Performance Evaluation of Maize Roasting Machine

Basil Olufemi Akinnuli
Department of Industrial and Production Engineering
Federal University of Technology, Akure, Nigeria

Abstract. The performance evaluation of a maize roasting machine was carried out in the research with the aim of achieving efficient roasting of maize kernel. The performance evaluation of the machine was carried out using maize purchased at Ejigbo market in Osun State as a sample. The machine was tested with 1000 g of peeled and unpeeled maize with three different temperature modes of 200°C, 300°C and 350°C and four different speed modes of 6.6 rpm, 15 rpm and 19 rpm. The machine optimum functional efficiency was recorded for peeled and unpeeled maize at a temperature of 200°C and the speed of 6.6rpm which were 76% and 80.9% respectively. Also the machine optimum conveyance efficiency recorded for both peeled and unpeeled maize were 76.84% and 81.4% respectively at a temperature of 200°C and the speed of 6.6 rpm. Hence, the two evaluation parameters: speed and temperature – have significant effect on the performance of the machine. The experiment shows that as the temperature increases, the conveyance efficiency decreases due to linear expansively of the metal. The temperature of 200°C with the speed of 6.6 rpm shows the optimum performance of the machine.

Key words: performance evaluation, maize, roasting machine, throughput capacity, conveyance efficiency, roasting efficiency, temperature mode, speed mode.

Introduction

Maize roasting is one of the most important tasks in the processing of maize kernels for the production of corn starch, corn oil, corn syrup, corn sugar and by product. The kernel contains on the average about 40 - 50% oil, and is rich in carbohydrate and protein, making it a valuable feed for human being and poultry (Purseglove, 1992: 300-305; Osagie and Eka, 1998: 62). The main commercial product of maize seed processing is highly mechanized in developed countries. However, in the developing countries like Nigeria and indeed in many West African Countries traditional method of processing is the norm. This is very cumbersome and labour intensive. Maize seeds are roasted traditionally in an open mesh wire over an open wood fire (Kochhar, 1986: 88-95; Fakorede et. al., 1993: 15-39). The kernel of maize has a pericarp of the fruit fused with the seed coat referred to as "caryopsis", typical of the grasses, and the entire kernel is often referred to as the "seed" (AbdulRahaman and Kolawole, 2008: 43-49). The grains are about the size of peas, and adhere in regular rows round a white, pithy substance, which forms the ear. An ear contains from 200 to 400 kernels, and is from 10 - 25 cm (4 - lOin) in length (Ekpenyoung et. al., 1977: 710-716). The average caloric content of the whole meal from maize is 3,578 Calories per kilogram. Maize is recognized to have a high medicinal value s it contributes to the effectual cure of some illness. AbdulRahaman and Kolawole (2006: 219-227) explained some of the medicinal value of maize.

The global production of maize is estimated to about 300 million tons per year. 145 million (or about 50 per cent) are produced in USA alone (Kochhar, 1986: 88-95; Purseglove, 1992: 300-305). The seed-coat or pericarp is characterized by a high crude fibre content of about 87 percent, which is constituted mainly of hemicelluloses (67 percent), cellulose (23 percent) and lignin (0.1 percent) (Burge and Duensing, 1989: 535-538).

The germ is characterized by a high crude fat content, averaging about 33 percent. The germ also contains a relatively high level of protein (18.4 percent) and minerals (Burge and Duensing, 1989: 535-538). About 92 percent of the protein in teosinte comes from the endosperm. Protein in the maize kernel has been reported on by a number of researchers (Bressani and Mertz, 1958: 227-235, Adenola and Akinwumi, 1993: 223-232).

Table 1. Chemical Components of the Maize Kernel

Chemical Component	Pericarp	Endosperm	Germ
Protein	3.7	8.0	18.4
Ether Extract	1.0	0.8	33.2
Crude Fibre	86.7	2.7	8.8
Ash	0.8	0.3	10.5
Starch	7.3	87.6	8.3
Sugar	0.34	0.62	10.8

Source: (Watson, 1987: 55).

Aside the above components, vitamins in large quantities have been found present in maize and this implies that it is a complete food for low level income people. A report from Osagie and Eka (1998: 62) and Ekpenyoung et. al. (1977: 710-716) stated that maize is the second most important cereal crop in Nigeria ranking behind sorghum in the number of people it feeds.

Maize uses includes: corn starch, corn oil, maize gluten, grain alcohol, starch source for beer, commercial animal food products, popcorn production, plastic, fabrics, adhensive, livestock and poultry feed, biofuel and fodder to mention few (Olaofe, 1988: 191-194; Burge and Duensung, 1992: 535-538).

The maize processing starts from the harvesting of stage down to the last point in the chain order Harvesting → Dehulling → Drying or Roasting → Shelling Winnowing → Further Processing. Drying is of greate importance because it prevents germination, growth of bacteria and fungi and retard considerably the development of mites and insects. One of the problem in tropical areas is high relative humility due to rainfall, poor insulation levels and shortage of household labour. Roasting is done to maize in order to serve as a cooking means and this is done by directly placing it on fire unthrashed. In few minutes of 15 to 20 minutes, the maize gets done. Thus is done mechanically by placing threshold maize kernels in mechanical dryers at very high and controlled temperature.

