Design and development of annatto (*Bixa orellana* L.) seed separator machine

R. G. Math¹ · G. Ramesh¹ · A. Nagender¹ · A. Satyanarayana¹

Revised: 4 May 2015 / Accepted: 4 September 2015 / Published online: 15 September 2015
© Association of Food Scientists & Technologists (India) 2015

Abstract A small, continuous power operated machine with a capacity of 132 kg/h was designed, fabricated and evaluated its performance for separation of annatto (*Bixa orellana* L.) seeds from freshly harvested pods. Physical and engineering parameters of annatto pods and seeds were evaluated to design a machine. The densities of pod, seed, and husk are 134.7 to 186.0 kg/m³, 1206 to 1253.9 kg/m³, 317 to 381.4 kg/m³ respectively. The moisture content of seeds were in the range 18.83 – 20.1 % (db) and pod 8 to 10 % (db). Bixin content of seed was in the range 1.34 to 1.765 %. The friction angle for pod, seed, and husk lies between angle 30.15° to 35.76°. Breaking force was 98 N at a span of 14.5 mm. The machine consisted of concentric cylinders and beaters with different pitch of 40, 45 and 50 mm and a length of shaft is 800 mm. The actual machine output was observed to be 132.5 kg/h. Maximum bixin content was found to be retained at 300 rpm.

Keywords Annatto · Seed Separator · Design · Development · Mechanical properties · Seed quality · Fabrication · Machine

Nomenclature

N_{sh}	Rotational speed of rotor cylinder shaft in rpm
T	Torque applied, N m
P	Power, watt
E_1	Kinetic energy, joule

V_{lin}	Linear velocity m s ⁻¹
m_1	Mass of beater in N
m_2	Mass of annatto pod in N
δV	Change in velocity after collision, m s ⁻¹
E_0	Energy required to break one pod, joule
F_{max}	Maximum cutting (shear) force, N
D_{pod}	Diameter of annatto pod, m
D_{in}	Inner cylinder, m
D_{eff}	Effective diameter, m
g	Gravitational force, 9.81 ms ⁻¹
D_{sh}	Diameter rotor cylinder shaft, m
K_t	Co-efficient of fatigue and shock factor in torsion, 1.5
k_b	Co-efficient of fatigue and shock factor in bending, 2
M	Bending moment, N m
τ	Shear stress, N m ⁻²
W_{btt}	Weight of each beater, kg
L	Length of beater, m
R_2	Radial distance between centre of rotor shaft to the circumference of inner cylinder, m
Y_m	Deflection at midpoint, m
W	Total weight, kg
W_{sh}	Weight of shaft, kg
E	Young's modulus of mild steel, 210 GPa
L_{sh}	Length of rotor shaft, m
N_c	Critical speed of shaft, rpm
K	Radius of gyration
R_n	Number of rows
M	Equivalent mass, kg
D_e	Dehulling Efficiency
μ	Co-efficient of friction
S_e	Specific energy consumption, kj/kg
W_{seed}	Weight of seed, kg
W_{husk}	Weight of husk, kg
W_{dust}	Weight of dust, kg

✉ R. G. Math
rchyderabad@cftri.res.in; rgmath2001@hotmail.com

¹ CSIR-Central Food Technological Research Institute, Resource Centre, Habshiguda, Uppal Road, Hyderabad 500 007, India

W_e	Total power consumed by the machine during dehulling, watts
W_o	Power consumed at no load condition, watts
t	Time in hrs
t_p	Passed time for breaking of one pod, sec
F	Feed in kg
S_e	Specific energy consumption of machine, kj/kg
W_{pod}	Total weight of annatto pod processed in machine (W_{pod})
AFBMA	Anti-Friction Bearing Manufacturers Association
ASME	American Society of Mechanical Engineers

