Original Research Article

Physical and Aerodynamic Properties of “Jafra”(*Bixa orellana*L.) Seed

ABSTRACT

Jafra (*Bixa Orellana L.*)seed which is also known as a “annatto” or “achiote” at different parts of the world~~and it~~has ~~got~~ the various applications as a natural dye, and condiment in food preparations. During the course of its utilization, jafra seed undergoes various processing operations such as drying, cleaning, grading, conveying, soaking, grinding, etc. which need the various physical and aerodynamic properties for its proper processing. Keeping in view of ~~this~~ theseneeds physical and aerodynamic properties of jafra seed as a function of moisture at five different levels were determined. The physical and aerodynamic properties of the jafra seeds measured were size and shape, thousand grain weight, bulk density, true density, and angle of repose. The terminal velocity was measured and the drag coefficient was calculated. The above physical and aero dynamic properties of jafra seeds were measured as a function of moisture content in the range of 11.7~~1% d.b.~~ to 35.08% d.b. Most of the physical properties of jafra seeds were increased with an increase in moisture content in the experimental moisture content range. However, the bulk density, true density, and Drag Coefficient of jafra seeds were decreased with an increase in moisture content. Regression equations for various parameters of jafra seed as a function of moisture content (M) in the experimental moisture content range were fitted. The regression relationships have high coefficient of determination. The physical and aerodynamic property data in the present research will help in design of the processes and process equipment for jafra seed processing.

Keywords*: angle of repose, density, drag coefficient, shape, terminal velocity*

1. INTRODUCTION

The knowledge of physical and aerodynamic properties of biological materials is necessary for the design of various separating, handling, storing, and drying systems [1]. The thousand grain mass of ‘jafra seed’ is useful in measuring the relative amount of dockage or foreign material. Bulk density values of jafra seeds have practical applications in the calculation of thermal properties in heat transfer problems, in pneumatic handling of the material, and in separating the product from undesirable materials. In the design of pneumatic conveyors and in fluidized bed drying,the terminal

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Comment [EA2]: Change all the others velocity of the grain is important. The drag coefficient (C_d) depends on the velocity of the falling body, viscosity of the fluid, the shape of the particle and roughness of the particle's surface. The resistance of bulk grain to airflow is a function of the porosity and the kernel size. The angle of repose determines the maximum angle of a pile of grain ~~with~~ onthe horizontal plane. It is important in the filling of a flat storage facility when grain is not piled at a uniform bed depth but rather is peaked [2]. The physical properties such as bulk density, true density, and angle of repose depend on moisture content [3, 4].

*Bixa Orellana*L.plant is cultivated in warm regions of the world spreading in India, Sri Lanka, and Java and is mainly used for preparing or extracting the natural food color [5]. *Bixa Orellana*L.has got some common names andit is most frequently called “annatto” or “achiote” in North America, and “jafra” in India. The dye obtained from the pulp of the *Bixa orellana* seed (bixin) is used all over the world as a red orange dye for coloring rice, cheeses, soft drinks, oil, butter, and soup. The dye is also used in some regions to dye textiles [6, 7],the seeds are ground, and used as a condiment [8]. Bixin (the red carotenoid) is obtained from the seed either by attrition and impact or by the solvent extraction [9].Jafra seed undergoes various unit operations such as drying, cleaning, grading, conveying, soaking, grinding, etc. during its processing for various uses. The physical and aerodynamic properties of Jafra seeds are needed in various processing steps as described above. However, the physical and aerodynamic properties of Jafra seeds are sparsely available in the literature. Hence, the present study was undertaken with the objective of determining various physical and aerodynamic properties of jafra seed as a function of moisture content.

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2. MATERIALS AND METHODS

2.1 Material procurement

Jafra seeds wereas procured immediately after harvesting from Regional Agricultural Research Station, Chintapalle ofVishakapatnam district, Andhra Pradesh, India. The seeds wereas stored by placingina polyethylene bag, sealed and stored in a refrigerator until further use in the experiments.The samples were drawn from the refrigerator and allowed overnight to bring to the room temperature.

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2.2 Samples of different moisture content

The initial moisture content of the Jafra seed was determined ~~following~~ usinghot air oven method at 105°C for 24 h [10]. The moisture content of the jafra seeds were adjusted to the required moisture levels by adding required amount of water(sprinkling water) or drying in a ~~try~~ traydryer at 40°C [3]. The final weights of seeds after moisture content adjustment was calculated using following equation.

$$W_f = \frac{W_i\,(100 + M_f)}{(100 + M_i)}$$

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Where,

W_f = final weight (after moisture content adjustment) of the sample, g

W_i = initial weight (before moisture content adjustment) of the sample, g

M_i and M_f = initial and final moisture contents of the samples, in %.

Such moisture adjusted samples were transferredinto a polyethylene bag and sealed to prevent moisture loss or ~~gain, and~~gain and kept for one day to enable the moisture to distribute uniformly throughout the sample. A total of 5 moisture content levels were prepared. At the beginning and end of each set of experiments, the moisture content of the sample was determined. The minimum and maximum moisture contents of the samples were 11.71% d.b.and35.08% d.b., respectively.The other three intermediate levels were 19.49%, 25.09%, and 29.09% d.b.