Ayatse et. al., (2003: 135-147) reported that the proximate analysis showed no significant difference ($p > 0.05$) between raw and roasted maize in ether extract, crude protein, crude fibre, ash and carbohydrate content; except moisture content ($p > 0.05$), which showed a 42.3% decrease. Elemental composition analysis showed decreases of potassium (13.8%) and calcium (41.1%). Significant differences ($p < 0.05$) were observed for vitamins B_t, 82 and C contents with 26.8%, 32.4% and 35.1% destruction, respectively. Amino acid analysis showed losses for lysine (26.7%), iso-leucine (20.8%) and leucine (23.4%). There was significant ($p < 0.05$) variation in phytic acid, oxalic acid, tannin and hydrocyanic acid with reductions of 15.4%, 6.02%, 51.3% and 34.6% respectively. This result simply shows that there is a direct effect of temperature and other factors on the nutritive values of the maize product depending on the extent of exposure to high temperature or the level of temperature. Sample of roasted corn is shown in Fig. 1.

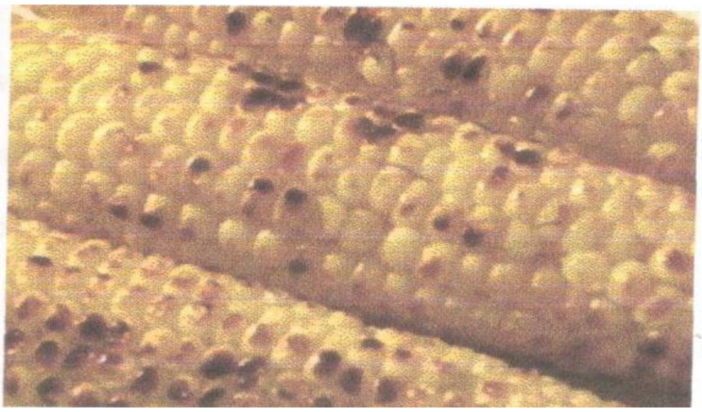

Fig. 1. Roasted corn. Source: (Ayatse et. al., 2003: 136)

Factors affecting mechanical roasting were listed by (Bressani and Mertz, 1958: 227-235; Adenola and Akinwumi, 1993: 223-232) as temperature of the drying chamber, humidity level of the drying chamber, flow direction and intensity (flow rate) of the drying air (if present); area of exposed surface of the food particle, composition and structure of food, speed and pitch of screw conveyor. Burge and Duensing (1989: 535-538) discussed processing and dietary fiber ingredient applications of corn bran. While Watson (1987: 22) and Purseglove (1992: 300-305) worked on structure and composition maize as well as complexity of carbon content of maize. Processing of maize stated includes: harvesting, dehulling drying or roasting, shelling, winnowing and further processing (AbdulRahaman, 1996: 22).

The most popular models are TCR (Texas Corn Roaster), Original Corn Roaster, and roasters made by Holstein. These three manufacturers make excellent corn roasters (Watson, 1987: 53-82; Fakorede et. al., 2002: 15-39). The models are shown in Fig. 2.

Fig. 2. TCR's Corn Roaster. Source: (Fakorede et,al., 2002: 21)

Materials and Methodology

Maize kernel was used to carry out the performance evaluation of the roasting machine which was obtained from Ejigbo market in Osun State. White maize was adopted for the experiment and kept in air tight place in order to prevent moisture re -absorption and in order to maintain constant moisture content throughout the course of the experiment. Some of the experiment used include: the electric digital weigh balance, bowls, grain moisture meter and the tachometer which was used for measuring the speed of the grains conveyor shaft.

The maize roaster consisted of a cylindrical drum which was placed horizontally on a frame. Inside the drum was affixed a screw conveyor which moves and mixes the maize kernels from the inlet point of the roaster to the exit point. Heat was supplied to the roasting chamber by a means of electric heating rods which were placed in beneath the roasting chamber. The length of the rods was nearly equivalent to the length of the roasting chamber. Fiber glass was used as insulation between the roasting chamber and the outer cover of the machine in order to prevent heat loss and hazards due to touching of the outer part of the machine. The heater and the screw conveyors are regulated. The temperature is measured and controlled by a temperature regulator to which thermocouple wires are attached. The thermocouple wire was linked into the machine to the base of the roasting chamber. Fig. 3 shows the roasting machine and Fig. 4 shows the internal view of the machine.

Fig. 3. The Maize Roaster

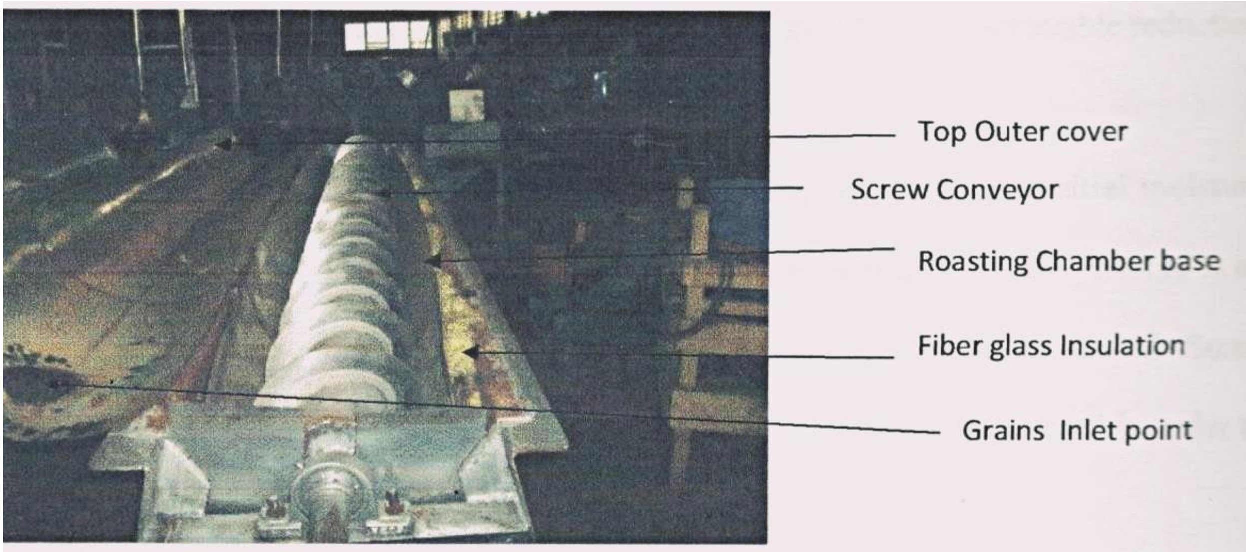

Fig. 4. Internal View of Maize Roaster.

