Result of the throughput capacity from the developed corn roaster.

Temperature ° C	Replication No.	Throughput capacity (kg/h) Loaded weight 500 g	1000 g	2000 g
176	1	1.68	2.97	3.61
	2	1.57	2.91	3.66
	3	1.88	2.82	4.10
	4	2.10	2.64	4.32
	Mean	1.79	2.83	3.90
210	1	2.11	2.80	4.84
	2	1.94	3.40	4.40
	3	2.19	3.65	4.44
	4	1.94	3.57	4.65
	Mean	2.04	3.33	4.57
250	1	1.80	4.38	4.30
	2	2.56	3.72	4.54
	3	2.27	3.44	4.68
	4	2.15	4.11	4.26
	Mean	2.17	3.89	4.44
260	1	2.79	5.48	5.06
	2	2.89	4.76	4.52
	3	3.07	5.15	5.10
	4	2.76	5.03	4.75
	Mean	2.88	4.93	4.85
Over all Mean		2.16	3.59	4.41

2. Determination of the maximum percentage of weight lost after roasted

It was an important aspect to determine the water removes in the roasting to evaluate the machine performance. The duration of roasting was depends on the percentage of weight lost during operation. Initially, average moisture content of the soaked corn measured by the grain moisture tester was 34.2%. Then the soaked corn was roasted and average moisture content was 16.8%, which measured from random experimental sample.

Table 7 Result of the percentage of weight lost after roasted.

Temperature ° C	Replication No.	Percentage of weight lost after roasted (%) Loaded weight 500 g	1000 g	2000 g
176	1	25.66	20.45	15.08
	2	24.77	18.79	17.07
	3	22.49	18.88	17.49
	4	18.85	19.96	15.45
	Mean	22.94	19.52	16.27
210	1	27.17	23.59	19.84
	2	26.31	20.42	18.82
	3	20.52	17.03	19.56
	4	26.55	21.79	20.83
	Mean	25.14	20.70	19.76
250	1	26.45	19.56	20.22
	2	22.31	23.68	22.33
	3	28.21	23.49	21.07
	4	24.45	23.59	24.32
	Mean	25.35	22.58	21.99
260	1	22.82	11.46	16.14
	2	20.19	17.33	19.69
	3	15.71	15.21	16.78
	4	22.75	20.71	19.78
	Mean	20.37	19.01	18.10

The raw data of roasted weight was in the Appendix Table A2. The sample calculation for percentage of weight lost after roasted was given in the page no. 81. The percentages of weight lost after roasted were depicted in the Table 7; result to determine the performance of the machine in connection of water removed in a roasting operation. The average values of these parameters were displayed in the form of graph for a clear determination of the maximum percentage of weight lost after its operations. The above mentioned performance was evaluated by the use of Equation 21 and showed that the initial weight of corn before roast minus weight of roasted corn after operation by the initial weight of corn before roast. The Figure 16 showed the averaged value of all treatments combination of temperatures and weights to find out the maximum percentage of water removed.

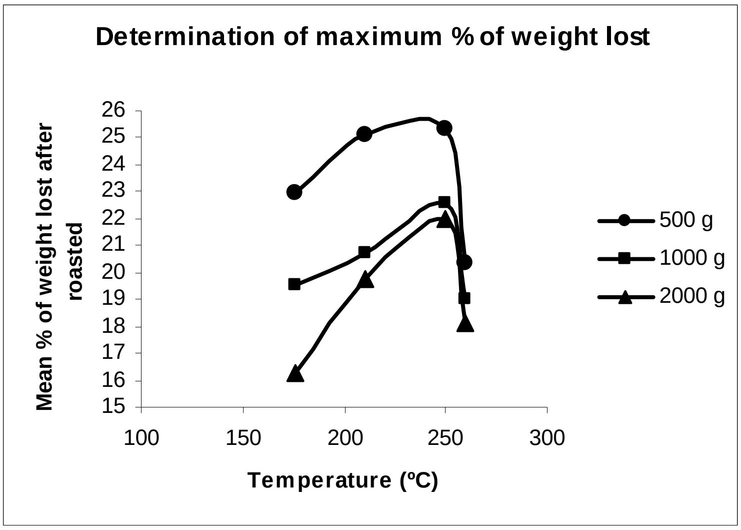


Figure 16 Percentage of weight lost after roasted.

The result from the Figure 16 showed that the percentage of weight lost was increased when the temperature increases for all loaded weights until 250°C. However, with further increase of temperature, its percentage was drop steeply for all loaded weights. It was roasted corn with high temperature and short time. The quality of roasted corn might be further improved due to water remove from corn was a small amount and constant gumming state. The highest percentage of weight lost was found in the 500 g treatment at 250°C. However, this further deduced that corn was dried as well as roasted. Consequently, the quantity of the roasted corn became smaller, thus increases the percentage of weight lost.

3.1 Identification of the optimum power efficiency

The data were evaluated to perform the optimum power efficiency. The Table 8 shows that the evaluated data and significances of the machine performance found out in term of power efficiency. The power efficiency was described in the units of percentage (%) in order to define the term of economical value and to be visualized the optimum efficiency prominently. The electric power consumption of unit used as a commercial power unit was also identified from this section.

Table 8 Result in the % unit of machine power efficiency.

Temperature	Replication	Power Efficiency (%)		
		Loaded Weight		
° C	No.	500 g	1000 g	2000 g
176	1	17.63	31.16	37.87
	2	16.49	30.47	38.41
	3	20.09	30.12	43.77
	4	21.92	27.53	44.98
	Mean	18.87	29.76	41.02
210	1	21.96	29.13	50.36
	2	19.96	35.04	45.28
	3	22.92	38.10	46.41
	4	20.61	37.99	49.46
	Mean	21.33	34.76	47.79
250	1	18.69	45.40	44.60
	2	27.33	39.73	48.40
	3	23.87	36.26	49.30
	4	23.14	44.16	45.73
	Mean	22.91	41.12	46.95
260	1	30.00	58.89	54.37
	2	30.08	49.52	47.00
	3	32.84	55.04	54.51
	4	29.36	53.58	50.54
	Mean	30.56	52.33	51.50
Over all Mean		22.77	37.84	46.46

For the temperature of 176°C, the mean power efficiencies of 18.87% (Loaded weight of 500 g) and 41.02% (loaded weight of 2000 g) were the minimum and maximum respectively (Table 8). Systematically, the minimum and maximum of the mean power efficiencies were followed at the temperature of 210°C and 250°C in the same trend of 176°C. However, at 260°C the over all mean maximum power efficiency was 52.33 % on the loaded weight factor of 1000 g and minimum power efficiency was 30.56 % (Loaded weight of 500 g). Nevertheless, the over all mean minimum power efficiency was at the temperature of 176°C corresponding to 500 g loaded weight.

3.2 Identification of the minimum electric power consumption

The data were evaluated to identify the minimum electric power consumption. The Table 9 shows that the evaluated data and significances of the machine performance found out in term of power consumption in kilogram.

Table 9 Result in the kW-h/kg unit of machine power consumption.

Temperature ° C	Replication No.	Power consumption (kW-h/kg) Loaded weight 500 g	1000 g	2000 g
176	1	1.21	0.68	0.32
	2	1.29	0.70	0.34
	3	1.08	0.72	0.35
	4	0.96	0.77	0.36
	Mean	1.13	0.72	0.34
210	1	0.96	0.72	0.35
	2	1.05	0.60	0.29
	3	0.92	0.56	0.29
	4	1.05	0.57	0.28
	Mean	0.99	0.61	0.30
250	1	1.13	0.46	0.23
	2	0.79	0.54	0.27
	3	0.89	0.59	0.29
	4	0.94	0.49	0.25
	Mean	0.94	0.52	0.26
260	1	0.73	0.37	0.20
	2	0.70	0.43	0.22
	3	0.66	0.39	0.20
	4	0.73	0.40	0.20
	Mean	0.70	0.41	0.20
Over all Mean		0.94	0.56	0.28

The result showed from the Table 9 that the minimum electric power consumption was observed the mean value on the 2000 g of weight level at 260°C of temperature level while the maximum was on the 500 g at 176°C. This speculated that less time (less power consumption) was required to roast the corn for first combination than later one. These perhaps was suggested a choice for the best treatment combination for the uniquely developed roasting machine.

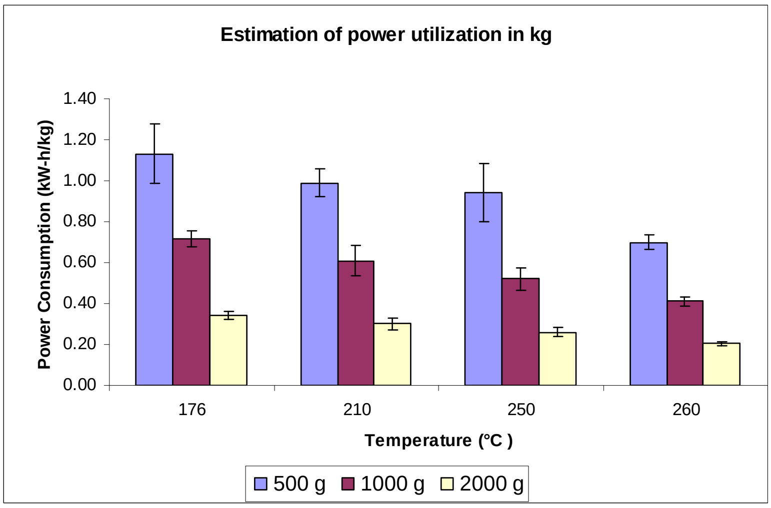


Figure 17 Power consumption in operating the machine.

The above Figure 17 show that the minimum power consumption was observed of the mean ± STDEV value on the 2000 g of weight level at 260°C of temperature level while the maximum was on the 500 g at 176°C. The estimation of power utilization in unit consumption of 0.4 unit/h from the highest mean machine capacity (time taken) was revealed to use in the commercial and evaluated from the maximum combination treatment.

4. Determination of the roasting efficiency from the further intensive experiment (FIE)

From FPE, the optimum machine capacity and the maximum power efficiency of the developed prototype was evaluated and determined the machine performance. Further evaluation of the research was prominent to analysis by statistical significant different at significance level $P \leq 0.05$, which was depicted in section 5. In this case, it was assured from FPE based on the performance evaluation and visual examination that the most appropriate temperature factors of the machine as 210, 250 and 260°C corresponding to weight factors of 1000 g. Thus, weight was selected as 1000 g for the further experiment and varied the mean time into three levels. The raw data of mean times were from 500 g and 1000 g weight levels and a third level of time was considered from all treatments combination. The roasting efficiency was the parameter found out from this section.

Table 10 Result of the roasting efficiency from the developed corn roaster.

Temp.	Rep.	Roasting efficiency (%)					
		Time level					
		11 min.		13 min.		15 min.	
°C	No.	Partial roasted	Complete roasted	Partial roasted	Complete roasted	Partial roasted	Complete roasted
210	1	37.73	62.27	35.76	64.24	27.64	72.36
	2	39.19	60.81	35.44	64.56	25.52	74.48
	3	36.34	63.66	36.56	63.44	30.41	69.59
	Mean	37.79	62.21	35.92	64.08	27.87	72.14
	STDEV	1.43	1.43	0.57	0.57	2.45	2.45
250	1	28.04	71.96	22.87	77.13	21.99	78.01
	2	28.45	71.55	24.85	75.15	20.79	79.21
	3	24.12	75.88	25.74	74.26	17.03	82.97
	Mean	26.87	73.13	24.50	75.50	19.94	80.06
	STDEV	2.39	2.39	1.47	1.47	2.59	2.59
260	1	27.93	72.07	20.99	79.01	16.67	83.33
	2	24.92	75.08	22.31	77.69	22.69	77.31
	3	22.22	77.78	19.68	80.32	20.38	79.62
	Mean	25.10	74.90	20.99	79.01	20.06	79.94
	STDEV	2.86	2.86	1.32	1.32	3.04	3.04

Note: Temp. = Chamber temperature at mid loci, Rep. No. = Number of replication.

The roasting efficiency of the machine was determined as per the Equation 24 given in the materials and methods. The ratios (roasting percentage) were displayed in the Table 10 in the form of partial and complete roasted. It was obvious that the roasting efficiency increases with an increase of time and temperature in roasting. The mean roasting efficiency of 80.06 % at the test conditions of 250°C in 15 minutes of completely roasted was the highest and then dropped gradually. The lowest was found to be 62.21% at 210°C corresponding to 11 minutes (lowest operating time). The partial roasting efficiency was the highest (37.79%) at 210°C and 11 minutes while the lowest (19.94 %) at 250°C in 15 minutes. It shows that the percentage of complete roasted increased as the operated time increased but it had the reverse relationship with partial roasted.

Partial roasted can be defined as after roasting operation, roasted corn kernels were seen that the corn roasted to some extend or not completely and thus, the roasted corn does not become dark in appearance on the bran. It is known as partial roasted. Complete roasted is also define as the appearance of corn become totally or utterly dark/cook to the greatest extend or degree.

5. Statistical analysis of the machine performance

In order to analyze the machine performance of the developed corn roasting machine, the data of the mean machine capacity was analyzed statistically. The summary of the statistically analyzed data were displayed in the Table 11. The details about the data of the statistical analysis were shown in Appendix Table A1.

Table 11 Effect of the temperature and the weight treatments on the mean machine capacity statistically.

Temperature (°C)	Mean machine capacity (kg/h)		
	Loaded weight		
	500 g	1000 g	2000 g
176	$2.33 \pm 0.18^{a,A}$	$3.51 \pm 0.10^{a,B}$	$4.66 \pm 0.27^{a,C}$
210	$2.73 \pm 0.06^{b,A}$	$4.20 \pm 0.14^{b,B}$	$5.70 \pm 0.17^{b,C}$
250	$2.90 \pm 0.18^{c,A}$	$5.02 \pm 0.32^{b,B}$	$5.69 \pm 0.12^{b,C}$
260	$3.61 \pm 0.03^{d,A}$	$6.08 \pm 0.21^{c,B}$	$5.92 \pm 0.18^{b,B}$

Mean ± STDEV values followed by the same small letters superscript in column and same capital letters superscript in row indicates no significant different at $P < 0.05$.

