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RESEARCH ARTICLE :

Design and development of charcoal fuelled corn roaster

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SUMMARY : In India, roasted corn is a popular snack which is sold on the roadsides by street vendors. However, consumers have become more health conscious and are slowly becoming aware of the ill-effects caused to their health upon consuming the roasted corn. This problem has arisen owing to the adherence of charcoal ash onto the corns as they are roasted directly on the charcoal cinders without any protective covering. Consequentially, the vendors not afford better technology needed for roasting them. Addressing the mentioned issues, a charcoal-fuelled corn roaster was developed and tested for its roasting efficiency on two corn varieties namely, Dent corn and Sweet corn. The roaster was integrated with a fan to blow air onto the charcoal cinders and keep them red-hot. Provision was made to vary the speed of the driving sprocket and roasting time. The effects of the sprocket speed (0, 70 and 100 rpm) and roasting time (2, 3, and 4 minutes) on percentage of roasted kernels, percentage of over roasted kernels, roasting efficiency and roasting capacity of the developed roaster were studied. For optimum roasting efficiency of the roaster, 100 rpm sprocket speed and roasting times of 4 minutes and 3 minutes were found appropriate for roasting Dent Corn and Sweet Corn, respectively. The cost of roasting corns with the developed roaster was Rs. 0.578 per corn and the Cost: Benefit ratio was worked out to be 1.00:5.19. The developed Corn Roaster was found to be advantageous for roasting the selected corn varieties.

KEY WORDS :
Dent corn, Sweet corn, Roaster, Sprocket speed, Roasting time

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BACKGROUND AND OBJECTIVES

The name maize is derived from the South American Indian Arawak-Carib word mahiz. Maize (*Zea mays*) is the most important cereal crop in the world after wheat and rice with regard to cultivation areas and total production (Abdulrahaman and Kolawole, 2006). Corn (*Zea mays*) is an important cereal crop plant belonging to the *Poaceae* family. It is also recognized by different synonyms such as Zea, Corn, Silk Corn, Maize etc. In Hindi it is called *Makka* and *Barajovar*.

Corn is considered to be the earliest cultivar of the new world and is valuable as livestock feed, human food and raw material for several industries. Roasted corns are liked by many people, especially during the winter and rainy seasons. The way the corns are roasted in India is detrimental to the health of the consumers as the corns are roasted directly on the charcoal cinders causing adherence of coal ash on the corns. In short, coal ash toxics have the potential to injure all of the major organ systems, damage physical health and development, and even contribute to mortality (Shrivastava *et al.*, 2015).

As a product of consumption, corn is quite vulnerable to adulteration, since it presents physical characteristics (particle size, texture and color) that are easily reproduced by roasting. (Oliveira *et al.*, 2009). Roasting, as the word implies, is the working mechanism by which the food product material are thermally subjected into irreversible structural changes and reduction of moisture contents purposely to bring about digestible content for human consumption (Fellows, 2000).

Roasting the corns by indirect contact with the charcoal cinders can generate better profits for the vendors who generally are below the poverty line and at the same time, it can also nullify the ill-effects being caused currently due to consumption of the roasted corn. The traditional way of roasting by barbecue or grilling is considered very stressful because of processes involved, which include regular blowing of air to ensure constant heat supply from heat source (charcoal) and regular changing of the position of the food item to prevent from burning (Mato and Obembe, 2008).

Technological advancement of the corn roasting process has to be made so that both consumers and vendors get benefitted.Although mechanised corn roasters are being used by street vendors in the United States and other developed countries, there are no manufacturers of Corn Roasters in India. Hence, the need of developing an affordable, efficient and user-friendly corn roaster was felt mainly to alleviate the economic condition of the street side vendors of India and other third world countries. The development of the roaster is also focussed upon preventing the adverse affects caused to consumers by consumption of coal ash with every bite of the roasted corn.

RESOURCES AND METHODS

Development of manual charcoal-fuelled corn roaster :

A simple machine that could be operated manually was designed and developed for roasting the cobs of the two varieties. The roaster was fabricated in the workshop of Department of Agricultural Processing and Food Engineering, College of Agricultural Engineering, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Sangareddy, Telangana during the year 2015-16. The following factors were considered while developing the roaster:A. Suitability of the machine to roast Dent and Sweet Corn cobs B. Ease of operation and maintenance C. Energy efficiency and low operational costs.

The developed 'Charcoal-Fuelled Corn Roaster' (Fig. 1) consisted of i) Frame ii) Roasting Unit iii) Air Blowing Unit and iv) Power Transmission System. The machine was fabricated in such a way that the entire unit can be dismantled and assembled, making its transportation easy.