The machine was powered by variable electric gear motor which is connected to the screw conveyor by means of belts and pulley. When the machine is switch on, the screw conveyor moves and then the heating elements are powered on. The temperature regulator is set to a certain temperature of about 200°C and at a point when the temperature is up to that level, the regulator switches off the heating element. When the materials are fed into the machine, the screw conveyor pushes the grains forward and as well, mixes them in order to have uniform contact with the heating surface. The roasted grains are collected at the exit point of the machine.

The experiment was carried out at four speeds of the screw conveyor. This was done in order to check for the effect of auger speed on the evaluation parameters. The speeds chosen were 6.6 rpm, 11 rpm, 15 rpm and 19 rpm. All the speeds were derived by using various pulley sizes on the screw conveyor and the power or motion was generated from an adjustable reduction gear motor which had the highest speed of l00 rpm.

Grains of constant mass (1000 g) were introduced to the machine. The initial moisture contents of the grains were recorded before introducing to the roaster and the temperature is as well recorded. The final weight and moisture content of the products were measured. Some products were left in the roaster so these were retrieved and the weight was measured in order to check for the conveyance efficiency of the roaster.

The effects of roasting temperature were checked by conducting the experiments at three temperature levels of 200°C, 300°C and 350°C. Also, some maize kernels were peeled and roasted at the same temperatures in order to check for the optimum grain condition for the roaster to achieve the best performance. The time taken for each experiment was recorded using a stopwatch.

The machine was checked at four conditions of speed and three temperature conditions. The evaluation parameters used to check the machine were:

- Machine through put capacity
- Conveyance efficiency
- Roasting efficiency

All above parameters were derived for each test and the overall values were recorded and compared.

Determination of Evaluation Parameters

- Throughout capacity

The machine was fed at constant feed rate therefore the through put capacity was derived as the ratio of collected product to the time spent in the roasting chamber, this is given mathematically as: *M*

$$C_t = \frac{M_f}{t} \quad \ldots (2.1)$$

Where:

C_t = Throughout put capacity

Mf = Final mass of collected product

t = Roasting Time

- Roasting (Functional) efficiency

The roasting efficiency was calculated as the ratio in percentage of the collected products to the initial mass of products let into the machine. This is represented mathematically as:

$$R.E = \frac{M_f}{M_f} x\ 100\% \quad \ldots. (2.2)$$

Where,

Mf = Final mass of collected product MI = Initial mass of maize MI is constant all through experiment and is given as 1000g

- Conveyance efficiency

Some products were observed to be left in the machine conveyed and the percentage of conveyed products is given as:

$$C.E = \frac{M_f}{M_r + M_f} x\ 100\% \quad \ldots. (2.3)$$

Where:

C. E. - Conveyance Efficiency

M_r = Mass of retained products (retrieved from the roaster)

Mf = Final mass of collected product

Results

The results of performance evaluation of maize roaster are as follow:

- Effect of Temperatures, Speed and Treatment on throughout Capacity

The results from the experiments showed that the throughput capacity of the machine had a directly proportional relationship with speed of screw conveyor. Highest capacity of 19.12 kg/hr was recorded at 19 rpm. A non - significant trend was found between the throughput capacity and the temperature. It was also noticed that lower capacities were recorded at lower temperatures (Fig. 5, 6).