Introduction

Annatto (*Bixa orellana* L.) is an ancient crop of tropical lowlands of Latin America, where it is extensively grown for the seeds that produce bixin, a bright yellow to orange red dye. Bixin is the natural apo-carotenoid pigment derived from the pericarp of annatto (*Bixa orellana* L.) seed. The dye has been extensively used to colour butter and cheese by Riel and Gibson (1958). Formulations such as water soluble, oil soluble, liquid or powder formulations have been developed (Prabhakara Rao et al. 2002, 2005) for application in variety of foods. The aspects of chemistry, processing methods, toxicology and application of annatto in foods were reviewed by Satyanarayana et al. (2003). Screening of published literature on application of the dye or formulations has indicated fruits and vegetable products such as tutty-fruity, jams and jellies (Satyanarayana et al. 2006); extruded and bakery foods such as wafers, noodles, sugar cones (Prabhakara Rao et al. 2007); and a ready-to-serve beverage model system (Prabhakara Rao et al. 2002). The effect of seed source, processing methods and quality of dyes and formulations on the colour as measured by a Lovibond and Hunter color was studied (Satyanarayana et al. 2010). Analytical methods for quantifying the dye in formulations and products by spectrophotometry (Reith and Gielen 1971) and HPLC (Scotter et al. 1998) were known.

Annatto plant yields between 300 and 600 kg per hectare and exceptionally 750 to 900 kg. Peru is the world's largest producer and exporter of annatto seeds, followed by Brazil and Kenya (Encyclopaedia of spices 2011; Mohesenin 1970). India is a small volume producer, but commercial cultivation has started in recent past which resulted in export of the seeds to some extent.

A 3 year old plant on an average may yield about 0.5 to 1.0 kg of seeds per tree per year. The maximum yield is obtained from 4 to 10 years age plantation and thereafter, there is a gradual decline in the yield. Seed yield may be around 250 to 500 kg per hectare per year from 4 year old plantation. Central and South American natives use the seeds to make body paint and lipstick. For this reason, the achiote is sometimes called the "lipstick-tree". It is also grown in other tropical or

subtropical regions of the world, including Central America, Africa and Asia. In India, (The wealth of India 1988) earlier to commercial cultivation, the annatto seeds were collected by the tribal from the forest mostly from the states of Madhya Pradesh, Orissa and Andhra Pradesh. The tribal people used to sell these seeds directly to buyers or through Girijan Co-op. Corporation (GCC) in Andhra Pradesh. The heart-shaped fruit are brown or reddish brown at maturity, and are covered with short, stiff hairs. When fully mature, the fruit splits open, exposing the numerous dark red seeds.

The traditional method of obtaining the annatto seeds is by beating the dried pods on the ground or in a bag with a stick. Each pod may contain between 10 and 50 seeds, according to the variety, which are distributed between two halves. Extraneous matter is therefore removed by sieving and winnowing, but care must be taken to avoid abrasion which results in loss of the valuable pigmented seed coat.

Mechanical separation of annatto seeds from pods is a better option to overcome the loss of pigment. Mechanisation not only improves the quality of seeds but also creates the facility to process large quantities of raw material, which are being expected from commercial cultivation of annatto orchards thereby lower environmental pollution. The demand for development of a seed separator machine is important to overcome loss of the essential pigment and also minimise the manual drudgery.

The main objectives of the annatto seed separator machine design

- To design and fabricate prototype model of annatto seed separator machine of 150 kg/h capacity.
- To utilize materials of adequate strength and stability for fabrication i.e., mild steel and the life of mild steel is approximately 30 years.
- To use locally available materials and components in the fabrication of the machine.
- To correlate the physical and engineering properties of pods and seeds of annatto (*Bixa orellana* L.) for designing the machine

To ensure economical selection of materials for the fabrication to bring down costs of the machine without sacrificing of quality of the seed which is the ultimate product.