5.1 Effect on mean machine capacity of the prototype

The lowest and highest mean values of machine capacity from all treatments combination were 2.34 kg/h and 6.08 kg/h, respectively. The electric heater temperature and loaded weight factors significantly affected the machine capacity at $P < 0.05$ (Table 11). It was observed that the optimum machine capacity was on the loaded weight of 1000 g with corresponding temperature of 260°C.This might be the reason, roasted the corn at high temperature and short time. Although, almost of all mean data were significantly different at 95% level of significance. But the mean machine capacity for 2000 g in column wise were not significantly different with respect to temperature of 210, 250 and 260°C as the time taken at these temperature levels were almost equivalent. Similarly, the mean capacity at 260°C in row wise were insignificant different on the weight of 1000 g and 2000 g. It means that an increase in weight to roast the soaked corn caused no effect in the machine capacity. The mean machine capacities were also correlated with the temperature and loaded weight to obtain the relationship.

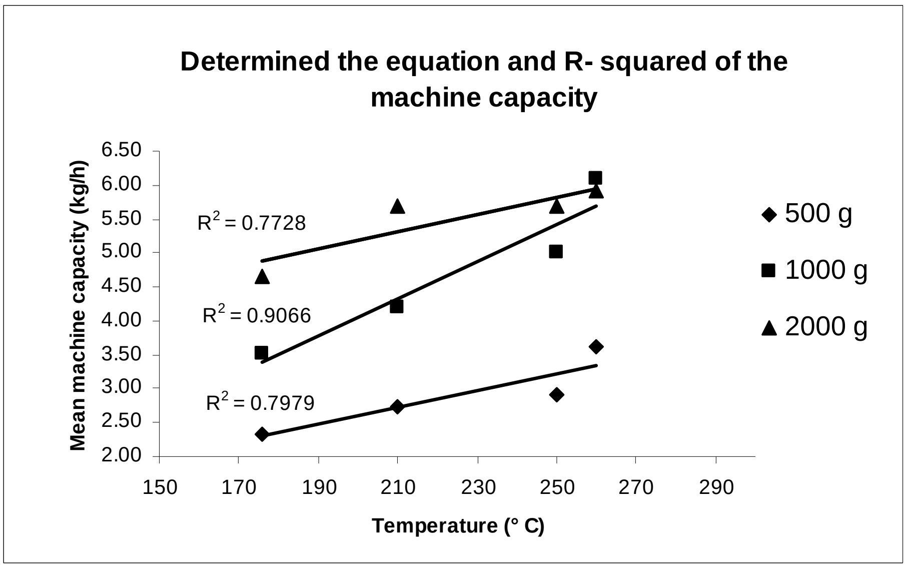


Figure 18 Mean machine capacity vs roasting chamber temperature relationship.

Figure 18 shows a graph of mean machine capacity versus roasting chamber temperature relationship of the developed prototype. It is obvious that the machine capacity of the prototype increased with an increase in the chamber temperature. From the graph, the following equations were fitted.

At 500 g loaded weight, it has the relationship equation:

$$Mc = 0.0129\,T + 2.6025 \qquad \text{---- (25)}$$

where Mc = Machine capacity (kg/h)
T = Temperature (°C)

At 1000 g loaded weight, it has the relationship equation:

$$Mc = 0.0273\,T - 1.4108 \qquad \text{--- (26)}$$

At 2000 g loaded weight, it has the relationship equation:

$$Mc = 0.0124\,T + 0.1071 \qquad \text{--- (27)}$$

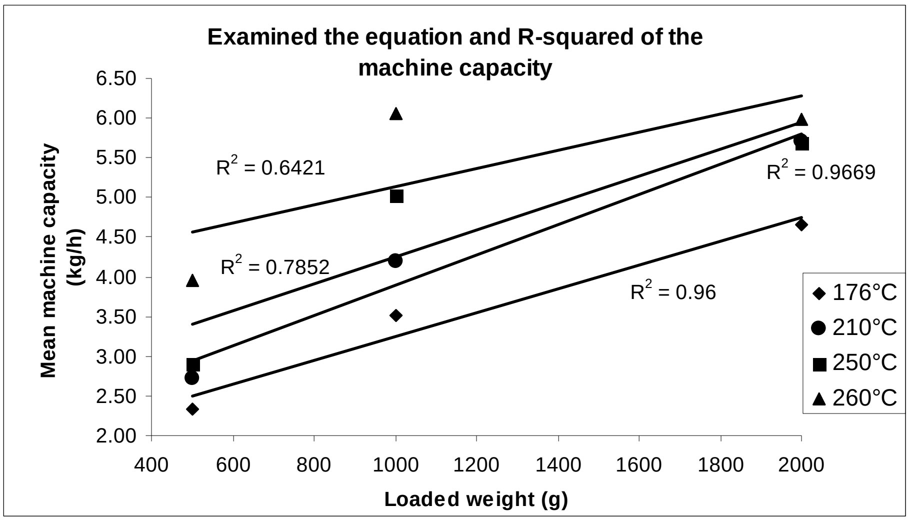


Figure 19 Mean machine capacity vs loaded weight relationship.

Figure 19 shows the graph of average of machine capacity versus loaded weight in the experiment. An increase the loaded weight increased the machine capacity of the developed prototype. The following equations were fitted to correlate the relationship between machine capacity vs loaded weight (kg).

At 176°C roasting temperature, it has the relationship equation with $R^2 = 0.96$

$$Mc = 0.0015\ wt. + 1.7563 \qquad \text{--- (28)}$$

At 210°C roasting temperature, it has the relationship equation with $R^2 = 0.96$

$$Mc = 0.0019\ wt. + 1.9748 \qquad \text{--- (29)}$$

At 250°C roasting temperature, it has the relationship equation with $R^2 = 0.78$

$$Mc = 0.0017\ wt. + 2.5663 \qquad \text{--- (30)}$$

At 260°C roasting temperature, it has the relationship equation with $R^2 = 0.64$

$$Mc = 0.0013\ wt. + 3.6952 \qquad \text{--- (31)}$$

where Mc = Machine capacity (kg/h)
wt. = Loaded weight (g)

5.2 Effect on mean power efficiency of the developed corn roasting machine

In the Table 12 showed that the average values of power efficiency affected by the weight and temperature treatments were significantly different at $P < 0.05$. The statistical analyses performed in column wise of small letters shows that the loaded weight of 500 g was 21.33% at 210°C of power efficiency or energy conversion from the electrical unit consumption into heat energy (generated the temperature) which was not significant at temperature of 176°C and 250°C respectively. Similarly, the mean value, 29.76 and 34.76% in the loaded weight of 1000 g and roasting chamber temperature of 176 and 210°C respectively were also not significant different of power efficiency. Nevertheless, higher temperature at 250 and 260°C were significantly different of mean power efficiency in same column (loaded weight, 1000 g). Although, the result showed that average power efficiency increases with the increase of the temperature. However, in the loaded weight level (2000 g) of power efficiency was 41.02% at 176°C showed the significant different with 47.79, 46.95 and 51.50% at the temperature of 210, 250 and 260°C respectively. In the same column with loaded weight of 2000 g shows that there were no significant differences as compare with the three chamber temperatures designated by 210, 250 and 260°C.

Table 12 Effect of the temperature and the weight treatments on the mean power efficiency statistically.

Temperature (°C)	Mean power efficiency (%) Loaded weight 500 g	1000 g	2000 g
176	$18.87 \pm 2.44^{a,A}$	$29.76 \pm 1.58^{a,B}$	$41.02 \pm 3.64^{a,C}$
210	$21.33 \pm 1.33^{ab,A}$	$34.76 \pm 4.20^{a,B}$	$47.79 \pm 2.42^{b,C}$
250	$22.91 \pm 3.55^{b,A}$	$41.12 \pm 4.19^{b,B}$	$46.95 \pm 2.21^{b,C}$
260	$30.56 \pm 1.55^{c,A}$	$52.33 \pm 3.87^{c,B}$	$51.50 \pm 3.58^{b,B}$

Mean ± STDEV values followed by the same small letters superscript in column and same capital letters superscript in row were not significant different at $P < 0.05$.

The statistical analyses performed in row wise designated in capital letters shown in the Table 12. In all treatment combination conditions, the mean power efficiencies were significantly different except in the treatment combinations at 260°C with corresponding to 1000 g and 2000 g. However, it shows that the temperature and weight parameters affected on the power efficiency at 95 % level of significance. The statistical analysis shows that the insignificant different of mean power efficiency were 52.33% and 51.50%. The maximum mean power efficiency (mean ± STDEV value) of 52.33% was observed for the 1000 g of the weight treatment at 260°C of temperature treatment levels while the lowest was 18.87% of mean power efficiency for 500 g weight levels at 176°C. This had been speculated that the less time required to roast the corn for first combination (1000 g at 260°C) than later one (500 g at 176°C). These perhaps suggested a choice for the best treatment combination for the uniquely developed roasting machine. Furthermore, the relationship between mean power efficiency and chamber temperature, loaded weight were shown in the Figure 20 and Figure 21.

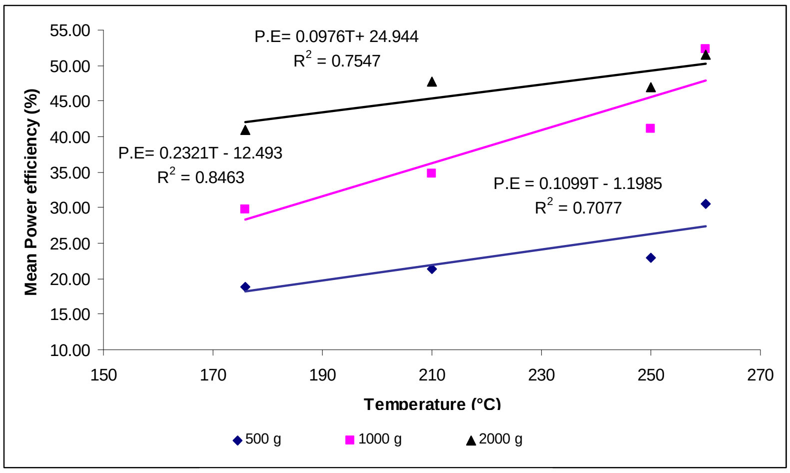


Figure 20 Mean power efficiency (%) vs roasting chamber temperature relationship.

Note: P.E. = power efficiency (%); T = Roasting chamber temperature

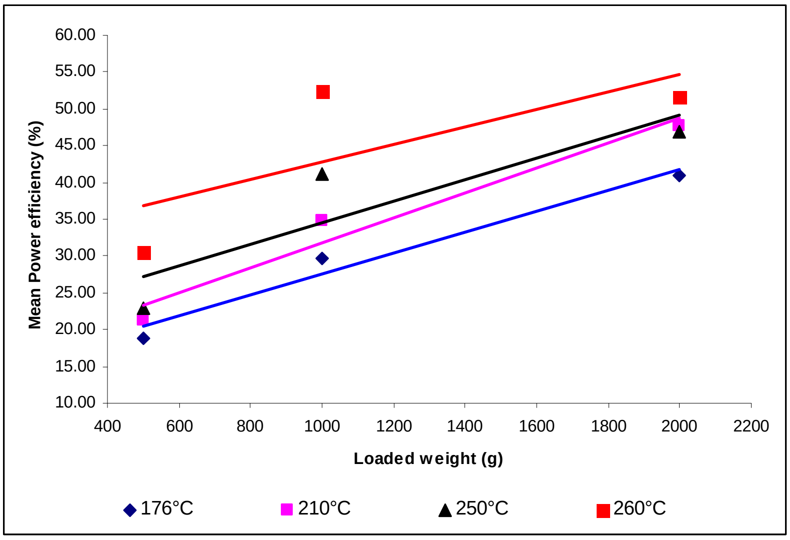


Figure 21 Mean power efficiency (%) versus loaded weight relationship.

It has found the linear equation such as:

P.E. = 0.0118 wt. + 30.977, R^2 = 0.6378 at 260°C --- (32)

P.E. = 0.0146 wt. + 19.994, R^2 = 0.7876 at 250°C --- (33)

P.E. = 0.017 wt. + 14.816, R^2 = 0.9610 at 210°C --- (34)

P.E. = 0.0143 wt. + 13.240, R^2 = 0.9678 at 176°C --- (35)

From the Figure 20 & 21, it was observed that as the roasting temperature and loaded weight increased the average power efficiency also increased. The equation fitted line also varied with the different temperature and loaded weight, which ranges R-squared from 0.6378 to 0.9678. The slope and interception also varied with respect to temperature and loaded weight. The best curve fitted found to be in lower temperature because observed data became almost constant and accurately.

5.3 Effect on mean roasting efficiency of machine by statistical analysis

In order to determine the roasting efficiency statistically of the data collected in the further intensive experiment (FIE) were tabulated below (Table 13 and Table 14). In the FIE, the recommended suitable temperatures and operated time factors were selected from the first phased experiment based on the optimum mean machine capacity and maximum mean power efficiency. The performance evaluation and visual examination with audible clue, the most appropriate temperature factors of the machine were 210, 250 and 260°C corresponding to weight factor of 1000 g and the other pertinent time factors were 11 minutes, 13 minutes and 15 minutes respectively. The partial and complete roasted corn analyses of the mean roasting efficiency were depicted in the separate Table 13 and Table 14.

Table 13 Effect of temperature and time levels on the partial corn roasted of mean roasting efficiency.

Temperature	Mean roasting efficiency (%)		
	11 min.	13 min.	15 min.
° C	Partial roasted	Partial roasted	Partial roasted
210	$37.79 \pm 1.43^{a,A}$	$35.92 \pm 0.57^{a,A}$	$27.87 \pm 2.45^{a,B}$
250	$26.87 \pm 2.39^{b,A}$	$24.50 \pm 1.47^{b,A}$	$19.94 \pm 2.59^{b,B}$
260	$25.10 \pm 2.86^{b,A}$	$20.99 \pm 1.32^{c,AB}$	$20.06 \pm 3.04^{b,B}$

Mean ± STDEV values followed by the same small letters superscript in column and same capital letters superscript in row indicates no significant different at $P < 0.05$.