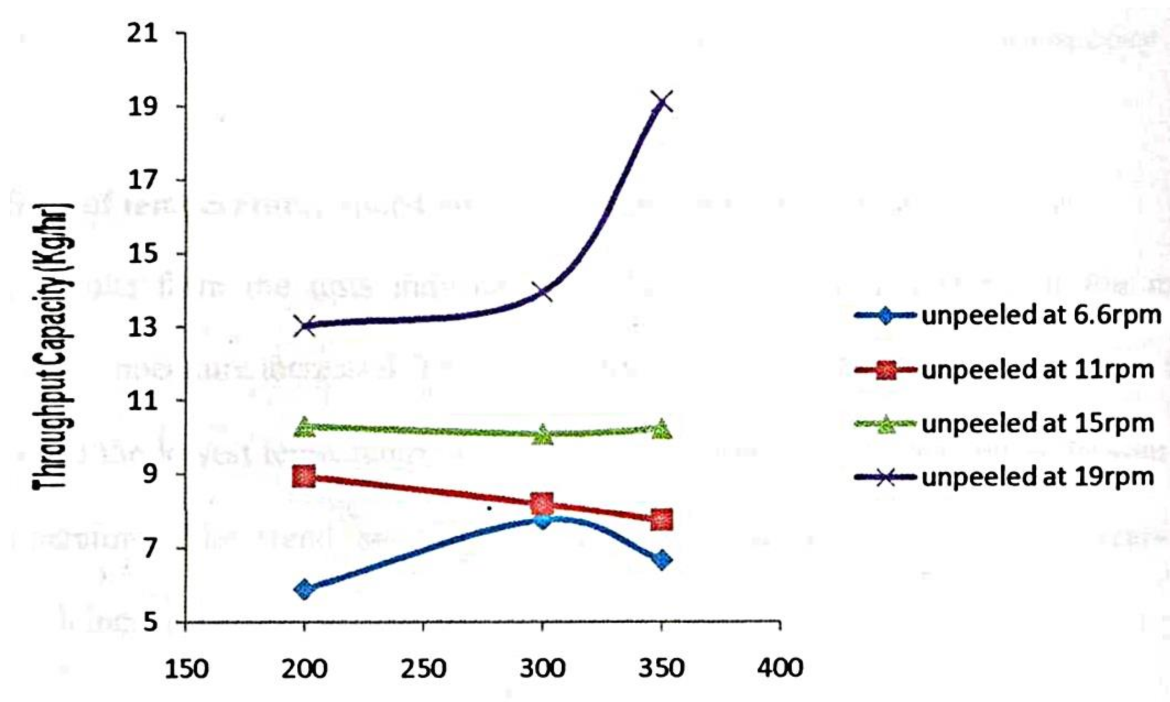

Fig. 5. Effects of temperature, speed and treatment on throughput capacity

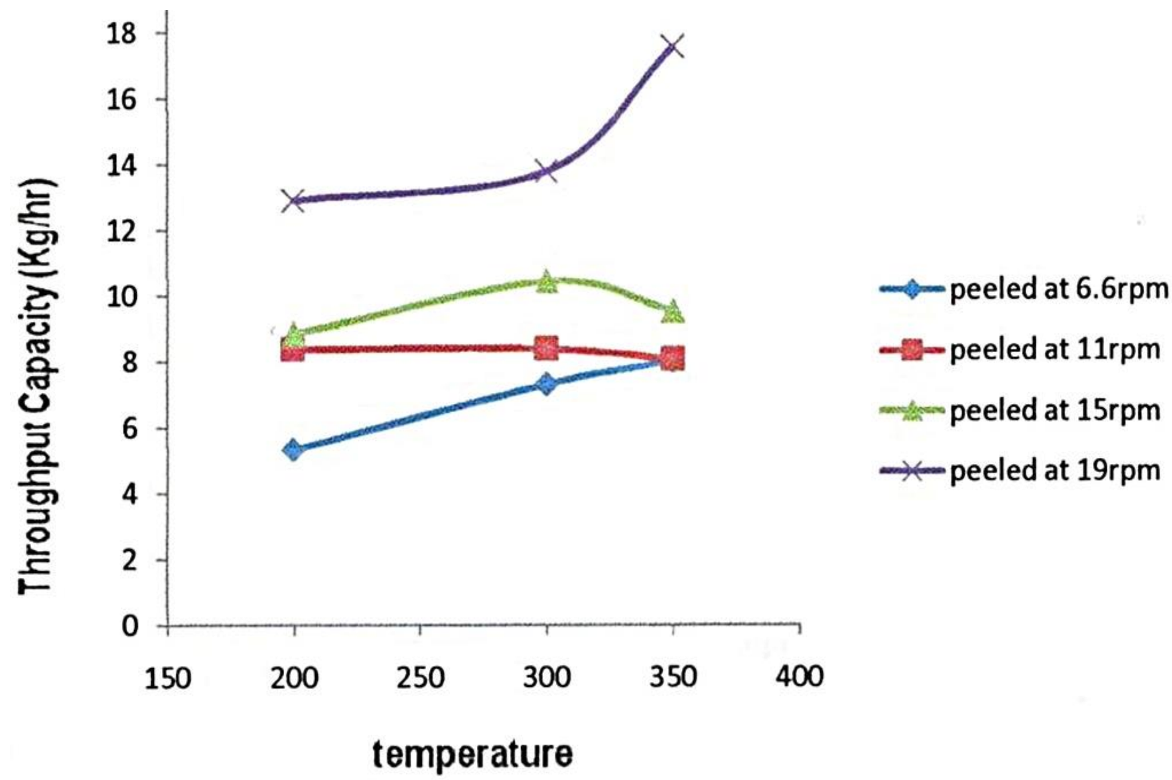

Fig. 6. Effects of temperature, speed and treatment on throughput capacity

- Effect of Temperature, Speed and Treatment on Conveyance Efficiency

The results from the tests indicated that the conveyance efficiency of the machine reduced as the temperature increased. The highest conveyance efficiency 81.47 % of the machine was obtained at the lowest temperature of 200°C and the lowest was obtained at 19 rpm and at 350°C temperature. The trend showed a continuous reduction in machine's conveyance efficiency with increase in temperature and increase in speed (Fig. 7, 8).