Materials and methods

Raw material Freshly harvested annatto pods were procured from different places namely, Girijan Co-op. Corporation Ltd. (GCC), Visakhapatnam, A.P. Forest Development Corporation Ltd., Paderu in Andhra Pradesh and CFTRI campus, Mysore (Karnataka). The material was heterogeneous in nature and variations were observed in size and moisture

content. To determine the average size of the annatto pod, a sample of hundred annatto pods was randomly selected. Three major perpendicular dimensions of the pod were measured. To obtain the mass, each pod is weighed by analytical balance with an accuracy of 0.01 g. The geometric mean diameter (D_p) of the pod was calculated using the equation $D_p = (LMT^{-3})$ (Mohesenin 1970).

Bixin content The collected annatto pods were sun dried to a constant moisture. The bixin in annatto seed was analysed spectrophotometrically by extracting into chloroform by vigorously shaking for one hour, which was suitably diluted to read optical densities in the range of 0.3 to 0.8 at 470 nm in a Shimadzu double beam UV-Visible spectrophotometer (UV-160 A, Shimadzu Corporation, Kyoto, Japan). Quantification of bixin was conducted using the $E_{1\%}^{1\text{cm}}$ value (3230) in chloroform as reported in the literature (Reith and Gielen 1971).

Equilibrium moisture content (RH) study Sorption isotherm was plotted by exposing the annatto pods to different RH conditions (10, 20, 30, 50, 70 and 100 % RH) obtained using sulphuric acid solutions of varying strengths in air tight glass desiccators. The samples exposed were weighed daily till constant weight was attained or appearance of fungal growth. The equilibrium moisture content (EMC) for all the samples kept at different RH were computed using the data obtained from the study and they were plotted against % EMC.

Physical and mechanical properties The density was determined using liquid displacement method. Kerosene was used in place of water. The moisture were determined using standard air oven method at a temperature of 105 ± 1 °C and drying time of 24 h (ISI 1966). Friction angle was measured by slope method i.e., pods, husks and seed are kept on a glass surface and raised slowly upward direction to note down the angle side (Güzela et al. 2005; Aydin 2003). All the data was evaluated statistically. The absolute density, moisture, friction angle and bixin content in the material were analysed. The force required to separate the seed from the pod was determined using a Brookfield (CT3) Texture Analyser (490 N).

Design considerations The mechanism of the annatto seed separator machine utilises various operational forces such as compression, shearing and impact.

Design of machine components Based on the physical and mechanical properties of annatto pods, husk and seed, the basic design of machine (Pradhan et al. 2010; Omid et al. 2008) was proposed. The main considerations were the size/dimension, capacity of the machine, the number of

beaters, diameter of inner and outer cylinders and diameter of shaft. The design of hopper was based on flow characteristics of the annatto pods.

Description of machine components The machine was evaluated for its working performance. The annatto seed separator consists of a hopper, vibratory sieve (grader), aspirator, frame, two cylindrical drum (inner and outer) having 12 mm diameter fins attached to the outer peripheral of inner cylinder and inner periphery of outer cylinder acts like beater. The machine was conceived as a low-cost, easy-to-adjust, easy-to-dismantle and easy to fabricate device for removing the seed from the annatto pod. The feed hopper is mounted on the concentric cylinder frame to process the annatto pods. The concentric cylinder consists of beaters with different pitch of 40, 45 and 50 mm of a 500 mm span of cylinder with a clearance of 12, 14.5 and 17 mm respectively between two beaters. The inner cylinder is fixed to a shaft of 25 mm diameter, which is supported by two pedestal bearings. Outer cylinder is fixed permanently on the frame. A vibratory grader having perforations of dia. 3 and 8 mm was provided at the outlet to separate the seeds and bigger pod particles. An aspirator was used to remove the dust and husk by suction.

Design of shaft The shaft diameter (D_{sh}) was designed considering fluctuating load or shock load computed by using Eq. 6 (Khurmi and Gupta 2005). The length of the shaft is 800 mm simply supported on the frame by using pedestal bearing with a pulley weight of dia. 12 in. Inserted driven pulley to the shaft from the distance of 50 mm from right side frame. The shaft is used in the machine was subjected to a fluctuating bending moment load and hence torque was given by Eq. 3. Ball Bearings were used for reduction the frictional effect as indicated by the Anti-friction bearing manufactures Association (AFBMA). In the prototype model, the output of the machine was checked by varying the rpm of motor by using a servo controller.