Table 14 Effect of temperature and time levels on the complete roasted corn of mean roasting efficiency.

Temperature	Mean roasting efficiency (%)		
	11 min.	13 min.	15 min.
° C	Roasted (dark)	Roasted (dark)	Roasted (dark)
210	$62.21 \pm 1.43^{b,B}$	$64.08 \pm 0.57^{c,B}$	$72.14 \pm 2.45^{b,A}$
250	$73.13 \pm 2.39^{a,B}$	$75.50 \pm 1.47^{b,B}$	$80.06 \pm 2.59^{a,A}$
260	$74.90 \pm 2.86^{a,B}$	$79.01 \pm 1.32^{a,AB}$	$79.94 \pm 3.04^{a,A}$

Mean ± STDEV values followed by the same small letters superscript in column and same capital letters superscript in row indicates no significant different at $P < 0.05$.

The statistical analysis shows that mean roasting efficiencies were affected significantly different at $P < 0.05$ for both the tables in all treatments combination. It was obvious that the roasting efficiency increases with an increase of time in roasting. The completely roasted mean roasting efficiency of 80.06 % was the highest in 15 minutes but it does not show any significant different with temperature of 260°C (Table 14). The lowest mean partial roasting efficiency was found to be 19.94 ± 2.59 (%) at 250°C in 15 minutes however it does not show significant different at the temperature of 260°C (Table 13). It shows that the percentage of complete roasted become high as the operated duration increased but it had the reverse relationship with the partial roast (Figure 22).

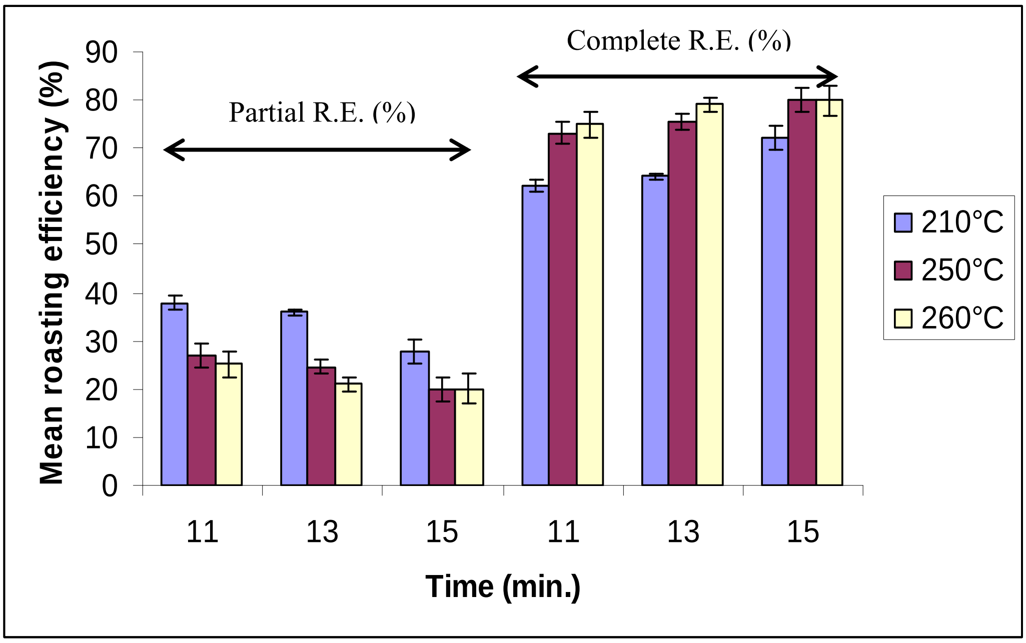


Figure 22 Determination of the partial and completely mean roasting efficiency.

R.E = Roasting efficiency.

6. Discussions on the development of the small scale corn roasting machine

The detailed development of pertinent parts and testing procedure of the corn roaster was aforementioned in the materials and method section. The preliminary results from the laboratory experiment as presented in this section, the agitation fins design, thickness of chamber, selection of corn variety and study on the distribution of heat in the roasting chamber were important factors, which deal with the machine performance. The detail part of corn roasting machine was also given in the materials and method section (Figure 9) and the details of quantity required of different components for power drive were shown in the Figure 9 and Table 1. The view of the fabricated of the prototype machine in the private workshop was shown in the Figure 23. The initial development of corn roaster model from mild steel material was depicted in the Figure 24. In the Figure 25, it was the power drive connection with thermostat, overload relay, motor and electric heater of the developed prototype. Figure 26 showed the complete set of the manual corn roaster and conducted the experiment on this machine.

Figure 23 The roaster chamber with lid being fabricated in the workshop.

Figure 24 Development of corn roaster model.

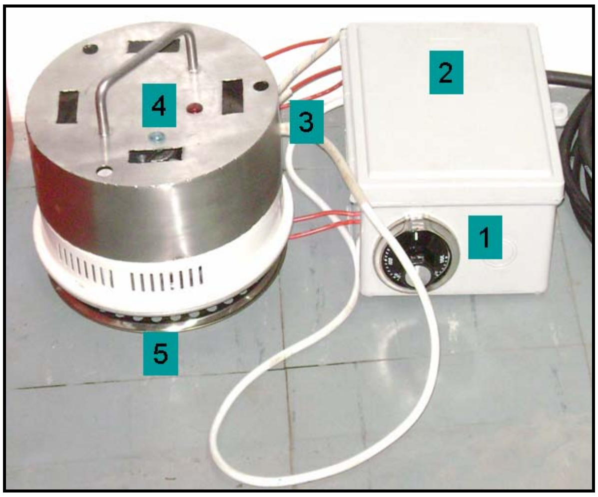


Figure 25 Electrical connection and assembled view.
1 = Thermostat, 2 = Overload relay, 3 = Heat resistance electric wire, 4 Indicators and 5 = Heater coil and safe guard.

Figure 26 A 3D view of the developed prototype.

7. Discussions on preliminary data and performance of the corn roasting machine

7.1 Preliminary data for performance evaluation of the corn roaster

For preliminary testing of the corn roaster upon the production of cornflake, the several measuring instruments were used. Grain moisture tester was used to measure the moisture content of dried and soaked corn. The average moisture content of dried corn was in the range of 12 to 14 % (wb) and the average soaked corn was 34.2 % (wb) but the highest was 36.2 %. The average voltage of 220.40V and 11.50A of average current were found by the digital type multi meter. In the preliminary test, the current ranges from 11.38 to 11.59A at different temperatures. The heated hot air flow (velocity) of the heater element measured at center of the chamber was 6.1 m/sec. These values were range from the 2.6 to 7.4 m/sec. by anemometer. The time lost owed in the operation had a preliminary test data, such as time lost for adjustment machine, unloaded the roasted corn and recorded the data. The average time lost per operation was around seven minutes (Appendix Table A5). The other pertinent parameter included in the preliminary test was the revolution per minute (rpm) of agitation fin in the developed prototype machine. The average rotation of the agitation fins was 24 rpm, which was manually rotated with replications. This perhaps gave a choice for selection of speed reducer and electric motor. The average uniform temperature distribution at the mid chamber (mid loci) by the data logger were 175, 230, 266 and 274°C with respect to thermostat set temperature of 150, 200, 250 and 300°C respectively. The test was carried out without loaded weight of corn and depicted in Appendix Table 8 – 11. Similarly, the grand mean uniform temperature distribution at the base chamber surface by data logger was 348.76°C (without corn) correspond to different thermostat temperatures (Appendix Table 12 – 15).

7.2 Machine performance evaluation

The performance evaluation of the developed corn roaster was evaluated under various criteria of parameters. The prime importance terms were machine capacity, power efficiency, percentage of weight lost after roasted and roasting efficiency. From the results and discussion, the most appropriate temperature were 210, 250 and 260°C corresponding to weight factor of 1000 g. Furthermore, other best value of time factor was 13 minutes, which characterized by not significant percentage of roasting efficiency with the highest of it. It was stated in the Table 13 and 14 about the significantly affected the parameters at $P < 0.05$.

The other preliminary test evaluation was the production of cornflake from the experiment. The amount of cornflake quantity produced was 580 g from the pounded corn of 1000 g in an average of the experiment (Figure 28). It is very convenient to unload the hot roasted corn and depicted in the Figure 27.

Figure 27 Manually unloaded the roasted corn mechanism.

Figure 28 Roasted corn per operation of 1000 g.

Figure 29 Cornflake produced in the research (pounded manually).

Figure 30 Cornflake pounded by machine in Bhutan.

CONCLUSION AND RECOMMENDATION

Conclusion

Following conclusions drawn from the research conducted in this particular thesis were:

1. The basic configuration design was considered in this research to a single phase electricity supply and other significance consideration of the subsequence pounding machine capacity per operation was 500 to 1000 g.

2. Performance experiments of the developed corn roaster under laboratory condition revealed that this principle of roasting was successfully used.

3. The most important features of this corn roaster were the free and force convection of heat dissipation and other prominent feature was the agitation system in the chamber.

4. The performance tests concluded that temperature, weight and time factors on the developed prototype were significantly affected the roasting performance at $P < 0.05$.

5. Mean optimum machine capacity and mean maximum power efficiency had on the level factors of loaded weight 1000 g at 260°C.

6. Mean maximum percentage of weight lost after roasted was on loaded weight 500 g with temperature factor of 250°C.

7. Mean roasting efficiency was the highest on the time level of 15 minutes corresponding to temperature level at 250°C.

8. The best parameters found from the performance evaluation and visual examination were 210, 250 and 260°C of temperature levels, 1000 g of weight level and 15 minutes of time level.

9. The fabrication cost of the corn roaster was US$ 310, while other cost were the experiment material cost, labour cost and miscellaneous not included in the corn roaster cost.

10. The electricity supply is available in the rural areas and electric unit rate is low in Bhutan, which can also substitute the firewood (source of energy) and may become environment friendly in the country. The rudimentary corn roasting will be alleviated.

Recommendation

Based on this research work, the following recommendations are made for further work:

1. Since the corn roaster (prototype) was designed for small scale production of roasting, it is necessary to increase machine capacity and developed based on same principle of designed for commercial purpose.

2. As these tests were limited only under laboratory condition of tropical climate and flint corn variety, testing in other climate and variety are recommended.

3. The source of heat for the corn roaster was electric heater; it will be interesting to investigate heat transfer in further research.

4. The procedure for mass production of the corn roaster should be developed, upon discussion with particular concerned organization (Agriculture Machinery Center, Bhutan).

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APPENDICES

Appendix A

Raw data of the experiments

Appendix Table A1 Observed data of the time taken to roast corn in the operation.

Temperature °C	Replication No.	500 g R.No.	500 g Time	1000 g R.No.	1000 g Time	2000 g R.No.	2000 g Time
		Time taken to roast the corn (min.) – Loaded weight					
176	1	01	13.27	06	16.07	18	28.23
	2	11	14.35	04	16.77	15	27.17
	3	16	12.37	14	17.27	05	24.17
	4	31	11.57	17	18.17	43	23.50
	Mean		12.89		17.07		25.77
210	1	28	10.35	24	16.37	45	19.87
	2	19	11.40	23	14.03	03	22.15
	3	33	10.87	29	13.65	26	21.73
	4	12	11.38	30	13.15	20	20.45
	Mean		11.00		14.30		21.05
250	1	02	12.25	38	11.03	08	22.27
	2	39	9.10	21	12.30	41	20.55
	3	22	9.50	25	13.33	40	20.23
	4	10	10.52	42	11.15	35	21.33
	Mean		10.34		11.95		21.10
260	1	47	8.30	44	9.70	36	19.90
	2	32	8.28	13	10.42	09	21.33
	3	34	8.23	48	9.88	27	19.58
	4	46	8.40	37	9.45	07	20.27
	Mean		8.30		9.86		20.27
Over all mean			10.63		13.30		22.05

R.No. = Random number assigned in the experiment design

Calculation: Sample random number of 37

1. Optimum capacity of the machine:

$$= \frac{\text{Weight of corn before roast}}{\text{time taken to roast}} \text{ (kg/h)}$$

$$= \frac{1000/1000}{9.45/60} \text{ (kg/h)}$$

= 6.35 kg/h

Appendix Table A2 Observed data of the roasted weight from digital balance in the operation.

		Weight of roasted corn (g)					
		Loaded weight					
Temperature	Replication	500 g		1000 g		2000 g	
° C	No.	R.No.	Weight	R.No.	Weight	R.No.	Weight
176	1	01	371.72	06	795.55	18	1698.38
	2	11	376.14	04	812.12	15	1658.52
	3	16	387.54	14	811.24	05	1650.23
	4	31	405.77	17	800.42	43	1691.04
	Mean		385.29		804.83		1674.54
210	1	28	364.14	24	764.14	45	1603.14
	2	19	368.43	23	795.84	03	1623.70
	3	33	397.42	29	829.68	26	1608.82
	4	12	367.23	30	782.15	20	1583.38
	Mean		374.31		792.95		1604.76
250	1	02	367.75	38	824.85	08	1595.60
	2	39	388.47	21	786.60	41	1553.38
	3	22	358.95	25	837.92	40	1578.57
	4	10	377.77	42	857.53	35	1513.54
	Mean		373.24		826.73		1560.27
260	1	47	385.90	44	885.42	36	1677.12
	2	32	399.06	13	782.67	09	1606.28
	3	34	421.46	48	847.93	27	1664.38
	4	46	386.26	37	723.58	07	1604.34
	Mean		398.17		809.90		1638.03
Over all mean			382.75		808.60		1619.40

Calculation: Sample random number of 44

2. Optimum throughput capacity:

$$= \frac{\text{Weight of corn after roasted}}{\text{time taken to roast}} \text{ (kg/h)}$$

$$= \frac{885.42/1000}{9.70/60} \text{ (kg/h)}$$

= 5.48 kg/h

3. Minimum percentage of weight lost after roasted:

$$= \frac{\text{Initial weight of corn} - \text{Roasted weight of corn}}{\text{Initial weight of corn}} \times 100\ (\%)$$

$$= \frac{1000 - 885.42}{1000} \times 100$$

$= 11.46\ \%$

4. Power consumption:

$$= \frac{\text{P.F. x power input x operating time}}{\text{weight of roasted corn}}\ (\text{kW - h/kg})$$

$$= \frac{(0.8 \times 220.4 \times 11.50 \times 9.70/60)/1000}{885.42/1000}$$

$= 0.3702$ kW-h/kg

Appendix Table A3 Observed data of the Chamber temperature from thermocouple in the operation.