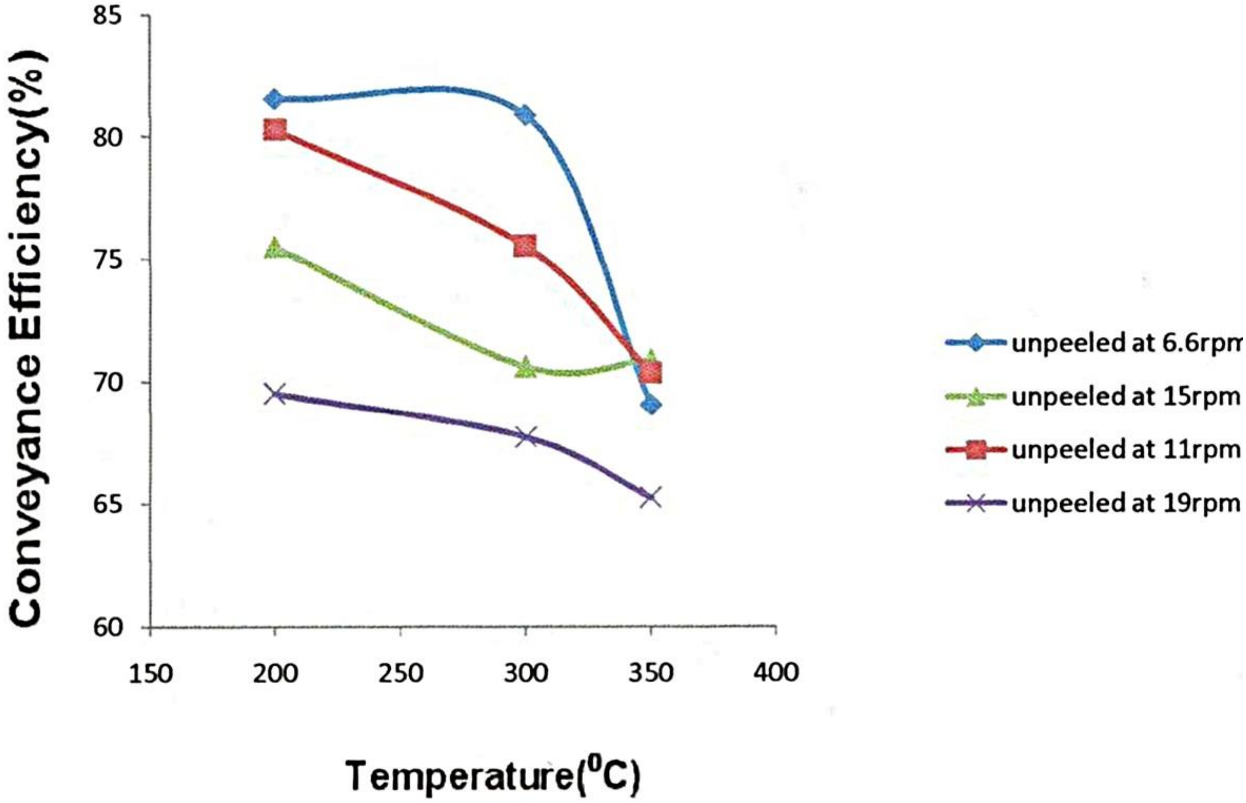

Fig. 7. Effects of Temperature, Speed and Treatment on Conveyance Efficiency

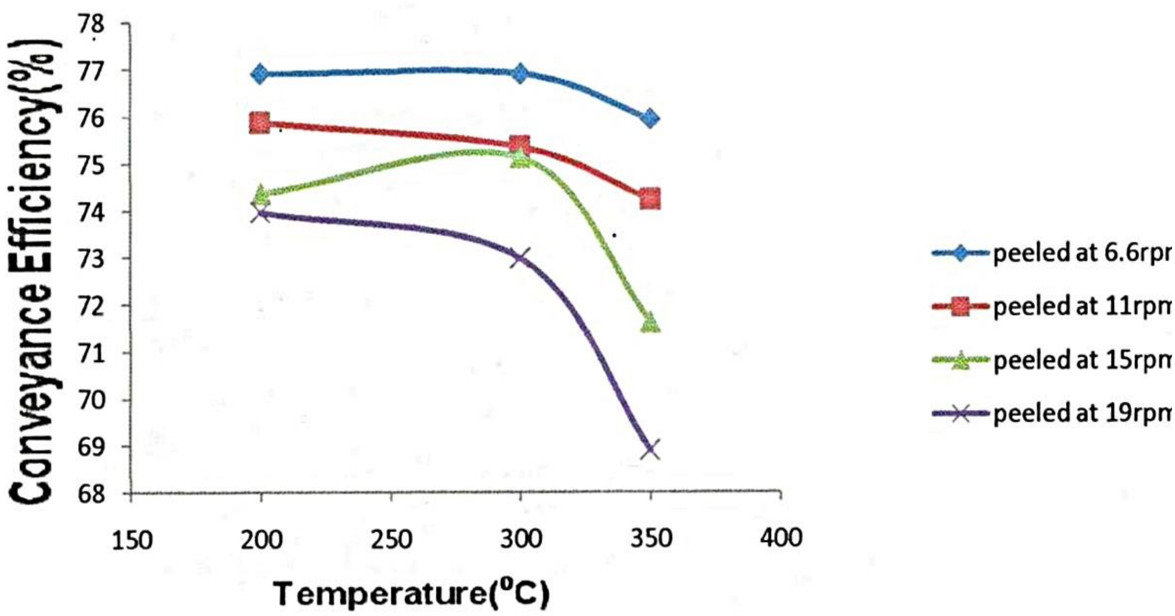

Fig. 8. Effects of Temperature, Speed and Treatment on Conveyance Efficiency

- Effects of Temperature, Speed and Treatment on Roasting Efficiency

Roasting efficiency from Figure 3 shows a similar reduction trend as does the conveyance efficiency. For all tests carried out, conveyance efficiency reduces as temperature increases and also as the speed increases. This is an inversely proportional relationship between speed, and roasting efficiency and temperature, it can be given mathematically as:

$$T \propto \frac{1}{R.E} \qquad \ldots..(3.1)$$

Where, T = Temperature; R.E = Roasting Efficiency.

$$S \propto \frac{1}{R.E} \qquad \ldots..(3.2)$$

This indicates that optimum performance can only be derived at low speed and temperature as the highest R. E. of 80.9% was derived at 200°C and at 6.6 rpm. The peeled kernels were also observed to have lower roasting efficiencies than the unpeeled at every tests carried out (Fig. 9, 10).