Design of beaters The beater length was assumed to be 127 mm and diameter 12 mm based on average annatto pod bunch length of 127 mm. The diameter of the beater was calculated to be 1/3rd size of pod diameter and shape of beater was selected to be cylindrical, because it will reduce damage of seeds if outer surface is polished. The number of beaters were calculated using the Eq. 7 utilising data on the effective diameter (D_{eff}) of the inner cylinder (D_{in}) plus twice the length of beater (L_{bt}). The peripheral velocity (linear velocity) was calculated by using Eq. 8. Energy (E_0) for breaking a single pod was calculated using Eq. 9 considering pod diameter (D_{pod}) to be 40 mm, max shear force of 68.67 N is $E_0 = 1.373$ joule (Omid et al. 2008; Ojolo and Ogunsina 2007).

By considering the maximum pod diameter of 40 mm, the beater movement will be $\pi/40$ or $180/4$ is 45° . According to the Eqs. 11 and 12, passed time (t_p) for breaking of one pod is 0.011 s with the rotational speed of 300 rpm. Preliminary trials were conducted at different rpm to assess the retention of bixin on the seed coat. The needed time for passing from one pod to another pod (t_1) was calculated by Eq. 13. The outer cylinder have 6 passages and the inner cylinder have 3 beaters. The distance travelled (D_{travel}) Eq. 14 from one pod to another pod is 0.603 m and time (t_1) 0.1 s. The power needed (P_{need}) for breaking one pod was evaluated by using the Eq. 15, so P_{need} is 13.729 watt for one pod. The amount of power needed for two breaking in one cycle (3 hammer cutting per cycle) is equal to 6. Then the (P_{cycle}) power needed for one cycle was 82.376 watt ($P_{cycle} = 6 \cdot P_{need}$).

Number of rows (R_n) on the circumference of the inner cylinder with 3 beaters was evaluated by using Eq. 16 by considering the safety factor of 1.25. Safe number of rows is approximately 8. Hence the total number of beaters are 24 (8×3). The outer cylinder is stationary and beater is arranged radially at 60° with a pitch of 40 mm. It is known that increase in span length would result in increase in breaking load. Maximum force require to break the pod is 98 N. Equations 1–21 used to calculate the design parameter of the machine (Khurmi and Gupta 2005).

Feed calculation The required raw material to feed the machine was evaluated by using a linear velocity (V_{lin}) and collision of two bodies having mass of beater (m_1) and mass of pod (m_2) in kg using the Eq. 17 as kinetic energy (E_1) of the beater, assuming the pod to be stationary. The change in velocity (δV) after collision of beater with pod was evaluated by Eq. 18 is 0.843 m/s. Pod material was dry having moisture content 8 to 10 % (db.), co-efficient of velocity (C_V) was assumed 10 % of the actual velocity by using Eq. 19 is 0.716. Therefore feed rate per sec is evaluated by using Eq. 21 is 0.047 kg/s or 168 Kg/h.

$$P = 2\pi N_{sh} T_{rq} \quad (1)$$

$$T_{rq} = \frac{P}{2\pi \cdot N_{sh}} \quad (2)$$

$$Y_m = \frac{wL_{sh}^3}{48EI} \quad (3)$$

$$N_c = \left(\frac{1}{2\pi} \right) \cdot \sqrt{\frac{g}{Y_m}} \quad (4)$$

$$D_{sh} = \sqrt[3]{\frac{16 \cdot \sqrt{(K_t \cdot T)^2 + (k_b \cdot M)^2}}{\pi \cdot \tau}} \quad (5)$$