		Roasting Chamber temperature						
		Loaded weight						
Temp.	Rep.	500 g		1000 g		2000 g		Over all
° C	No.	R.No.	° C	R.No.	° C	R.No.	° C	Mean
150	1	01	178.00	06	170.00	18	172.30	
	2	11	173.00	04	160.00	15	170.20	
	3	16	180.60	14	179.00	05	199.00	
	4	31	171.80	17	187.40	43	180.40	
	Mean		175.85		174.10		180.47	176.79
200	1	28	184.80	24	236.40	45	214.80	
	2	19	239.50	23	196.80	03	190.10	
	3	33	205.20	29	201.50	26	212.50	
	4	12	205.00	30	210.00	20	234.60	
	Mean		208.62		211.17		213.00	210.93
250	1	02	260.00	38	238.60	08	245.00	
	2	39	246.20	21	270.30	41	228.70	
	3	22	264.40	25	256.60	40	250.20	
	4	10	231.20	42	262.10	35	253.40	
	Mean		250.45		256.90		244.32	250.55

Appendix Table A3 (continued)

Temp. °C	Rep. No.	500 g R.No.	500 g °C	1000 g R.No.	1000 g °C	2000 g R.No.	2000 g °C	Over all Mean
		Roasting Chamber temperature – Loaded weight						
300	1	47	274.20	44	269.70	36	266.10	
	2	32	244.10	13	232.20	09	260.00	
	3	34	266.90	48	268.50	27	269.90	
	4	46	271.70	37	270.00	07	235.50	
	Mean		264.22		260.10		257.87	260.73

Appendix Table A4 Observed data of the product temperature from the temperature gun meter after roasted the corn.

Temperature °C	Replication No.	500 g R.No.	500 g °C	1000 g R.No.	1000 g °C	2000 g R.No.	2000 g °C
		Roasted product temperature – Loaded weight					
176	1	01	89.10	06	86.50	18	102.30
	2	11	94.60	04	98.70	15	84.10
	3	16	91.00	14	95.30	05	110.30
	4	31	100.10	17	90.70	43	80.00
	Mean		93.70		92.80		94.17
210	1	28	94.60	24	84.90	45	89.80
	2	19	80.00	23	90.50	03	88.40
	3	33	85.30	29	99.80	26	88.50
	4	12	106.20	30	102.40	20	84.20
	Mean		91.52		94.40		87.72
250	1	02	90.00	38	87.20	08	89.40
	2	39	98.10	21	96.10	41	88.40
	3	22	89.10	25	84.20	40	92.20
	4	10	102.60	42	100.90	35	98.40
	Mean		94.95		92.10		92.10
260	1	47	102.90	44	101.00	36	99.20
	2	32	85.90	13	94.80	09	88.60
	3	34	106.10	48	101.00	27	89.80
	4	46	90.60	37	100.10	07	101.70
	Mean		96.37		99.22		94.82
Over all mean			94.14		94.63		92.21

Calculation: Sample random number of 44

5. Maximum power efficiency in term of percentage unit:

$$= \frac{wt.\ x\ \Delta T\ x\ C p}{P.\ F.\ x\ V\ x\ I\ x\ t} x\ 100\ \ (\%)$$

wt. = Weight of roasted corn (885.42 g)

Tp = Change in corn temperature (101°C – 28.6°C)

Cp = Corn's specific heat at constant pressure with corresponding to the percentage of weight lost after roasted (MC_{wb}, 2.2712 kJ/(kg K.) from the grain's thermal properties of standards table (ASAE, 1994)

P.F. = Power factor (0.8 commonly in Thailand)

V = Voltage (220.40V)

I = Ampere (11.50A)

t = operation time per sample (9.70 min.)

$$= \frac{885.42/100\ 0\ x\ (72.4\ +\ 273.15)\ x\ (2.2712X10\ 00)}{0.8.\ x\ 220.40\ x\ 11.50\ x\ 9.70\ x\ 60} x\ 100\ (\%)$$

$$= \frac{kg\ x\ K\ x\ (J/kg\ K)}{P.F.x\ V\ x\ A\ x\ Sec} x\ 100(\%) = \frac{J = watt\ sec}{watt\ sec} x\ 100$$

= 58.89%

Appendix Table A5 Summarized data of other observed in the operation.

Parameters	Average value
Input voltage (a.c)	220.40V
Input current (a.c)	11.50A
Soaked corn moisture content	34.2 %
Roasted corn moisture content	16.8 %
Blower (air flow)	3.98 m/s
Manually rotated the agitation shaft	24 rpm
Time lost owing to adjustment, others	7 min.
Roasting base surface temperature by data logger	348.76°C
Ambient temperature at experimental day	28.6°C
Weather condition at experimental day	Partly cloudy and humid

Appendix Table A6 Counted the number of kernels (partial roasted) in the further intensive experiment.

Temperature	Replication	Number of partial roasted kernels (No.)								
		Time level								
		11 min.			13 min.			15 min.		
° C	No.	R. No.	Partial roasted	Total Kernels	R. No.	Partial roasted	Total Kernels	R. No.	Partial roasted	Total kernels
210	1	07	123	326	26	123	344	05	97	351
	2	06	136	347	16	112	316	19	86	337
	3	18	117	322	09	121	331	04	104	342
	Mean		125.33	331.67		118.67	330.33		95.67	343.33
250	1	01	90	321	23	75	328	17	73	332
	2	15	101	355	10	82	330	21	63	303
	3	11	82	340	08	87	338	20	55	323
	Mean		91.00	338.67		81.33	332.00		63.67	319.33
260	1	24	100	358	02	72	343	14	54	324
	2	25	78	313	22	83	372	27	86	379
	3	12	72	324	03	74	376	13	65	319
	Mean		83.24	331.67		76.33	363.67		68.33	340.67

Calculation: Sample random number of 14

6. Minimum partial roasting efficiency per unit time:

$$= \frac{\text{No. of kernels after operation per unit time}}{\text{No. of kernels before operation per unit time}} \text{ x } 100\ (\%)$$

$$= \frac{54}{324} \text{ x } 100\ (\%) = 16.67\ \%$$

Appendix Table A7 Counted the number of kernels (completely roasted kernels) in the further intensive experiment.

Temperature	Replication	Number of fully roasted kernels (No.)								
		Time level								
		11 min.			13 min.			15 min.		
° C	No.	R.No.	Fully roasted	Total Kernels	R.No.	Fully roasted	Total Kernels	R.No.	Fully roasted	Total kernels
210	1	07	203	326	26	221	344	05	254	351
	2	06	211	347	16	204	316	19	251	337
	3	18	205	322	09	210	331	04	238	342
	Mean		206.33	331.67		211.67	330.33		247.67	343.33
250	1	01	231	321	23	253	328	17	259	332
	2	15	254	355	10	248	330	21	240	303
	3	11	258	340	08	251	338	20	268	323
	Mean		247.67	338.67		250.67	332.00		255.67	319.33
260	1	24	258	358	02	271	343	14	270	324
	2	25	235	313	22	289	372	27	293	379
	3	12	252	324	03	302	376	13	254	319
	Mean		248.42	331.67		287.33	363.67		272.33	340.67

Calculation: Sample random number of 14

7. Maximum percentage of roasting efficiency per unit time:

$$= \frac{\text{No. of kernels after operation per unit time}}{\text{No. of kernels before operation per unit time}} \text{ x } 100\,(\%)$$

$$= \frac{270}{324} \text{ x } 100\,(\%) = 83.33\ \%$$

Appendix Table A8 Examined the uniform temperature distribution in the chamber by data logger at 150°C (not loaded the weight).

	Temperature (Recorded time (12min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
150	00.02	79.96	00.11	92.73	00.06	86.33
	60.00	115.59	60.09	127.51	60.05	113.29
	120.00	145.44	120.09	145.54	120.05	128.86
	180.00	170.75	180.09	160.72	180.05	142.89
	240.00	181.37	240.09	173.58	240.05	155.15
	300.00	195.30	300.09	185.34	300.05	166.01
	360.00	206.99	360.09	195.43	360.05	174.37
	420.00	171.53	420.09	167.85	420.05	154.37
	480.00	188.55	480.09	182.14	480.05	167.10
	540.00	188.71	540.09	190.70	540.05	173.55
	600.00	169.81	600.09	161.44	600.05	157.78
	660.00	184.85	660.09	178.23	660.05	172.99
	720.00	185.81	720.09	181.94	720.05	175.20
Mean		168.05		164.86		151.37

	Temperature (Recorded time (17min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
150	00.02	205.58	00.11	207.16	00.06	203.55
	60.00	192.33	60.09	197.91	60.05	192.94
	120.00	182.72	120.09	189.43	120.05	184.40
	180.00	174.61	180.09	182.21	180.05	177.75
	240.00	173.84	240.09	179.64	240.05	174.53
	300.00	195.69	300.09	192.58	300.05	190.48
	360.00	176.25	360.10	179.27	360.05	175.66
	420.00	178.16	420.09	179.65	420.05	175.42
	480.00	192.32	480.09	187.21	480.05	185.12
	540.00	171.09	540.09	172.85	540.05	169.72
	600.00	194.20	600.09	187.55	600.05	186.14
	660.00	181.86	660.09	179.35	660.05	177.48
	720.00	168.39	720.09	169.51	720.05	166.03
	780.00	195.77	780.09	187.55	780.05	187.88
	840.00	172.06	840.09	171.01	840.05	168.40
	900.00	190.46	900.09	182.95	900.05	181.56
	960.00	183.23	960.09	178.07	960.05	177.06

Appendix Table A8 (continued)

Thermostat Temp. (°C)	Temperature (Recorded time (12min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
150	1020.00	166.60	1020.09	166.58	1020.05	163.50
Mean		183.06		182.80		179.87

Appendix Table A9 Examined the uniform temperature distribution in the chamber by data logger at 200°C (not loaded the weight).

Thermostat Temp. (°C)	Temperature (Recorded time (11min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
200	00.02	241.82	00.11	242.72	00.06	238.71
	60.00	225.56	60.09	230.87	60.05	225.20
	120.00	257.65	120.09	249.73	120.05	246.90
	180.00	229.70	180.09	230.69	180.05	226.13
	240.00	248.18	240.09	240.53	240.05	237.43
	300.00	238.22	300.09	233.85	300.05	169.15
	360.00	233.08	360.09	229.64	360.05	226.06
	420.00	251.51	420.09	240.62	420.05	166.03
	480.00	222.68	480.09	221.74	480.05	164.28
	540.00	257.86	540.09	244.10	540.05	163.61
	600.00	227.65	600.09	224.11	600.05	163.59
	660.00	248.49	660.09	236.28	660.05	162.51
Mean		240.20		235.41		199.13

Thermostat Temp. (°C)	Temperature (Recorded time (14min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
200	00.02	169.34	00.11	165.16	00.06	163.43
	60.00	205.27	60.09	189.37	60.05	191.16
	120.00	223.78	120.09	201.74	120.05	120.79
	180.00	237.85	180.09	214.17	180.05	127.42
	240.00	245.62	240.09	220.78	240.05	135.75
	300.00	232.22	300.09	211.95	300.05	143.55
	360.00	236.93	360.09	217.09	360.05	147.19
	420.00	249.66	420.09	226.80	420.05	151.29

Appendix Table A9 (continued)

	Temperature (Recorded time (14min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
200	480.00	224.12	480.09	209.87	480.05	154.90
	540.00	252.37	540.09	231.26	540.05	156.63
	600.00	222.57	600.09	211.01	600.05	157.66
	660.00	245.71	660.09	226.19	660.05	158.23
	720.00	232.73	720.09	218.08	720.05	159.15
	780.00	235.76	780.09	221.48	780.05	218.77
	840.00	244.65	840.09	227.72	840.05	160.39
Mean		230.57		212.85		156.42

Appendix Table A10 Examined the uniform temperature distribution in the chamber by data logger at 250°C (not loaded the weight).

	Temperature (Recorded time (10 min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
250	00.02	220.67	00.11	215.32	00.06	211.93
	60.00	249.04	60.09	233.01	60.05	151.32
	120.00	265.39	120.09	243.86	120.05	155.28
	180.00	274.17	180.09	250.20	180.05	161.18
	240.00	282.05	240.09	258.36	240.05	166.65
	300.00	287.93	300.10	262.21	300.05	171.09
	360.00	294.34	360.09	268.53	360.05	177.22
	420.00	300.31	420.09	272.58	420.05	183.47
	480.00	306.52	480.09	276.14	480.05	187.75
	540.00	301.56	540.09	275.20	540.05	192.12
	600.00	289.47	600.09	268.01	600.05	190.90
Mean		279.22		256.67		177.17

	Temperature (Recorded time (11 min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
250	00.02	210.76	00.11	202.57	00.06	200.38
	60.03	242.54	60.09	221.93	60.04	219.84
	120.00	258.33	120.09	232.54	120.04	148.52

Appendix Table A10 (continued)

Thermostat Temp. (°C)	Temperature (Recorded time (11 min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
250	180	268.16	180.09	240.94	180.04	153.93
	240	276.95	240.09	246.89	240.04	159.63
	300	284.26	300.09	254.73	300.04	165.89
	360	290.67	360.09	261.13	360.04	171.52
	420	297.02	420.09	266.49	420.04	176.54
	480	302.94	480.09	271.69	480.04	183.38
	540	299.62	540.09	272.01	540.04	186.36
	600	286.16	600.09	265.08	600.04	187.68
	660	303.6	660.09	278.31	660.04	188.46
Mean		276.75		251.19		178.51

Appendix Table A11 Examined the uniform temperature distribution in the chamber by data logger at 300°C (not loaded the weight).