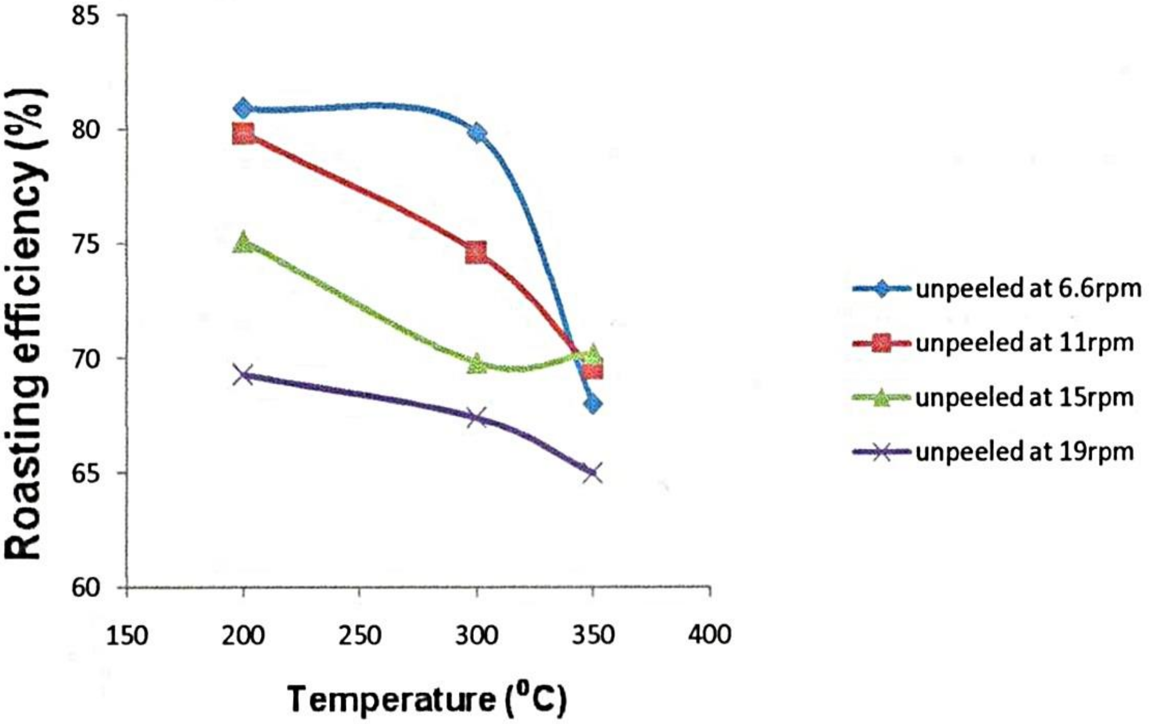

Fig. 9. Effects of Temperature, Speed and Treatment on Roasting Efficiency

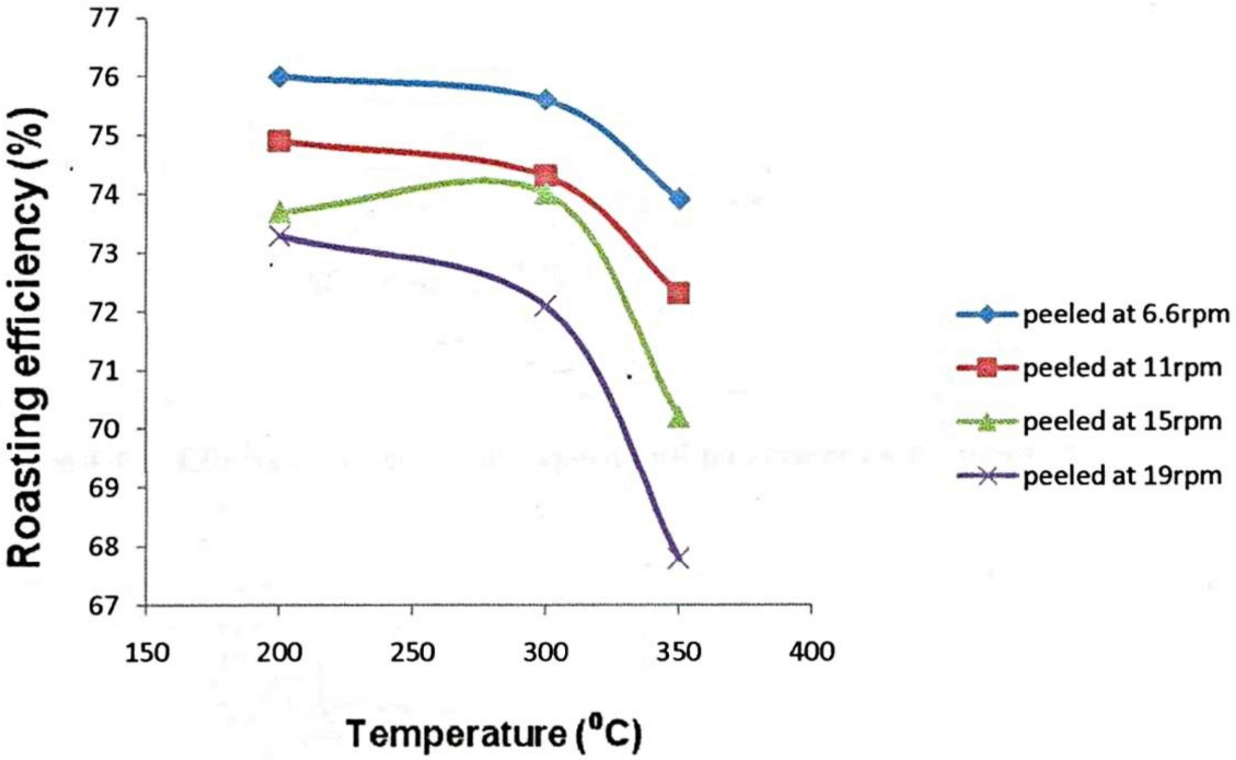

Fig. 10. Effects of Temperature, Speed and Treatment on Roasting Efficiency

- Effects of Temperature, Speed and Treatment on Roasting time

The time taken for maize to come out of the chamber was found to be reduced as the speed of screw conveyor increases. Also, peeled maize spent higher duration in the roasting chamber before coming out. The highest time taken of 8.57 s was recorded at 200 rpm and the lowest duration of 2.04 min was recorded at 19rpm for unpeeled maize kernels (Fig. 11, 12).