Table 1 Physico-chemical parameters of annatto pod and seed

Parameter	Pod	Seed
Length, mm	40.20±2.84	–
Thickness, mm	28.20±2.15	–
Width, mm	20.80±3.57	–
Geometric mean diameter, mm	28.65±1.22	–
Mass, g	1.88±0.43	–
Volume, cm ³	23.55±0.87	–
Density, kg/m ³	134.7 – 186.6	1206 – 1253.9
Density of husk, kg/m ³	317 – 381.4	–
Moisture content, % db	8.75±1.06	–
Bixin, %	–	1.65±0.10
Friction angle	30–35°	–

*Values are mean of triplicate measurements

$$D_{eff} = D_{cyl} + 2 \cdot L_{bt} \quad (6)$$

$$V_{lin} = \pi \cdot D_{eff} \cdot N_{sh} \quad (7)$$

$$E_0 = F_{max} \cdot g \cdot \frac{D_{pod}}{2} \quad (8)$$

$$\theta = \frac{180}{D_{pod}} \quad (9)$$

$$t_p = \frac{\theta \cdot \theta}{2 \cdot \pi \cdot N_{sh}} \quad (10)$$

$$P_{pod} = \frac{E_0}{t} \quad (11)$$

$$t_1 = \frac{D_{travel}}{V_{lin}} \quad (12)$$

$$D_{travel} = \pi \frac{D_{eff}}{6} \cdot 3 \quad (13)$$

$$P_{need} = \frac{E_0 - E}{t} \quad (14)$$

Fig. 1 Sorption isotherm for annatto pods

Fig. 2 Three point bending test

$$R_n = \frac{P}{P_{cycle}} \quad (15) \quad F_{feed} = \frac{E}{C_V \cdot V_{lin}^2} \cdot 3600 \quad (20)$$

$$E_1 = \frac{1}{2} \cdot m_1 \cdot V_{lin}^2 \quad (16) \quad F_{feed} = \frac{E}{C_V \cdot V_{lin}^2} \cdot 3600 \quad (21)$$

$$\delta V = \sqrt{2 \cdot \frac{(E_1)}{m_1 \left(1 + \frac{m_1}{m_2}\right)}} \quad (17) \quad \eta_{de} = (W_{seed} + W_{husk} + W_{dust} W_{pod}) \times 100 \quad (22)$$

$$C_V = \frac{V_{lin}}{\Delta t} \cdot 0.10 \quad (18) \quad \text{Design verification Design parameters were verified by varying the load (Khurmi and Gupta 2005).}$$

$$E = E_0 \left(1 - \frac{t}{t_1}\right) \quad (19) \quad \text{i. When cantilever beam is subjected to concentrated load at mid of the beater.}$$

Table 2 Mechanical properties of Annatto pod at different span length and speed

Parameter													
Span Length, mm		14.5				18.5				22.5			
Speed, mm/s		0.5	2	3	4.5	0.5	2	3	4.5	0.5	2	3	4.5
Breaking	Min.	27.4	28.4	33.0	27.4	54.3	35.5	49.9	42.4	30.0	30.6	41.4	38.7
Hardness	Max.	46.0	42.1	57.9	51.3	74.9	49.8	71.8	61.6	66.3	63.0	51.3	56.1
N	Avg.	35.7	33.9	40.4	38.9	65.8	43.9	61.0	50.5	44.4	48.1	46.0	45.1
	Std.	7.4	5.1	9.3	10.6	9.0	5.9	9.3	8.6	13.7	11.9	3.8	7.1

(Moisture content of pod varies between 14 and 25 % w.b)

Note: Data was reported are average of 10 samples

Table 3 Hardness and fracture analysis of annatto pods stored under different RH using texture analyser*

% of RH	Average Hardness in gm.	Maximum Hardness in gm.	Avg Fractures in Nos	Avg Work, J	(EMC) Moisture content % wb
Control	5387	5820	20	0.4314	8.85
10	2615	2860	67	0.2028	3.26
20	2658	3015	68	0.1999	4.58
30	3050	3590	53	0.2505	5.21
50	3757	5155	36	0.318	6.87
70	3407	4225	32	0.2854	9.01
100	3607	3860	13	0.2919	28.5

*Values are mean of triplicate measurements

- ii. Cantilever beam is subjected to concentrated load at the tip of the beater.
- iii. Static load or shearing using standard equation.