Frame :

The frame is made of cast iron sheet of 3 mm thickness and is rectangular in shape. The frame's length, breadth and height are 500, 280 and 90 mm, respectively. The frame is fitted with four L-angles (50.8×50.8 mm, 5 mm thickness) of length 800 mm which act as its stand. Three equidistant openings of 65 mm diameter are made lengthwise on the longer side of the frame. Similarly, on the opposite side, equidistant openings of 35 mm diameter are made. An assembly comprising two meshes of 9 openings per inch and 25 openings per inch placed former above the latter is fitted to the bottom of the frame. The hot charcoal cinders are filled into the space formed by frame and mesh assembly, upto the desired depth. The temperature of the charcoal cinders is maintained by supplying air to the bulk with the help of air blowing unit present beneath the frame.

Roasting unit :

The roasting unit is identical to a conical frustum in shape and made of stainless steel sheet of 2 mm thickness. The length and major and minor diameters of the roasting unit are 340, 65 and 35 mm, respectively. Three identical roasting units snug fit in the holes made in the frame of the roaster without using any nuts and bolts. They can also be easily removed when needed. The Corn cobs to be roasted are inserted into these conical frustums and are rotated by holding their stalks for uniform roasting of all kernels as the hot air is supplied from beneath.

Air blowing unit :

The Air Blowing Unit consists of a metallic fan which can be rotated with the help of a hand-powered chain-sprocket mechanism. The wind generated from the rotation of the fan is forced onto the bed of charcoal cinders from beneath, thus providing the heat to the roasting units. The fan is made of aluminium and has four blades, 2 mm thick and has a diameter of 480 mm. The fan is fixed upside down, at a distance of 30 mm beneath the mesh assembly.

Power transmission system :

The rotary motion of the fan is achieved through a hand-powered chain and sprocket mechanism. The chain has a length of 1540 mm with a spacing of 14 mm between consecutive links. The transmission system also comprises of two sprockets, the smaller one of 80 mm diameter with 18 teeth and the larger one of 180 mm diameter with 44 teeth. Both the sprockets are aligned horizontally and the chain runs over them. The smaller sprocket is integrated with the fan's hub and a handle is provided on the larger sprocket for its rotation.

Roasting operation :

The developed Corn roaster facilitates roasting of three cobs in each trial and before conducting trials, the labours are trained to rotate the sprocket of the transmission system at constant speeds of 70 and 100 rpm. The various performance indices of the developed Corn roaster are quantified as:

Percentage of roasted kernels :

The final percentage of roasted kernels (P_r) of the roaster was determined by calculating the mean of the percentages obtained after each trial. The percentage of roasted kernels (P_r) for one trial is given by the following equation:

$$P_r = \frac{\varepsilon_1 + \varepsilon_2 + \varepsilon_3}{3}$$

where, ε_1, ε_2, and ε_3 are the individual percentages of roasted kernels of the first, second and third roasting units respectively. They can be determined by the following equation:

$$\varepsilon_1, \varepsilon_2, \varepsilon_3 = \frac{\text{Roasted kernels}}{\text{Total kernels}} \times 100$$

Percentage of over roasted kernels :

The over roasted kernels were identified visually and counted manually. The final percentage of over roasted kernels (P_{of}) was determined by calculating the mean of the percentages obtained after each trial. The