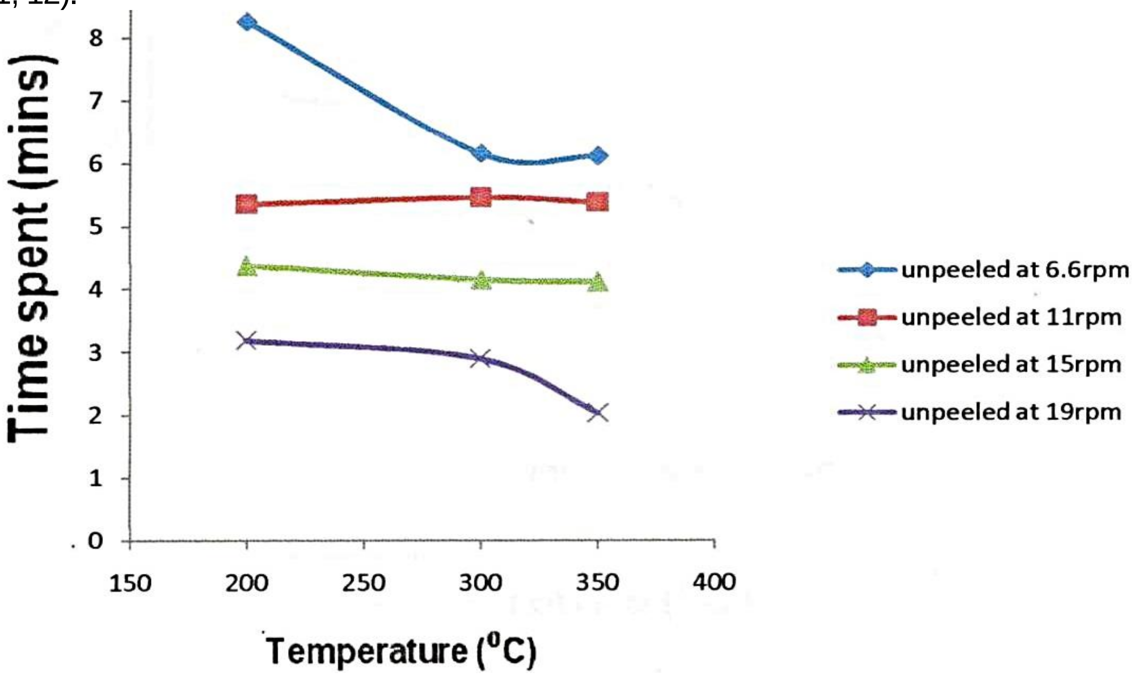

Fig. 11. Effects of Temperature, Speed and Treatment on Roasting time

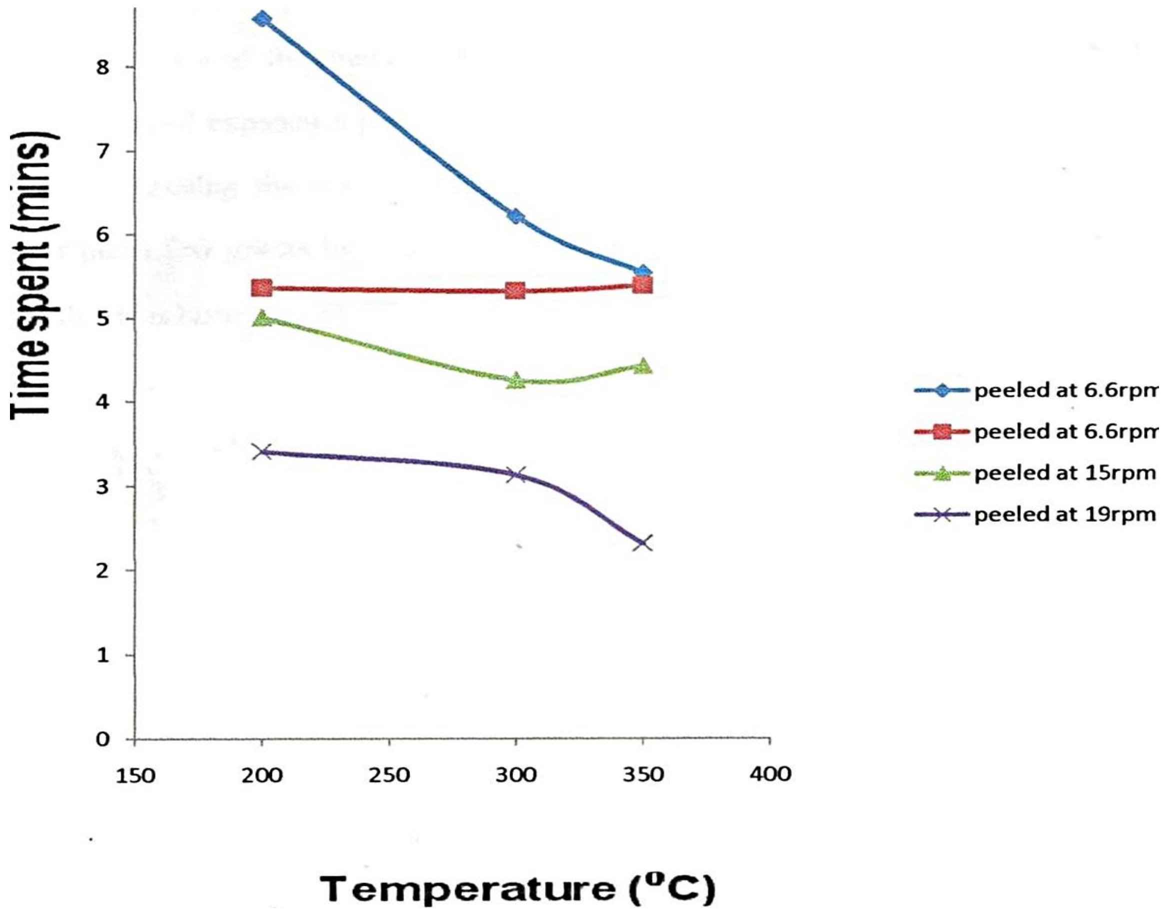

Fig. 12. Effects of Temperature, Speed and Treatment on Roasting time.

Discussion

The machine exhibited the maximum efficiencies at the lowest speed tested (200 rpm). The conveyance efficiency of the machine was low at temperature higher than 200°C and 6.6 rpms as nearly 20% of the materials are retained in the machine. This can be explained to be caused by thermal expansion that occurs on the roasting chamber as temperature becomes too high thereby causing the conveyor to pick few grains per time. Also, at higher speeds, the conveyor picks few grains leaving some in the roasting chamber. An optimum performance of the machine was however obtained at 200°C and 6.6 rpm speed of the conveyor.

Conclusion

At the end of the experiment, 1000 g of unpeeled maize processed at 200°C, 300°C and 350°C temperature at the same speed of 6.6 rpm, recorded a conveyance efficiency 81.47%, 80.76% and 69.02% respectively. It can be concluded that as temperature increases, the conveyance efficiency reduces at the same speed.

At 200°C, 300°C and 350°C temperature at the same speed of 11 rpm, conveyance efficiency recorded were 80.28%, 75.35% and 70.30% respectively. Concerning 15 rpm and 19 rpm, similar trend was recorded.

The highest roasting efficiency recorded was 80.9% at the temperature of 200°C and speed of 6.6 rpm. For the peeled maize treatment, the highest conveyance efficiency was 76.84% at the speed 6.6rpm and temperature of 200°C while the roasting efficiency was 76% at speed of 6.6 rpm and 200°C temperature.

Therefore, it can be concluded from the experiment that as the temperature increases, the conveyance efficiency decreases, this could as a result of thermal expansion of the material used in the roasting chamber. The temperature at 200°C with the speed of 6.6 rpm shows the optimum performance of the machine.

Limitation

The conveyance means should be improved in order to reduce the quantity of maize retained in the chamber. Roasting should only be carried out between 200°C and 300°C in order to achieve good roasting.