Principle of operation Separation of annatto seed from the annatto pod is achieved by passing the annatto pod to the gap between the concentric cylinder through the hopper where the seed is separated from the pod by impact and shear force applied by the beaters. After separating of seed from the husk it is passed through the suction pipe for separation of dust and husk through aspirator. The remaining seeds falling on the grader which is having perforations of 3 and 8 mm to facilitate separation of dust and other immature seeds. The frame is the mounting support for all the components of the machine.

Results and discussion

Mean and standard errors of the various physico-chemical parameters of annatto pod and seed are given Table 1. The pod has a density of 134.7 to 186.6 kg/m³ with an average weight of 1.88 ± 0.43 g. The average diameter of the pod was 28.65 ± 0.43 mm. The density of the seed was 1206–1253 kg/m³ whereas the bixin content of seed was 1.65 ± 0.10 .

Equilibrium relative humidity studies From the equilibrium relative humidity plot (Fig. 1), it can be observed that the critical moisture content was 68.5 % RH. The plot shows sharp increase in moisture above 60 % RH, which indicates

ANNATTO SEED SAPARATOR (100 Kg/hr)

GENERAL ASSEMBLY

Fig. 3 Front view and side view of the annatto seed separator

its non-hygroscopic nature. The study indicates that annatto pods can be stored at ambient temperatures with ordinary cloth/gunny bags and costly polythene coated packaging materials are not required.

Design parameters Various design parameters were standardized during the development of prototype machine. Tensile strength of annatto pod husk was 59 N. Compression test of annatto seed at 25 % of force applied (123 N), 50 % of force applied (286 N) and breaking strength of pod determined on a three point load using Brookfield Texture analyser was depicted in Fig. 2. The data on breaking strength and hardness at different span length and different speed are shown in Table 2. It was found that the flow characteristics such as co-efficient of friction (μ) varied between 0.59 and 0.63 and friction angle (θ_f) varied between 30.41° and 32.06° at different moisture contents. Hence, during the design of the hopper it was assumed that the angle should be greater than 40° for annatto pods of varying moisture content. The co-efficient of friction (μ) for annatto husk and seed was 0.6 and friction angle (θ) 32° to design winnowing mechanism. The fixation of pitch between the beaters inside the cylinder is computed based on the breaking strength of the annatto pod at varying span length (Table 2). It was observed that minimum force i.e., 57.9 N was required at a span length of 14.5 mm.

Detailed data of hardness and fracture analysis of annatto pods under different percentage of RH using texture analyser are given in Table 3. The torque (Trq) was calculated using Eq. 3 which is 23.71 Nm and maximum bending moment is negligible. The diameter of the shaft was found to be 15 mm by considering the factor of safety 1.6, so the diameter of the shaft is 25 mm. The detailed design of the machine along with dimensions is shown in Fig. 3.

The critical speed (N_c) of rotor cylinder is 2393 rpm was calculated using Eq. 5 by stress and strain failure theory, but the machine operating speed was 300 rpm, hence the cylinder is safe under elastic failure. The rotor cylinder running rpm was found to be optimum at 300 rpm for maximum retention of bixin content (Table 4). So the required power (P_{pod}) for

Fig. 4 Diagram of breaking force (F_{max}) verses blade movement(X) in pod diameter (D_{pod})

breaking one pod was calculated as 122.03 watts. Figure 4 shows the relation between maximum breaking force and distance travelled. Beaters are attached on the periphery of the inner cylinder with an angle of 120° radially (Fig. 5).

Machine output The annatto seed separator machine along with annatto pod and the output seed and husk fractions are shown in Fig. 6. The trial of the machine was carried out in triplicate by using 200 kg annatto pod, and it took an average time of 90 min. So the actual feed rate of the machine is calculated per hour is 132.5 kg/h. Hence it is the good agreement with the estimated design output (150 kg/h). It was found that, bixin content of the seed by machine processing was 1.62 %, compared to 1.22 % in the traditional process (Table 4). Specifications of annatto seed separator machine is given in Table 5.