Thermostat Temp. (°C)	Temperature (Recorded time (8 min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
300	00.02	261.00	00.11	249.00	00.06	244.00
	60.00	284.00	60.09	264.00	60.05	182.00
	120.00	295.00	120.09	273.00	120.05	180.00
	180.00	304.00	180.09	281.00	180.05	182.00
	240.00	308.00	240.09	284.00	240.05	188.00
	300.00	314.00	300.09	290.00	300.05	192.00
	360.00	317.00	360.09	293.00	360.05	196.00
	420.00	321.00	420.09	295.00	420.05	200.00
	480.00	325.00	480.09	299.00	480.05	204.00
Mean		303.22		280.89		196.44

Appendix Table A11 (continued)

	Temperature (Recorded time (9 min.))					
	Mid-Chamber (1)		Mid-Chamber (2)		Sensor point	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
300	00.02	213.00	00.11	200.00	00.06	196.00
	60.03	238.00	60.09	216.00	60.05	213.00
	120.00	251.00	120.09	226.00	120.05	222.00
	180.00	262.00	180.09	234.00	180.05	149.00
	240.00	269.00	240.09	239.00	240.05	152.00
	300.00	276.00	300.09	246.00	300.05	157.00
	360.00	284.00	360.09	251.00	360.05	164.00
	420.00	290.00	420.09	259.00	420.05	169.00
	480.00	297.00	480.09	264.00	480.05	173.00
	540.00	301.00	540.09	269.00	540.05	179.00
Mean		268.10		244.89		177.40

Appendix Table A12 Examined the uniform temperature distribution in the base chamber surface by data logger at 150°C (without corn).

	Temperature (Recorded time 13 min.)					
	Base-Chamber (1)		Base-Chamber (2)		Exterior cover surface	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
150	00.11	260.45	00.11	250.68	00.11	50.56
	60.09	270.85	60.09	262.56	60.09	58.63
	120.09	278.85	120.09	280.34	120.09	65.78
	180.09	280.04	180.09	298.34	180.00	70.89
	300.09	316.89	300.09	310.25	300.00	80.98
	360.09	342.63	360.09	320.46	360.00	96.34
	420.09	365.68	420.09	389.56	420.00	99.47
	480.09	370.45	480.09	390.69	480.00	101.49
	540.09	355.78	540.09	374.92	540.00	110.56
	600.09	352.82	600.09	360.74	600.00	120.45
	660.09	389.42	660.09	368.24	660.00	121.78
	720.09	345.67	720.09	370.68	720.00	118.56
	780.09	350.68	780.09	366.86	780.00	112.45
Mean		329.25		334.18		92.92

Appendix Table A13 Examined the uniform temperature distribution in the base chamber surface by data logger at 200°C (without corn).

	Temperature (Recorded time 13 min.)					
	Base-Chamber (1)		Base-Chamber (2)		Exterior cover surface	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
200	00.11	270.65	00.11	268.45	00.11	60.56
	60.09	275.34	60.09	273.56	60.09	62.90
	120.09	280.78	120.09	281.34	120.09	65.89
	180.09	285.04	180.09	290.86	180.00	73.36
	300.09	319.87	300.09	320.14	300.00	90.75
	360.09	343.09	360.09	323.16	360.00	98.49
	420.09	366.56	420.09	354.18	420.00	95.97
	480.09	372.78	480.09	360.72	480.00	102.66
	540.09	356.70	540.09	375.16	540.00	111.93
	600.09	357.46	600.09	365.20	600.00	117.93
	660.09	366.06	660.09	378.12	660.00	121.05
	720.09	353.71	720.09	372.45	720.00	103.74
	780.09	351.55	780.09	367.48	780.00	110.01
Mean		330.74		333.14		93.48

Appendix Table A14 Examined the uniform temperature distribution in the base chamber surface by data logger at 250°C (without corn).

	Temperature (Recorded time 13 min.)					
	Base-Chamber (1)		Base-Chamber (2)		Exterior lid surface	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
250	00.11	280.15	00.11	260.34	00.02	118.2
	60.09	297.16	60.09	290.36	60.00	125.46
	120.09	319.33	120.09	312.42	120.00	131.57
	180.09	340.78	180.09	330.82	180.00	140.78
	240.09	357.64	240.09	350.86	240.00	145.05
	300.09	373.18	300.09	355.86	300.00	148.23
	360.09	387.32	360.09	370.46	360.00	155.25
	420.10	398.38	420.10	390.48	420.00	149.47
	480.09	406.03	480.09	412.43	480.00	160.36
	540.09	413.56	540.09	408.62	540.00	161.87
	600.09	419.19	600.09	410.54	600.00	165.65
	660.09	420.25	660.09	418.67	660.00	168.17
	720.09	424.69	720.09	425.68	720.00	168.68

Appendix Table A14 (continued)

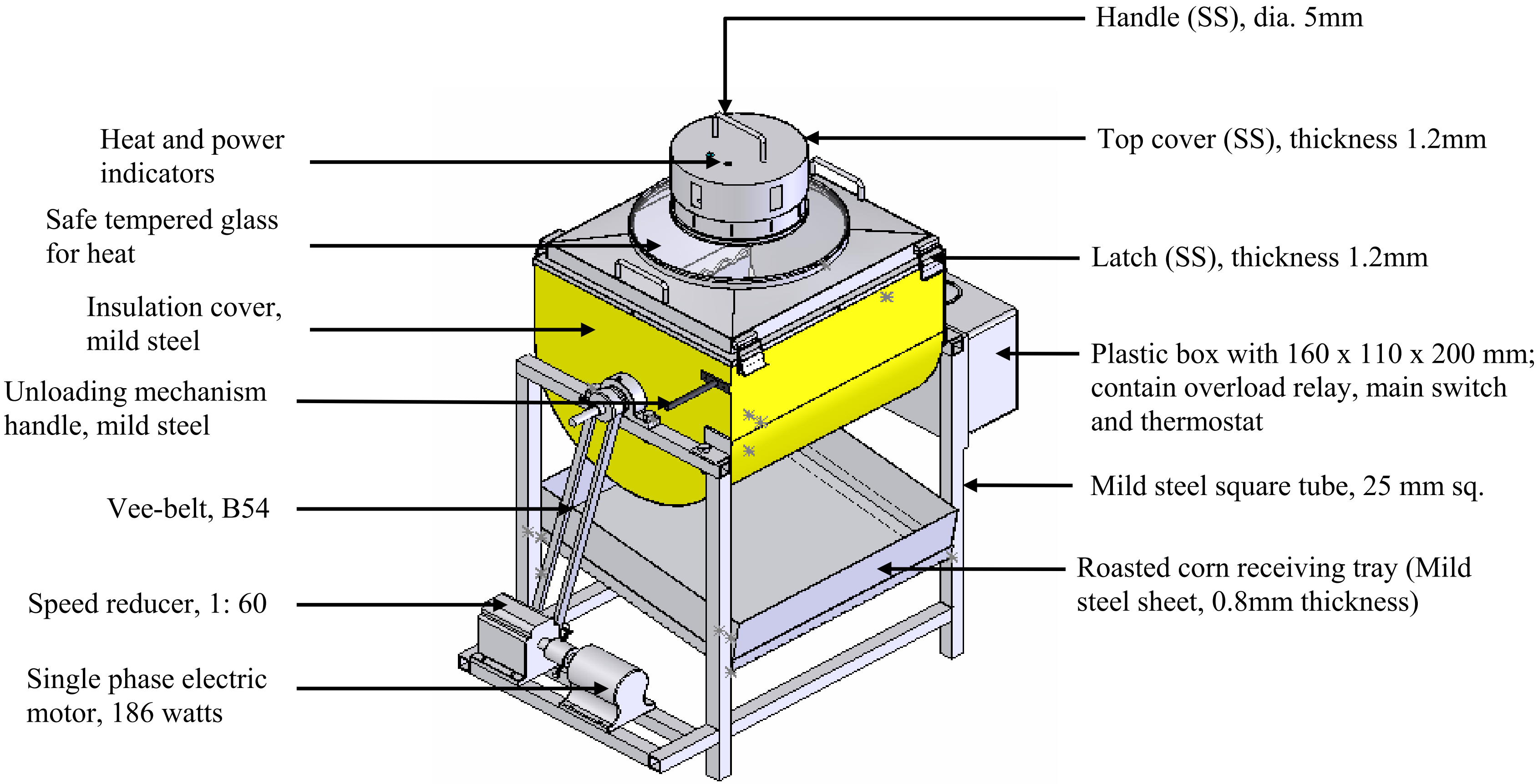
	Temperature (Recorded time 13 min.)					
	Base-Chamber (1)		Base-Chamber (2)		Exterior lid surface	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
250	780.09	424.69	780.09	420.78	780.00	171.84
Mean		375.88		368.45		150.76

Appendix Table A15 Examined the uniform temperature distribution in the base chamber surface by data logger at 300°C (without corn).

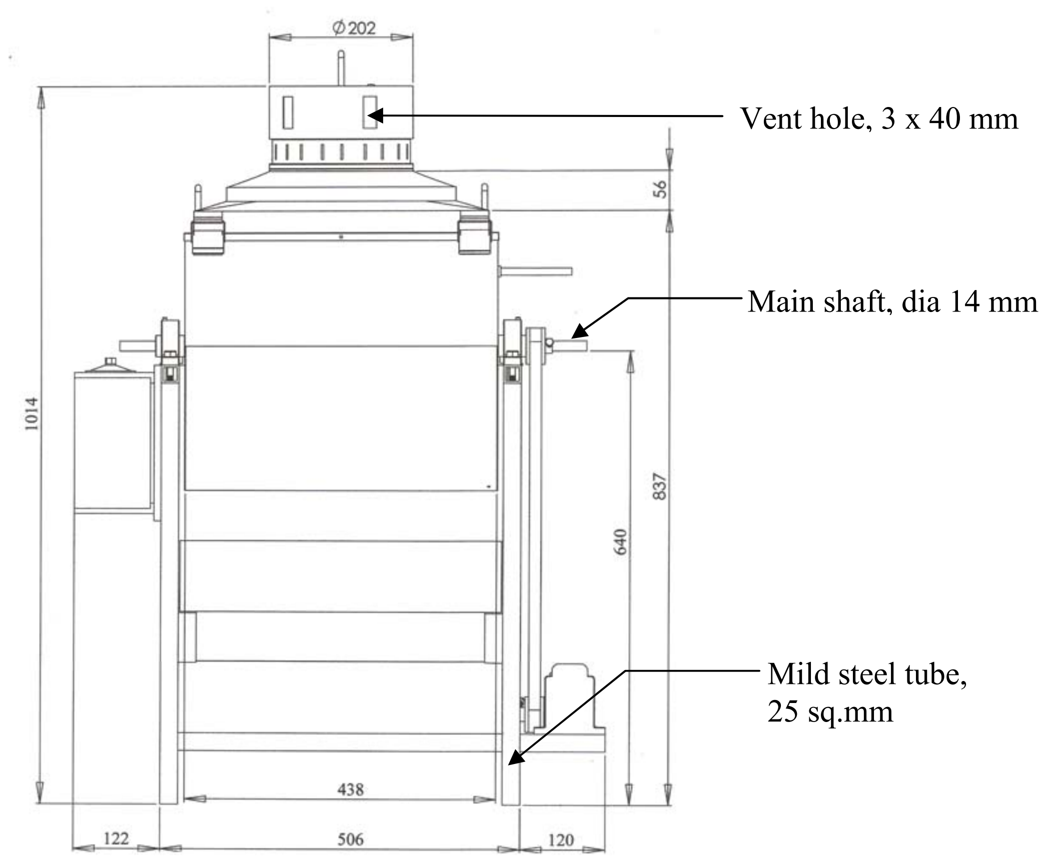
	Temperature (Recorded time 13 min.)					
	Base-Chamber (1)		Base-Chamber (2)		Exterior lid surface	
Thermostat Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)	Interval Time (s)	Recorded Temp. (°C)
300	0.11	265.39	0.11	255.67	0.02	136.00
	60.09	306.45	60.09	290.88	60.00	140.00
	120.09	299.10	120.09	301.42	120.00	140.00
	180.09	302.59	180.09	301.86	180.00	152.00
	240.09	311.05	240.09	310.82	240.00	162.00
	300.09	316.11	300.09	314.89	300.00	167.00
	360.09	406.12	360.09	350.14	360.00	160.00
	420.09	323.48	420.09	372.28	420.00	166.00
	480.09	430.51	480.09	401.54	480.00	168.00
	540.09	383.90	540.09	410.34	540.00	177.00
	600.09	397.37	600.09	390.67	600.00	179.00
	660.09	442.14	660.09	412.46	660.00	182.00
	720.09	441.86	720.09	430.56	720.00	176.00
	780.09	448.33	780.09	440.89	780.00	182.00
Mean		362.46		356.03		163.36