References

AbdulRahaman, A. A. (1996). *Medicinal Importance of Plants*. In: The Frontiers. 1st Ed. Edited by K. A. Omotoshe, Elepo Press, Ilorin, pp. 22-25.

AbdulRahaman, A. A. and Kolawole O. M. (2008). *Traditional Preparations and Uses of Maize in Nigeria,* 43-49.

AbdulRahaman, A. A. and Kolawole, O. M. (2006). Traditional Preparations and Uses of Maize in Nigeria. *Ethnobotanical Leaflets,* 10, 219-227.

AbdulRahaman, H. (1999). *Maize: Its Agronomy, Diseases, Pests and Food Values*. Optimal Computer Solutions Limited, Enugu.

Adenola, O. A. and Akinwumi, J. A. (1993). Maize production constraints in Nigeria. In: *Maize Improvement, Production and Utilization in Nigeria*. Maize Association of Nigeria, pp. 223-232.

Ayatse, J. O., Eka, O. U., Ifon, E. T. (1983). Chemical Evaluation of the Effect of Roasting on the nutritive value of maize (Zea mays, Linn.). *Food Chemistry*, 12 (2), 135-147.

Bressani, R. and Mertz, E. T. (1958). Studies on Corn Protein. IV. Protein and Ammo Acid Content of Different Corn Varieties. *Cereal Chem*., 35, 227-235.

Burge, R. M. and Duensing, W.J. (1989). Processing and dietary fiber ingredient applications of corn bran. *Cereal Foods World*, 34, 535-538.

Ekpenyoung, T. E., Fatuga, B. L. and Oyenuga, V. A. (1977). Fortification of maize flour based diets with blends of cashew nut meal, African locust bean meal and sesame oil meat. *J. Set. Food Agric.,* 28*,* 710-716.

Fakorede, M. A. B, Fajemisin, J. M., Kim, S. K., Been, J. E. (1993). *Maize improvement in Nigeria*. In: MAB, pp. 15-39.

Kochhar, S. L. (1986). *Tropical Crops: A Textbook of Economic Botany.* Hong Kong: Macmillian Publishers, pp. 88-95.

Olaofe, O. (1988). Mineral Contents of Nigeria grains and baby foods. *J. Sci. Food Agric.,* 5,191-194.

Osagie, A. U. and Eka, O. U. (1998). *Nutritional Quality of Plant Foods*. 1 st ed. The Post-Harvest Research Unit. Benin: UNIBEN, pp. 62.

Purseglove, J. W. (1992). *Tropical Crops (Dicotyledons)*. Longman House Burnt Mill, Harlow, Essex CM20 2 JE, pp. 300-305.

Watson, S. A. (1987). *Structure and Composition*. In: Corn: chemistry and technology (Watson, S. A., Ramstad, P. E., eds). Am Assoc Cereal Chem, Inc St Paul, MN, USA, pp. 53-82.