Dehulling Efficiency of machine (η_{de}) The dehulling efficiency of the machine is calculated by using Eq. 22. The effect of moisture content would affect the dehulling efficiency of the machine, less than 10 % moisture should maintain in annatto pod for better efficiency, at 8.5 % moisture 92.5 % dehulling efficiency was found (Gupta and Das 1999). As the moisture content of annatto pod increases, it would result in decrease in dehulling efficiency. A similar decreasing trend in dehulling efficiency has been reported for jatropha (Pradhan, et al. 2010). It was also seen that as the increase in

Table 4 Performance data for the developed machine

Seed removal method	Rotor Cylinder, rpm	Fluctuation in speed (%)	Bixin*, (%)	Moisture* in seed (%)
Traditional	—	—	1.22	8.50
Machine	180	3.333	1.59	2.57
Machine	217	3.687	1.58	7.00
Machine	298	3.020	1.62	9.10
Machine	398	3.518	1.61	6.90
Machine	400	3.760	1.42	7.1
Machine	500	4.013	1.10	6.8

*Values are mean of triplicate measurements

Fig. 5 Inner cylinder with beater

opening of hopper feeder would result in increased number beaters in action which results in increased dehulling efficiency. Capacity of the developed prototype machine for seed separation was found to be 132.5 kg/h. The prototype machine

Fig. 6 Annatto seed separator machine with annatto pod fractions after processing

Table 5 Specification of Annatto seed separator machine

SL. No	Description	Specification value
1	Length of outer cylinder	500 mm
2	Length of inner cylinder	500 mm
3	Diameter of outer cylinder	460 mm
4	Diameter of inner cylinder	130 mm
5	No. of beaters in action	24 Nos
6	Diameter of beater	12 mm
7	Length of beater	127 mm
8	Rotor cylinder running rpm	300 rpm
9	Vibratory sieve (grader) speed	35–40 mm/min.
10	Blower speed	2880 rpm
11	Critical speed of machine	2393 rpm
12	No. of rows of beaters in inner cylinder	3 rows (Each row 18 beaters)
13	No. of rows of beaters in outer cylinder	6 rows (Each row 19 beaters)
14	Hopper opening area	177.8 mm×177.8 mm
15	Motor specifications	1HP, single phase, 1440 rpm
16	Machine capacity	168 kg/h
17	Machine size	1395 mm×1100 mm×1190 mm
18	Weight of the machine	350 kg
19	Dehulling Efficiency	92.55 %
20	Specific Energy consumption	4.036 kJ/kg

reduces the dye losses by 25 % (bixin content increased from 1.22 to 1.62 %) of the valuable natural food colour from annatto seeds; good quality seeds fetch justifiable returns to tribals and farmers who grow annatto seeds. Processing of annatto pods through this machine will contribute to the quality of processed foods by reducing the quantity of dust and immature seeds. Hence, a reduction in costs for obtaining quality seed would help meet competition thereby encourage producers to use natural colours.

Specific energy consumption of machine (Se) The Specific energy consumption of machine during running with material is calculated using the Eq. (23). Specific energy consumption (Se) in kJ/kg of seed dehulled is calculated to be 4.03 kJ/kg as the net total electrical energy consumed by the machine to dehull unit mass of the feed (Gupta and Das 1999). As the moisture content in material is 8.5 %.

Conclusions

The present work describes an engineering solution for automatic separation of seed from annatto pods. A prototype for separating seed from the annatto pod was developed and evaluated, which could handle a maximum throughput of

132 kg/h. The initial moisture content of annatto pods should be maintained at $\leq 10\%$ to achieve 92.5 % dehulling efficiency. The machine eliminates the labour intensive manual operations and also ensures better health conditions of farmers by avoiding inhalation of dust and retains valuable natural food colour. Food industry can process these raw materials into value added products. Mechanical separation at 300 rpm not only improves the quality of seeds but also improves in bixin content of seed from 1.22 to 1.62 %. It's also creates a facility to process large quantities of raw materials, expected from annatto orchards of commercial cultivation. The processing cost is also reduced by mechanical separation through of higher outputs.