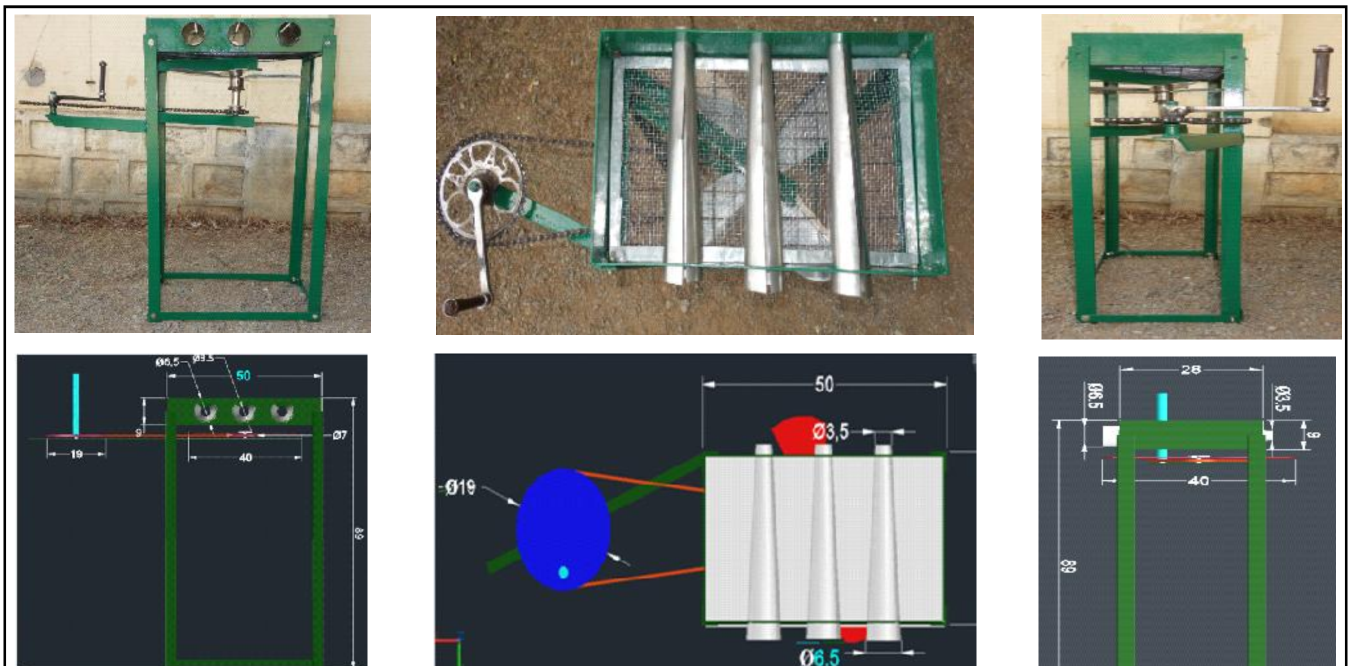

Fig. A : **Developed charcoal fuelled corn roaster (1.Frame 2.Roasting Unit 3.Air Blowing Unit 4. Power Transmission System)**

percentage of over roasted kernels (P_o) for one trial is given by the following equation:

$$P_r = \frac{P_{o1} + P_{o2} + P_{o3}}{3}$$

where, P_{01}, P_{02}, P_{03} are the individual percentages of over roasted kernels of the first, second and third roasting units respectively. They can be determined by the following equation:

$$P_{o1}, P_{o2}, P_{o3} = \frac{\text{Over roasted kernels}}{\text{Total kernels}} \times 100$$

Roasting efficiency :

The final roasting efficiency (E_f) was determined by calculating the mean of the efficiencies obtained after each trial. The roasting efficiency (E) for one trial is given by the equation:

$$E = P_r - P_o$$

Roasting capacity :

The roasting capacity (C_R) in corns per hour was calculated as given by the following equation:

$$C_R = \frac{\text{Number of corns rosted}}{\text{Time taken to roast the corns (h)}}$$

OBSERVATIONS AND ANALYSIS

The results obtained from the present study as well as discussions have been summarized under following heads:

Performance evaluation of the developed charcoal-fuelled corn roaster and optimization of operational parameters

Performance of manual charcoal-fuelled corn roaster for Dent Corn :

The performance of the developed corn roaster withDent Corn is shown in Table 1. As the sprocket speed and the roasting time increased, the roasting efficiency (E_f) of the roaster increased. There was also an increase in the percentage of roasted kernels (P_r) and percentage of over roasted kernels (P_o) with increase in the sprocket speed and roasting time. The roasting capacity (C_R) was not affected by the sprocket speed but it depended on the roasting time.

The increase in the roasting time and the sprocket speed encouraged the transfer of heat from the charcoal cinders to the corn kernels placed in the roasting units, thereby increasing the values of percentage of roasted kernels, over roasted kernels and finally, the roasting efficiency.

By looking at the three attributes (P_r, P_o and E_f), sprocket speed of 100 rpm and roasting time of 4 minutes was selected to be optimal for roasting Dent corn in the developed manual charcoal fuelled corn roaster. The roasting capacity thus obtained was 45 numbers of corns per hour.

Performance of manual charcoal-fuelled corn roaster for Sweet Corn :

The performance of the developed corn roaster with Sweet corn is shown in Table 2. As the sprocket speed and the roasting time increased, the roasting efficiency

Table 1 : Effect of sprocket speed and roasting time on operational parameter of developed charcoal-fuelled corn roaster for *Dent Corn*

Corn variety	Dent corn								
Roasting time	2 minutes (C_R = 90 corns/hour)			3 minutes (C_R = 60 corns/hour)			4 minutes (C_R = 45 corns/hour)		
Sprocket speed	P_r (%)	P_o (%)	E_f (%)	P_r (%)	P_o (%)	E_f (%)	P_r (%)	P_o (%)	E_f (%)
0 rpm	44.7	5.39	39.31	51.1	5.98	45.12	58.8	6.43	52.37
70 rpm	65.3	10.05	55.25	70.3	10.99	59.31	73.6	12.03	61.57
100 rpm	86.4	15.85	70.55	87.5	16.14	71.36	93.1	17.54	75.56