Appendix B

Engineering drawing of the developed machine

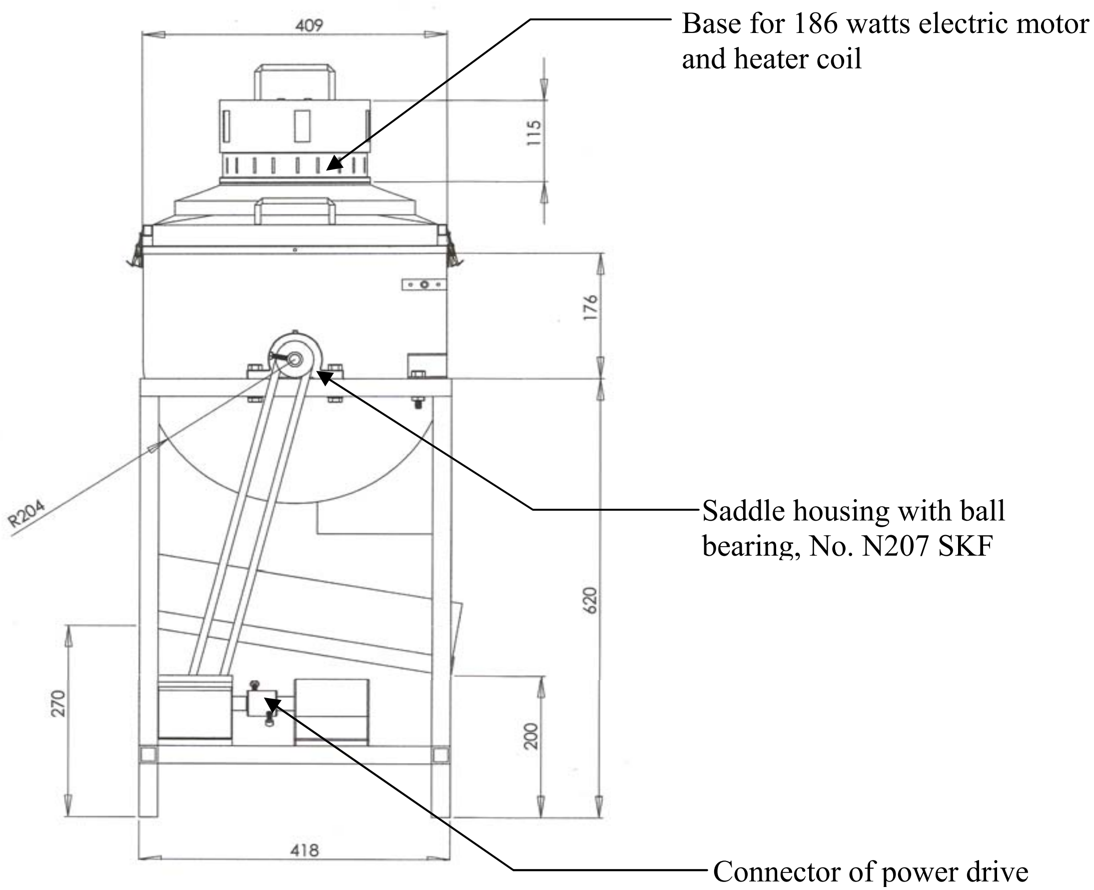


Appendix Figure B1 Assembled isometric view of the developed corn roaster.



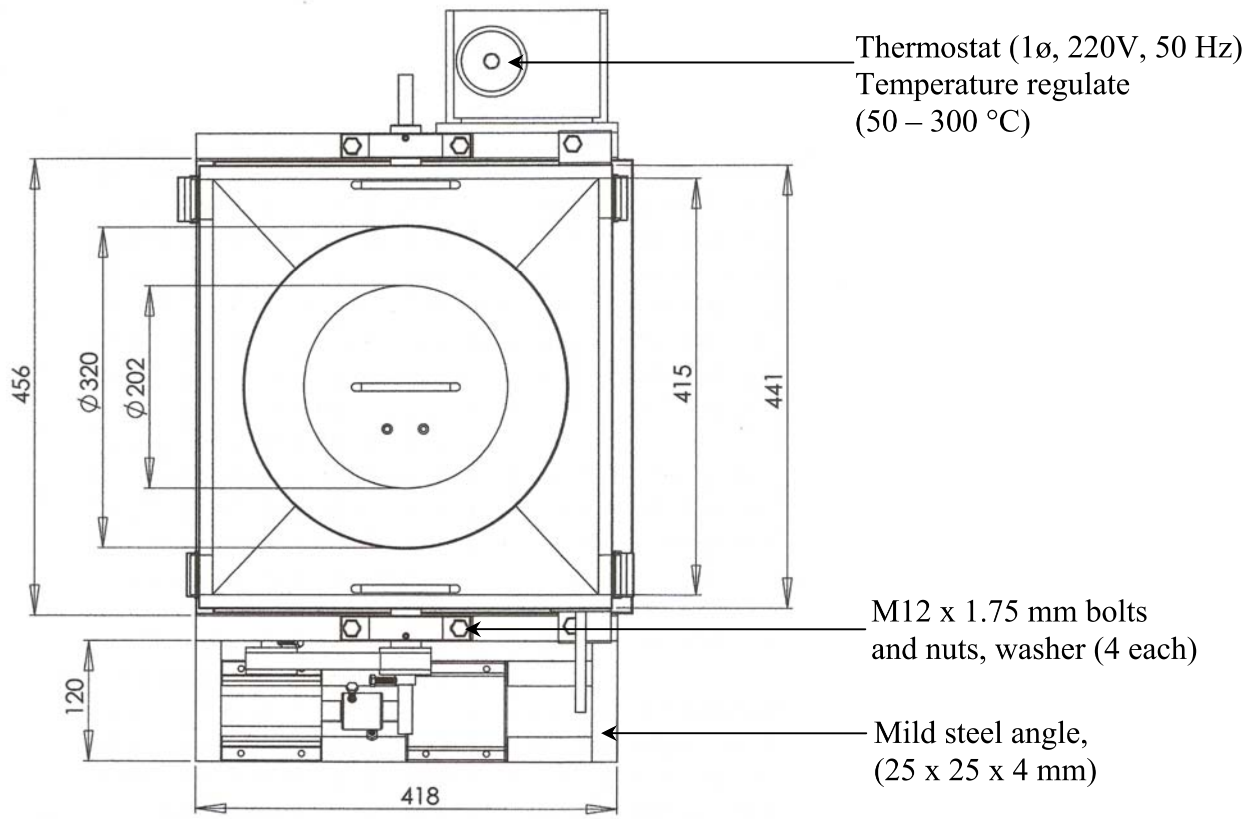
All dimensions are in mm, Scale 1:5

Appendix Figure B2 Front view of the developed machine.



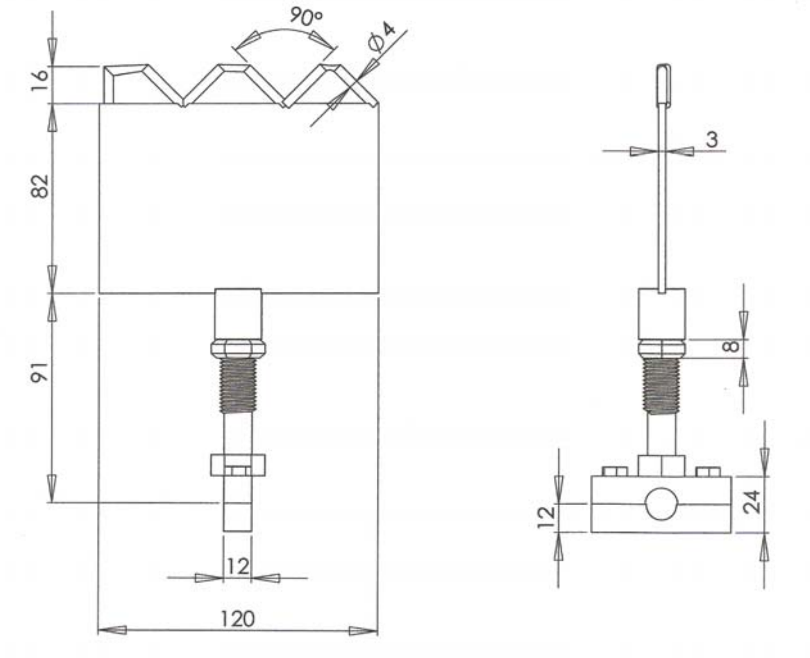
All dimensions are in mm and Scale 1:5

Appendix Figure B3 Side view of the developed machine.

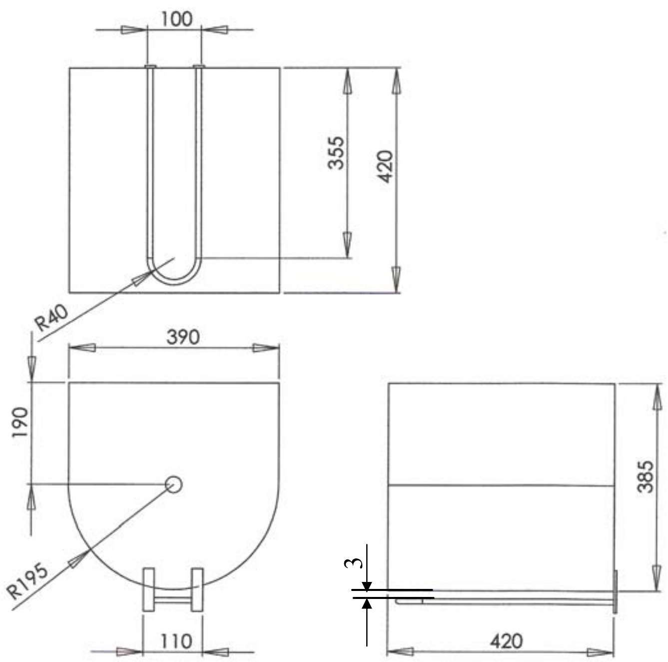


All dimensions are in mm and Scale 1:5

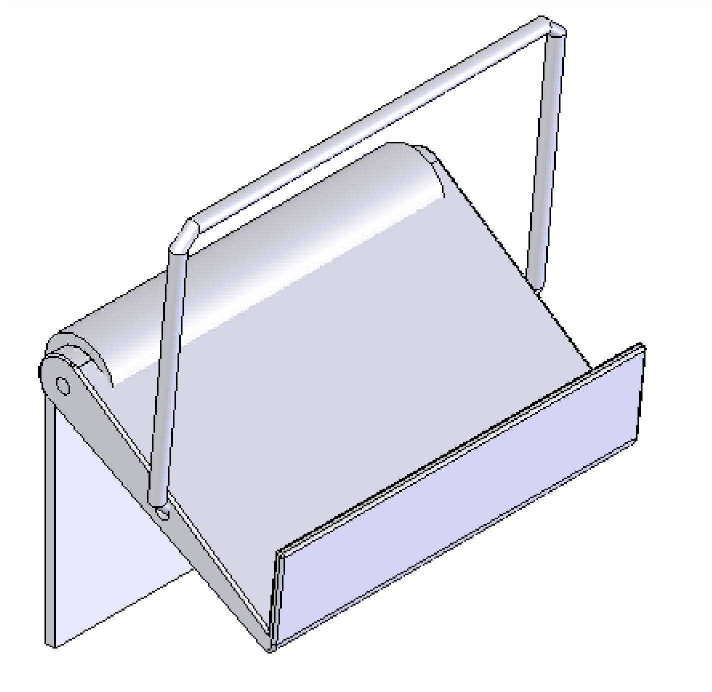
Appendix Figure B4 Top view of the developed machine.



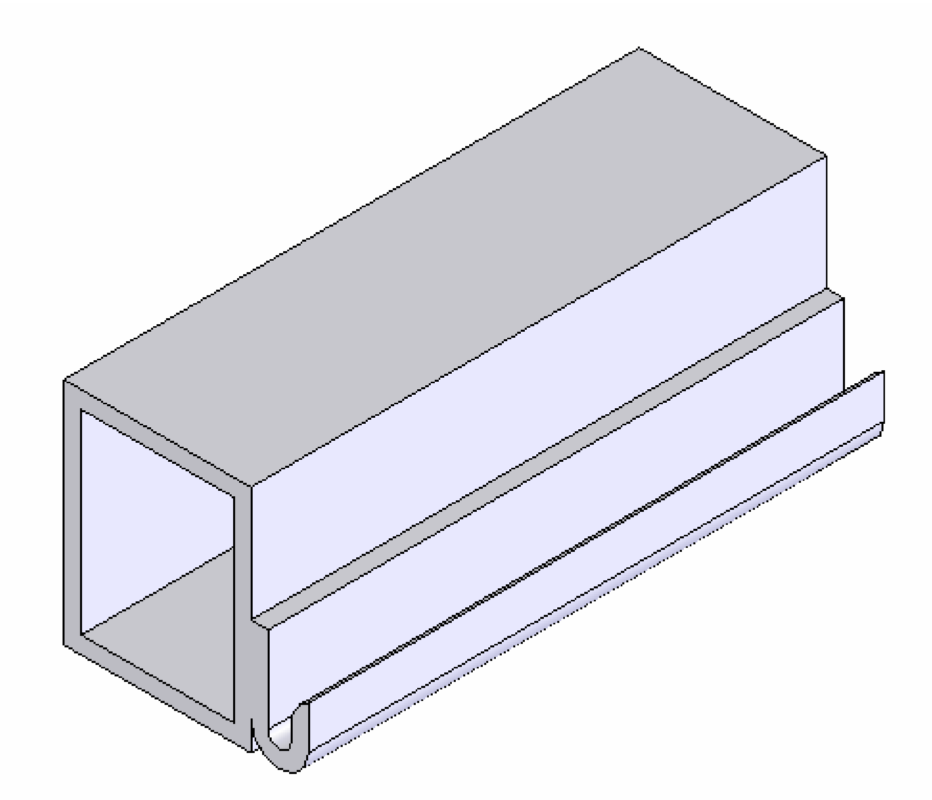
Appendix Figure B5 Agitation parts view of the developed machine.