Acknowledgments The authors thank the Ministry of Food Processing Industries, New Delhi for the award of a research grant (No. 52/ MFPI/ R&D/2006) to carry out this study. The authors wish to thank Director, CFTRI, and Head, CFTRI Resource centre, Hyderabad for their cooperation.

References

- Aydin C (2003) Physical properties of almond nuts and kernel. *J Food Eng* 60:315–320
- Encyclopaedia of Spices (2011) The Epicentre.com. Archived from the original on 16 July 2011
- Gupta RK, Das SK (1999) Performance of centrifugal dehulling system for sunflower seed. *J Food Eng* 42:191–198
- Güzela E, Akçalib İD, Mutluc H, Incea A (2005) Research on the fatigue behaviour for peanut shelling. *J Food Eng* 67:373–378
- ISI (1966) Indian standard methods for analysis of oil seed, IS: 3579. Indian Standard institute, New Delhi
- Khurmi R, Gupta J (2005) A Textbook of Machine Design. Eurasia Publishing House (pvt) Ltd, New Delhi
- Mohesenin NN (1970) Physical properties of plant and animal materials. Gordon and Breach Science Publishers, New York
- Ojolo SJ, Ogunsina BS (2007) Development of a cashew nut cracking device. *Agric Eng Int: CIGR E J IX*. Manuscript PM 06 030
- Omid G, Khoshtaghaza MH, Ahmad DB (2008) Design and development of special cutting system for sweet sorghum harvester. *J Cent Eur Agric* 9:469–474
- Prabhakara Rao PG, Satyanarayana A, Rao DG (2002) Effect of storage on the stability of water soluble annatto dye formulation in a simulated orange RTS beverage model system. *LWT Food Sci Technol* 35:617–621
- Prabhakara Rao PG, Jyothirmayi T, Balaswamy K, Satyanarayana A, Rao DG (2005) Effect of processing conditions on the stability of annatto (*Bixa orellana* L.) dye incorporated into some foods. *LWT Food Sci Technol* 38(7):779–784
- Pradhan RC, Naik SN, Bhatnagar N, Vijay VK (2010) Design, development and testing of hand operated decorticator for jatropha fruit. *Appl Energy* 87(3):762–768
- Prabhakara Rao PG, Satyanarayana A, Balaswamy K, Jyothirmayi T, Nagender A, Rao DG (2007) Application of annatto dye formulation in bakery and extruded food products. *J Foodserv* 18:53–58
- Reith JF, Gielen JW (1971) Properties of bixin and norbixin and the composition of annatto extracts. *J Foodserv* 36:861–864
- Riel RR, Gibson CA (1958) Use of annatto for colouring butter. *J Dairy Sci* 41(5):624–629
- Scotter MJ, Wilson AL, Appleton GP, Castle L (1998) Analysis of annatto (*Bixa orellana*) food colouring formulations. I. Determination of colouring compounds and coloured thermal degradation products by high performance liquid chromatography with photodiode array detection system. *J Agric Food Chem* 46:1031–1038
- Satyanarayana A, Prabhakara Rao PG, Rao DG (2003) Chemistry, processing and toxicology of annatto (*Bixa orellana* L.). *J Food Sci Technol* 40(2):131–141
- Satyanarayana A, Prabhakara Rao PG, Balaswamy K, Velu V, Rao DG (2006) Application of annatto dye formulations in different fruit and vegetable products. *J Foodserv* 17:1–5
- Satyanarayana A, Prabhakara Rao PG, Rao DG (2010) Influence of source and quality on the colour characteristics of annatto dyes and formulations. *LWT Food Sci Technol* 43:1456–1460
- The Wealth of India (1988) Raw Materials. PID, CSIR, New Delhi, pp 157–160