Note: P_{rf} :percentage of roasted kernels, P_{of} : percentage of over roasted kernels and E_f: roasting efficiency

Table 2 : Effect of sprocket speed and roasting time on operational parameter of developed charcoal-fuelled corn roaster for *Sweet Corn*

Corn variety	Sweet Corn								
Roasting time	2 minutes (C_R = 90 corns/hour)			3 minutes (C_R = 60 corns/hour)			4 minutes (C_R = 45 corns/hour)		
Sprocket speed	P_{rf} (%)	P_{of} (%)	E_f (%)	P_{rf} (%)	P_{of} (%)	E_f (%)	P_{rf} (%)	P_{of} (%)	E_f (%)
0 rpm	45.5	6.81	38.69	52.6	7.13	45.47	55.9	8.37	47.53
70 rpm	67.4	10.24	57.16	73.5	11.77	61.73	75.4	13.56	61.84
100 rpm	84.9	18.56	66.34	92.9	19.99	72.91	94.3	21.82	72.48

Note: P_{rf} :percentage of roasted kernels, P_{of} : percentage of over roasted kernels and E_f: roasting efficiency

Table 3 : Optimum operational parameters for best roaster performance with *Dent Corn* and *Sweet Corn*

Parameters	Dent Corn	Sweet Corn
	Sprocket speed – 100 rpm and Roasting time – 4 minutes	Sprocket speed – 100 rpm and Roasting time – 3minutes
Roasting efficiency (%)	75.56	72.91
Percentage of roasted kernels (%)	93.1	92.9
Percentage of over roasted kernels (%)	17.54	19.99
Roasting capacity (corns/h)	45	60

(E_f) of the roaster increased till a roasting time of 3 minutes after which it decreased at 4 minutes roasting time. Though there was an increase in the percentage of roasted kernels (P_r) and percentage of over roasted kernels (P_o) with increase in the sprocket speed and roasting time, the difference between the percentage of roasted and over roasted kernels was less for the roasting time of 4 minutes relative to that in 3 minutes of roasting time. The roasting capacity (C_R) was not affected by the sprocket speed but it depended on the roasting time.

The increase in the roasting time and the sprocket speed encouraged the transfer of heat from the charcoal cinders to the corn kernels placed in the roasting units, thereby increasing the values of percentage of roasted kernels, over roasted kernels and finally, the roasting efficiency. The decrease in the roasting efficiency with increase in the roasting time from 3 minutes to 4 minutes may be attributed to the thermal properties if the sweet Corn kernels.

By looking at the three attributes (P_r, P_o and E_f), sprocket speed of 100 rpm and roasting time of 3 minutes was selected to be optimal for roasting Dent corn in the developed manual charcoal fuelled corn roaster. The roasting capacity thus obtained was 60 corns per hour.

Optimum operational parameters for best roaster performance :

From the performance evaluation results of developed charcoal-fuelled corn roaster with selected two varieties of corn like Dent corn and Sweet corn. It was observed for high roasting efficiency, percentage of roasted kernels, percentage of over roasted kernels and roasting capacity effectiveness 100 rpm sprocket speed, 4 minute roasting time for Dent corn and 100 rpm sprocket speed, 3 minute roasting time for Sweet corn (Table 3).

Cost economics :

The cost economics of roasting with developed charcoal-fuelled corn roaster was worked out by taking into account the fixed cost and variable cost. The cost of roasting per corn was Rs. 0.578 in contrast to Rs. 3 per corn which is the case in conventional roasting. The Cost: Benefit ratio was obtained as 1.00:5.19.

The cost of the developed Corn Roaster is Rs. 3240 which is affordable by the street vendors. It is easy to manufacture the equipment and there is good scope for its mass production. Other advantages of the developed roaster are that it can be easily transported from one place to another and its operation requires practically no skill. Hence, the developed manual charcoal-fuelled corn roaster can be recommended for roasting Dent Corn and Sweet Corn.

Conclusion :

A charcoal-fuelled corn roaster was developed for roasting Dent corn and Sweet corn which comprised of a hand-powered fan in order to blow air onto the hot charcoal cinders, thereby roasting the corns. The developed prototype is recommended for roasting Dent corn and Sweet corn as the roasting efficiencies observed with the former and latter were 75.56% and 72.91% at fan's driving sprocket speed of 100 rpm and roasting times of 4 minutes and 3 minutes, respectively. The cost of roasting was obtained as Rs. 0.578 per corn and the Cost: Benefit ratio was worked out to be 1.00:5.19.

The future work could be focussed on improving the design of the developed corn roaster ergonomically and on decreasing the heat losses from the roaster by providing appropriate insulation to the roaster.

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