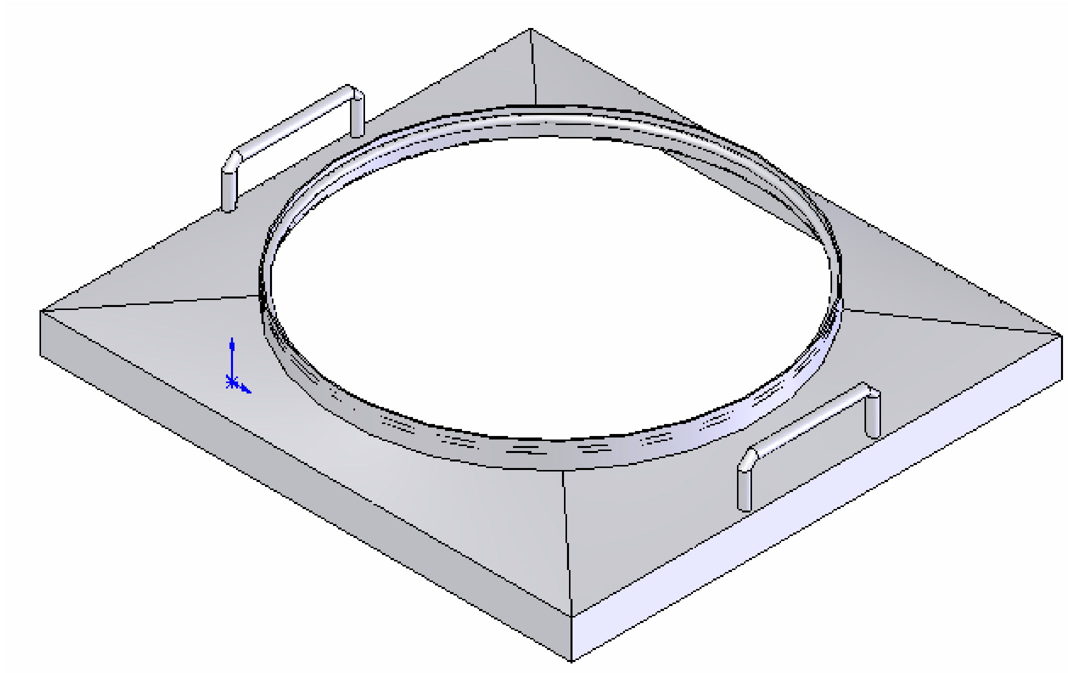
Appendix Figure B6 Schematic views of the roasting chamber.



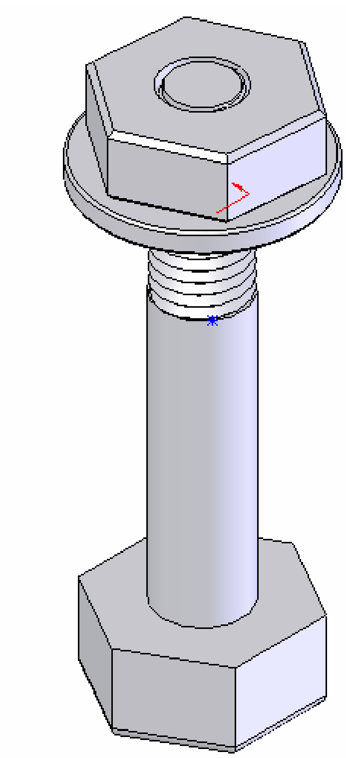
Appendix Figure B7 Schematic view of the latch assembled.



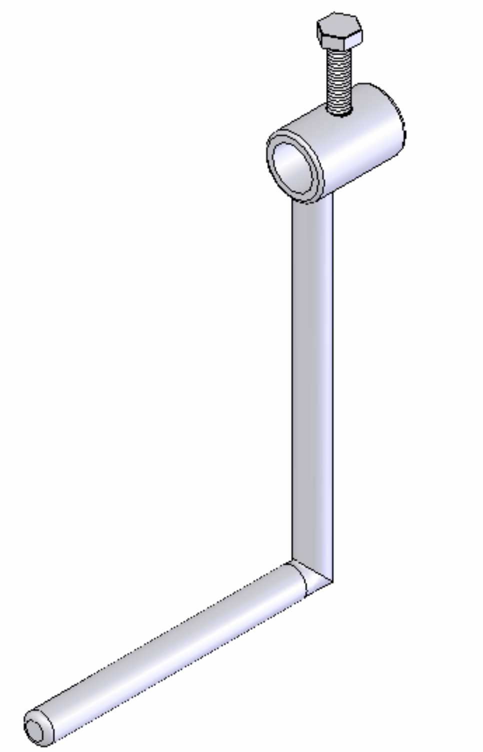
Appendix Figure B8 Schematic view of the latch part.



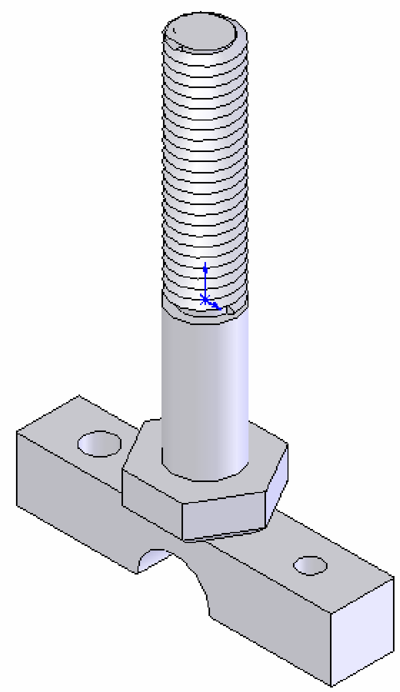
Appendix Figure B9 Isometric view of lid.



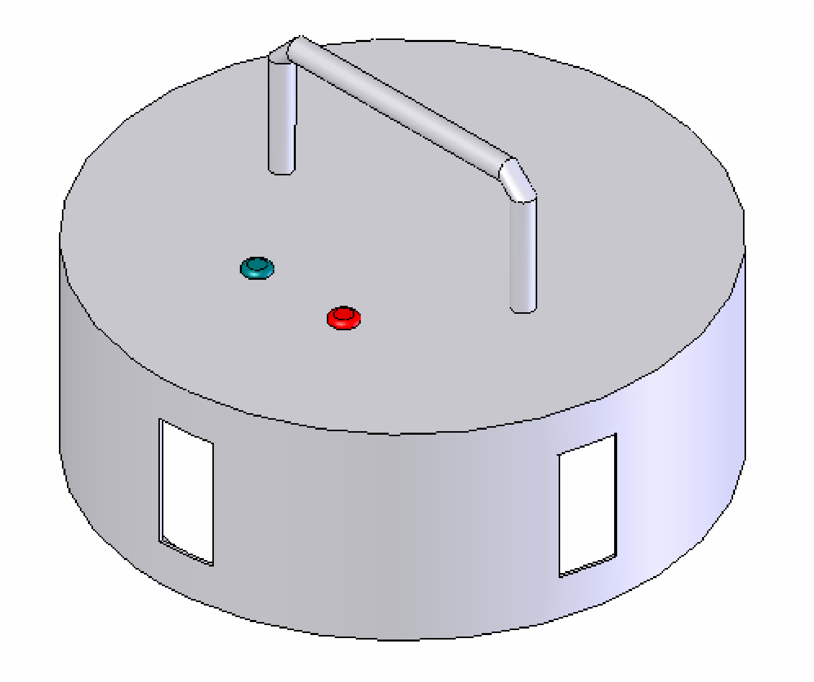
Appendix Figure B10 Assembled isometric view of fastener.



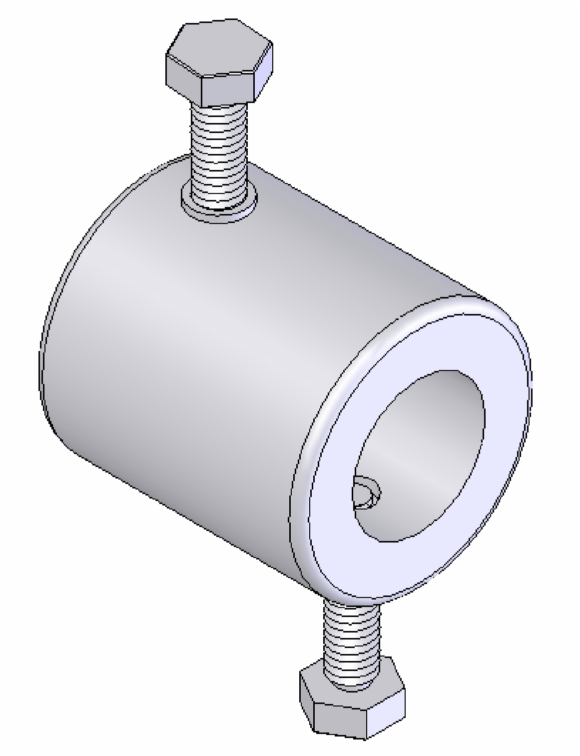
Appendix Figure B11 Isometric view of the stainless steel handle.



Appendix Figure B12 Isometric view of welded the bolt with clamp mechanism.



Appendix Figure B13 Top cover of motor and blower made from the stainless steel.



Appendix Figure B14 Fastener isometric view for motor and speed reducer connector

Appendix C

Statistical analysis

Statistical analysis

The purpose of statistical science is to provide an objective basis for the analysis of problems in which the data departs from the laws of exact casuality. These are mainly used in manufacturing; development of food products, computer software, pharmaceuticals and many other areas involves the gathering of information or scientific data. Data have been collected, summarized, reported and stored for perusal.

F distribution is one of the most important distributions in all applied statistics. A statistical hypothesis is a statement about one or more populations that may or may not be true. A Null Hypothesis (H_o) is a hypothesis, which we intend to test at a certain preselected level of significance. An Alternative Hypothesis (H_1) is a hypothesis, which we wish to accept if the sample does not provide enough evidence to reject H_o. Type I error is the error committed when we reject a null hypothesis, which is true. This is the significance level of a test α. The experimenter selects the significance level of a test. Therefore, we have complete control over Type I error. A null hypothesis (H_o) can never be proved correct, but it can be rejected with known risks of being wrong or falsifiable (Neter *et al.*, 1996). For example a chemically can never be statistically proved as perfectly safe. If result can be interpreted that the hypothesis is unfalsifiable then the result is performed from a poor experimental design. If the F statistic is not significant then this hypothesis is not rejected and there is nothing more to do, except possibly try to make the experiment itself more sensitive. If the null hypothesis is not accepted, then at least one mean is significant from atleast one after another. The ANOVA gives no indication of which means are significantly different. If there are only two treatments then there is no problem, but if there are more than two treatments then the problems remains of trying to determine which means are significantly different. Type II error is the error committed when we accept a null hypothesis, which is false. Probability of committing Type II error is usually denoted by β. The only way, this can be controlled is to select a sample size, which yields desired level of power, $(1 - \beta)$ to the test.

1. Basic of statistics (Means and Variances)

If y is a continuous random variable with population mean (μ) and variance (σ^2) and probability density function (f(y)). Mathematically expected values are:

$$E(y) = \mu = \int_{-\infty}^{+\infty} y\, f(y)\, dy$$

$$E(y - \mu) = \sigma^2 = \int_{-\infty}^{+\infty} (y - \mu)^2 f(y) dy = E(y^2) - \mu^2$$

2. Normal Distribution

y is a normal random variable and $-\infty < y < +\infty$ if

$$f(y) = \frac{1}{\sqrt{2\pi\sigma}} e^{-1/2[(y-\mu)/\sigma]^2}$$

$$\text{Mean}(\mu) = E(y) = \int_{-\infty}^{+\infty} yf(y)dy$$

$$\text{Variance}(\sigma^2) = E(y - \mu)^2$$

3. Statistical Test Procedure

a) Select an H_o

b) Specify an $H_{1.}$ Note this can be one tailed or two tailed

c) Select a significant level, α.

d) Establish the critical region.

e) Compute the statistic

f) Draw your conclusion

4. Measure of Central Tendency and Dispersion

Notation: The individual values of a population are denoted Yi, i = 1.......N, where N is the size of the population. The individual values of a sample are also denoted Yi, but in this case i = 1,….., r, where r is the size of the sample.

5. Mean

Population mean $\mu = \dfrac{\sum_{i=1}^{N} Yi}{N}$

Sample Mean $\bar{Y} = \dfrac{\sum_{r=1}^{r} Yi}{r}$

6. Variance

Population variance $\sigma^2 = \dfrac{\sum_{i=1}^{N} (Yi - \mu)^2}{N}$

Sample variance $S^2 = \dfrac{\sum_{r=1}^{r} (Yi - \bar{Y})^2}{r - 1}$

The quantities $(Yi - \bar{Y})$ are called the deviations.

Sample variance of the mean $S^2{}_{\bar{Y}} = \dfrac{S^2}{n}$

The standard deviation of a mean is often called standard error

Coefficient of variation $CV = \dfrac{S}{\bar{Y}}$

The various types of experimental designs are used in all field areas such as Completely Randomized Design, Randomized Completely Block Design, Latin Square Design, Repeated Measures Design, Split Plot Design and Factorial Experiment or Factorial Design.

Factorial experimentation is a systematic method of investigating the relationships between the effects of different factors. The investigator have been compared all treatments that can be formed by combining the levels of the different factors. It is also highly efficient, because observation supplies information about all the factors included in the experiment (Fisher, 1996).

The linear model for two-way factorial experiments

The linear model of two-factor analysis is-

$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$

Where, α_i represents the main effect of factor Ai, i = 1,….,a, βj represents the main effect of factor B, j = 1, ….., b, $\alpha\beta_{ij}$ represents the interaction of factor A level i with factor B level j., and ε_{ijk} is the error associated with replication k of factor levels ij, k = 1,….,r.

Appendix Table C1 The ANOVA table for the CRD factorial design.

Source of variance	df	SS	MS	F
Factor A	a – 1	SSA	MSA	MSA/MSE
Factor B	b – 1	SSB	MSB	MSB/MSE
A x B	(a – 1) (b – 1)	SSAB	MSAB	MSAB/MSE
Error	ab (r – 1)	SSE	MSE	
Total	rab - 1	SS		

Notation: df stand for degree of freedom; a : factor levels A; b : factor level B; r : rep.; SS : sum of squares; SSA : sum of square (factor A); SSB : sum of square of factor B ; SSAB : sum of square of interaction factors A and B; SSE : sum of square of experimental error; MS : mean square; MSA : mean square of factor A; MSB : mean square of factor B; MSAB : mean square of interaction factor A and B; MSE : mean square of experimental error; F : F distribution value (F test).

When F value of computed is greater than the F value from the standard statistical table then we have to reject assumption of the null hypothesis since statistically significance difference are not same. The assumptions of null hypothesis for a two factors experiment are $\alpha_i = 0, \beta j = 0,$ and $(\alpha\beta)$ij= 0. Each F statistic may be interpreted independently.

1. Statistical results of the developed machine on the performance

Appendix Table C2 Statistical analysis of the machine capacity (kg/h) from the developed corn roaster.

Factors		N
TEMP (°C)	176	12
	210	12
	250	12
	260	12
WEIGHT (g)	500	16
	1000	16
	2000	16

Number of observations in the data set = 48
Dependent variable: MACHINE CAPACITY (kg/h)

Source	DF	S. S	M. S	F	Sig.	R Squared
Corrected Model	11	76.624	6.966	135.28	.0000	.976
Intercept	1	921.289	921.289	17892.24	.0001	.998
TEMP	3	17.698	5.899	114.56	.0000	.905
WEIGHT	2	55.715	27.857	541.01	.0000	.968
TEMP * WEIGHT	6	3.212	.535	10.39	.0000	.634
Error	36	1.854	.051			
Total	48	999.767				
Corrected Total	47	78.478				

a Computed using alpha = .05
b R Squared = .976 (Adjusted R Squared = .969)

Tests of Hypotheses using the ANOVA and statistical table as an error term

Source	DF	S. S	M. S	F com.	F table	Remark
TEMP	3	17.698	5.899	114.56	2.888	F com>F table (S)
WEIGHT	2	55.715	27.857	541.01	2.286	F com>F table (S)
TEMP * WEIGHT	6	3.212	.535	10.39	2.386	F com>F table (S)

S = Significance (all treatment levels are different)

Grand Mean:
Dependent Variable: MACHINE CAPACITY

Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
4.381	.033	4.315	4.447

Appendix Table C2 (continued)

TEMP * WEIGHT (interaction)
Dependent Variable: MACHINE CAPACITY

TEMP (°C)	WEIGHT (g)	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
176	500	2.343	.113	2.112	2.573
	1000	3.520	.113	3.290	3.750
	2000	4.685	.113	4.455	4.915
210	500	2.690	.113	2.460	2.920
	1000	4.360	.113	4.130	4.590
	2000	5.628	.113	5.397	5.858
250	500	3.053	.113	2.822	3.283
	1000	4.945	.113	4.715	5.175
	2000	5.772	.113	5.542	6.003
260	500	3.613	.113	3.382	3.843
	1000	6.065	.113	5.835	6.295
	2000	5.900	.113	5.670	6.130

Multiple Range Tests (Temperature 176°C,row wise analysis)

Method: 95.0 percent LSD

	Count	Mean	Homogeneous Groups
Loaded weight 500	4	2.3425	X
Loaded weight 1000	4	3.52	X
Loaded weight 2000	4	4.685	X

Multiple Range Tests (Temperature 210°C, row wise analysis)

Method: 95.0 percent LSD

	Count	Mean	Homogeneous Groups
Loaded weight 500	4	2.7325	X
Loaded weight 1000	4	4.2275	X
Loaded weight 2000	4	5.7125	X

Multiple Range Tests (Temperature 250°C, row wise analysis)

Method: 95.0 percent LSD

	Count	Mean	Homogeneous Groups
Loaded weight 500	4	2.94	X
Loaded weight 1000	4	5.05	X
Loaded weight 2000	4	5.6975	X

Appendix Table C2 (continued)

Multiple Range Tests (Temperature 260°C, row wise analysis)

Method: 95.0 percent LSD

	Count	Mean	Homogeneous Groups
Loaded weight 500	4	3.6125	X
Loaded weight 2000	4	5.9275	X
Loaded weight 1000	4	6.0925	X

Multiple Range Tests (weight 500 g, column wise analysis)

Method: 95.0 percent LSD

	Count	Mean	Homogeneous Groups
Temp. 176°C	4	2.3425	X
Temp. 210°C	4	2.7325	X
Temp. 250°C	4	2.94	X
Temp. 260°C	4	3.6125	X

Multiple Range Tests (Weight 1000 g, column wise analysis)

Method: 95.0 percent LSD

	Count	Mean	Homogeneous Groups
Temp. 176°C	4	3.52	X
Temp. 210°C	4	4.2275	X
Temp. 250°C	4	5.05	X
Temp. 260°C	4	6.0925	X

Multiple Range Tests (Weight 2000 g, column wise analysis)

Method: 95.0 percent LSD

	Count	Mean	Homogeneous Groups
Temp. 176°C	4	4.685	X
Temp. 250°C	4	5.6975	X
Temp. 210°C	4	5.7125	X
Temp. 260°C	4	5.9275	X

Appendix Table C3 Statistical analysis of the mean power efficiency (%) from the developed corn roaster.

Factors		N
TEMP	176	12
(°C)	210	12
	250	12
	260	12
WEIGHT	500	16
(g)	1000	16
	2000	16

Number of observations in the data set = 48
Dependent variable: POWER EFFICIENCY (%)

Source	DF	S. S	M. S	F	Sig.	R Squared
Corrected Model	11	6131.988(a)	1226.398	75.357	.0000	.951
Intercept	1	65268.750	65268.750	4010.470	.0001	.995
TEMP	3	1503.854	501.285	30.802	.0000	.818
WEIGHT	2	4628.134	2314.067	142.189	.0000	.933
TEMP * WEIGHT	6	80.553	101.393	6.230	.0000	.509
Error	36	683.533	16.275			
Total	48	72084.271				
Corrected Total	47	6815.521				

a Computed using alpha = .05
b R Squared = .900 (Adjusted R Squared = .888)

Tests of Hypotheses using the ANOVA and statistical table as an error term

Source	DF	S. S	M. S	F com.	F table	Remark
TEMP	3	1503.854	501.285	30.802	2.888	F com>F table (S)
WEIGHT	2	4628.134	2314.067	142.189	3.286	F com>F table (S)
TEMP * WEIGHT	6	80.553	101.393	6.230	2.386	F com>F table (S)

S = Significant (all treatment levels are not same)
Grand mean:
Dependent Variable: Power efficiency (%)

		95% Confidence Interval	
Mean	Std. Error	Lower Bound	Upper Bound
36.875	.582	35.700	38.050

Appendix Table C3 (continued)

Multiple Range Tests (Temperature 176°C, row wise analysis)

Method: 95.0 percent LSD

Loaded weight (g)	Count	Mean	Homogeneous Groups
500	4	9.1825	X
1000	4	14.3825	X
2000	4	19.9	X

Multiple Range Tests (Temperature 210°C, row wise analysis)

Method: 95.0 percent LSD

Loaded weight (g)	Count	Mean	Homogeneous Groups
500	4	10.3075	X
1000	4	16.9225	X
2000	4	23.1	X

Multiple Range Tests (Temperature 250°C, row wise analysis)

Method: 95.0 percent LSD

Loaded weight (g)	Count	Mean	Homogeneous Groups
500	4	11.21	X
1000	4	19.955	X
2000	4	22.6625	X

Multiple Range Tests (Temperature 260°C, row wise analysis)

Method: 95.0 percent LSD

Loaded weight (g)	Count	Mean	Homogeneous Groups
500	4	14.7325	X
2000	4	24.87	X
1000	4	26.1475	X

Multiple Range Tests (Weight 500 g , column wise analysis)

Method: 95.0 percent LSD

Temperature (°C)	Count	Mean	Homogeneous Groups
176	4	9.1825	X
210	4	10.3075	X X
250	4	11.21	X
260	4	14.7325	X

Appendix Table C3 (continued)

Multiple Range Tests (Weight 1000 g, column wise analysis)

Method: 95.0 percent LSD

Temperature (°C)	Count	Mean	Homogeneous Groups
176	4	14.3825	X
210	4	16.9225	X
250	4	19.955	X
260	4	26.1475	X

Multiple Range Tests (Weight 2000 g, column wise analysis)

Method: 95.0 percent LSD

Temperature (°C)	Count	Mean	Homogeneous Groups
176	4	19.9	X
250	4	22.6625	X
210	4	23.1	X
260	4	24.87	X

Appendix Table C4 Statistical analysis of the mean partial roasting efficiency (%) from the developed corn roaster.

Factors		N
TEMP	210	9
(°C)	250	9
	260	9
TIME	11	9
(min.)	13	9
	15	9

Number of observations in the data set = 27
Dependent variable: PARTIAL ROASTING EFFICIENCY (%)

Source	DF	S. S	M. S	F	Sig.	R Squared
Corrected Model	8	1021.090(b)	127.636	27.313	.000	.924
Intercept	1	19001.051	19001.051	4066.094	.000	.996
TEMP	2	736.794	368.397	78.834	.000	.898
TIME	2	245.626	122.813	26.281	.000	.745
TEMP * TIME	4	38.670	9.667	2.069	.127	.315
Error	18	84.115	4.673			
Total	27	20106.256				
Corrected Total	26	1105.204				

a Computed using alpha = .05
b R Squared = .924 (Adjusted R Squared = .890)

Tests of Hypotheses using the ANOVA and statistical table as an error term

Source	DF	S. S	M. S	F com.	F table	Remark
TEMP	2	736.794	368.397	78.834	3.566	F com>F table (S)
TIME	2	245.626	122.813	26.281	3.566	F com>F table (S)
TEMP * TIME	4	38.670	9.667	2.069	2.946	F com<F table (NS)

S = significant ; NS = not significant (for interaction not enough at $P < 0.05$)
Grand Mean:
Dependent Variable: Partial Roasting Efficiency (%)

		95% Confidence Interval	
Mean	Std. Error	Lower Bound	Upper Bound
26.528	.416	25.654	27.402

Appendix Table C4 (continued)

Temperature * Time (Interaction)
Dependent Variable: Roasting efficiency (%)

TEMP (°C)	TIME (min.)	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
210	11	37.753	1.248	35.131	40.375
	13	35.920	1.248	33.298	38.542
	15	27.857	1.248	25.235	30.479
250	11	26.870	1.248	24.248	29.492
	13	24.487	1.248	21.865	27.109
	15	19.937	1.248	17.315	22.559
260	11	25.023	1.248	22.401	27.645
	13	20.993	1.248	18.371	23.615
	15	19.913	1.248	17.291	22.535

Homogeneous subset (Temperature factor)
Duncan's and Tukey Multiple Range Test for variable: Partial Roasting Efficiency

	TEMP (°C)	N	Subset 1	2
Tukey HSD(a,b)	260	9	21.9767	
	250	9	23.7644	
	210	9		33.8433
	Sig.		.213	1.000
Duncan(a,b)	260	9	21.9767	
	250	9	23.7644	
	210	9		33.8433
	Sig.		.096	1.000

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares error term is Mean Square (Error) = 4.673.
a Uses Harmonic Mean Sample Size = 9
b Alpha = .05.

Homogenous subset (Time factor)

	TIME	N	Subset 1	2	3
Tukey HSD(a,b)	15.00	9	22.5689		
	13.00	9		27.1333	
	11.00	9			29.8822
	Sig.		1.000	1.000	1.000
Duncan(a,b)	15.00	9	22.5689		
	13.00	9		27.1333	
	11.00	9			29.8822
	Sig.		1.000	1.000	1.000

Appendix Table C4 (continued)

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares error term is Mean Square (Error) = 4.673.
a Uses Harmonic Mean Sample Size = 9.000.
b Alpha = .05.

Appendix Table C5 Statistical analysis of the mean fully roasting efficiency (%) from the developed corn roaster.

Factors		N
TEMP	210	9
(°C)	250	9
	260	9
TIME	11	9
(min.)	13	9
	15	9

Number of observations in the data set = 27
Dependent variable: FULLY ROASTING EFFICIENCY (%)

Source	DF	S. S	M. S	F	Sig.	R.Squared
Corrected Model	8	1021.090(b)	127.636	27.313	.000	.924
Intercept	1	145749.051	145749.051	31189.289	.000	.999
TEMP	2	736.794	368.397	78.834	.000	.898
TIME	2	245.626	122.813	26.281	.000	.745
TEMP * TIME	4	38.670	9.667	2.069	.127	.315
Error	18	84.115	4.673			
Total	27	146854.256				
Corrected Total	26	1105.204				

a Computed using alpha = .05
b R Squared = .924 (Adjusted R Squared = .890)

Tests of Hypotheses using the ANOVA and statistical table as an error term

Source	DF	S. S	M. S	F com.	F table	Remark
TEMP	2	736.794	368.397	78.834	3.566	F com>F table (S)
TIME	2	245.626	122.813	26.281	3.566	F com>F table (S)
TEMP * TIME	4	38.670	9.667	2.069	2.946	F com>F table (NS)

S = significant; NS = not significant (Interaction levels are almost same at P<0.05)

Appendix Table C5 (continued)

Grand Mean
Dependent Variable: Fully roasting efficiency (%)

		95% Confidence Interval	
Mean	Std. Error	Lower Bound	Upper Bound
73.472	.416	72.598	74.346

TEMP * TIME (Interaction)
Dependent Variable: Roasting efficiency (%)

TEMP (°C)	TIME (min.)	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
210	11	62.247	1.248	59.625	64.869
	13	64.080	1.248	61.458	66.702
	15	72.143	1.248	69.521	74.765
250	11	73.130	1.248	70.508	75.752
	13	75.513	1.248	72.891	78.135
	15	80.063	1.248	77.441	82.685
260	11	74.977	1.248	72.355	77.599
	13	79.007	1.248	76.385	81.629
	15	80.087	1.248	77.465	82.709

Homogenous subset (Temperature factor)

Roasting efficiency (%)

	TEMP (°C)	N	Subset 1	2
Tukey HSD(a,b)	210	9	66.1567	
	250	9		76.2356
	260	9		78.0233
	Sig.		1.000	.213
Duncan(a,b)	210	9	66.1567	
	250	9		76.2356
	260	9		78.0233
	Sig.		1.000	.096

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares in the error term is Mean Square (Error) = 4.673.
a Uses Harmonic Mean Sample Size = 9.000.
b Alpha = .05.

Appendix Table C5 (continued)

Homogenous subset (Time factor)

	TIME (min.)	N	Subset 1	2	3
Tukey HSD(a,b)	11	9	70.1178		
	13	9		72.8667	
	15	9			77.4311
	Sig.		1.000	1.000	1.000
Duncan(a,b)	11	9	70.1178		
	13	9		72.8667	
	15	9			77.4311
	Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares in the error term is Mean Square (Error) = 4.673.

a Uses Harmonic Mean Sample Size = 9.000.

b Alpha = .05.

CIRRICULUM VITAE

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