2.3.Size and shape

The axial dimensions namely,major (a), intermediate (b) and minor (c)dimensions of jafra seeds were measured with the help of grain vernier having an accuracy of 0.01 mm. A sample of 50 seeds was randomly selected from each sample lot having different level of moisture content ranging from 11.71% d.b. to 35.08% d.b.The geometrical mean diameter (GMD)for jafra seeds at different moisture contents was calculated from measured axial dimensions through the following equation [2].

$$\text{Geometrical mean diameter, GMD} = (a \times b \times c)^{1/3} \text{mm}$$

The sphericity (ϕ) defined as the ratio of the surface area of sphere having the same volume as that of the seed to the surface area of the grain was calculated as [2].

$$\emptyset = \frac{(a \times b \times c)^{1/3}}{a}$$

The average values of each size property from measurements for 50 kernels at each moisture content level were reported.

2.4Thousand Grain mass

One thousand seeds were counted at each moisture content level, and the weight of 1000 kernels at five levels of moisture content ranging from 11.77 % to 35.08 % d.b.was measured with an electronic balance having accuracy of 0.0001 g [11]. Triplicated experiment at each moisture content level was conducted and average of three measurements at each moisture content level was reported.

2.5 Bulk and true densities

The bulk density, ρ_b in kg/m^3 considered as the ratio of the weight of the grain to its total volume was determined using a 1000 cc graduated measuring cylinder, and an electronic balance. The empty measuring cylinder weight was measured prior to the filling of the jafraseed samples. The graduated cylinder was filled with jafra seed from a fixed height of 15 cm above the brim [12]. Ensured that the filled jafra seed was exactly at 1000 cc line and levelled uniformly at 1000 cc line. Then the weight of the filled jafra seed along with the cylinder was measured using top pan electronic balance (Model: CL10T05) with 0.5 g accuracy. The empty weight of a cylinder was deducted from the total weight of sample and cylinder to get a weight of jafra seeds. The bulk density of jafra seed was obtained by dividing the weight of the sample by the volume (1000 cc) of the sample ~~i.e., 1000 cc~~. The experiment was triplicated at each moisture content level ranging from 11.71% d.b. to 35.08% d.b.

The true density ρ_t in kg/m^3 defined as the ratio of weight of the sample to its true volume, was determined using an electronic balance and multivolume pycnometer (Model: 1305, Helium gasdisplacement method, 50 mL sample cup, Micromeritics, USA). About 15-20 g of sample was accurately weighed and its true volume was measured with pycnometer. The true density was calculated from the mass of jafra seed and its corresponding true volume. The true density was measured at five moisture content levels ranging from 11.71% d.b. to 35.08% d.b.The representative values of bulk and true densities were reportedas the average of three replications.

The porosity ε, defined as the percentage of void space in the bulk grain not occupied by the bulk seed [13] was calculated from the bulk and true density values obtained as abovewith the help of followingrelationship. The porosity values were calculated from the average bulk and true densities values at each moisture content levels.

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100$$

2.6 Angle of repose

The angle of repose, θ considered as the angle in degrees made by the surface of the grain with the horizontal when the grain is piled was determined following a standard method [2, 14, 15]. The apparatus consisted of a galvanized Iron (GI) cylinder of 25 cm diameter at top and 28 cm height, a circular fixed platform of 150 mm diameter D_c fitted inside and a discharge gate at the bottom of the setup. The cylinder above the platform was filled with jafra seeds and the gate was quickly and gently opened. As the gate opened, the jafra seed drained from the hopper leaving the heap on a circular platform. The height H_c in mm of the jafra on the circular platform was measured with a height gauge having a least count of 0.01 mm. The angle of repose was calculated as:

$$\theta = \tan^{-1}\left(\frac{2H_c}{D_c}\right)$$

Triplicated experiments were carried out at five different moisture content levels ranging from 11.71% d.b. to 35.08% d.b. and the average values were reported.

2.7 Terminal velocity and drag coefficient

Terminal velocity of jafra seeds is considered as the air velocity at which seeds remain in suspension position in flowing air. The terminal velocity of jafra seeds at different moisture contents were measured with the wind tunnel apparatus (air column). The system consisted of centrifugal air blower (Eltek, Type: M63), plenum chamber, vertical Perspex tube, air flow control ring (25 mm length, 46 mm ID and 50 mm OD), air flow strainer, and inlet pipe. The single kernel at aspecified moisture content were placed in a vertical Perspex tube. The kernel was made to float in airsteadily and the air velocity in that condition was measured with a digital vane anemometer (Lutron AM – 4201, Taiwan) at open end of a Perspex tube [16]. Before measuring the terminal velocity, mass of a single kernel was measured with the sensitive balance (Model: HTR, ±0.0001 g; EssaeTeraoka Pvt. Ltd., Japan). Later, kernel's axial dimensions namely major (a), intermediate (b) and minor (c) dimensions were measured with the help of grain Vernier(accuracy of 0.01 mm). From the axial dimensions, Geometrical Mean Diameter (GMD) was calculated. The calculated GMD was used to calculate the projected area of the individual jafra kernel. From, the above terminal velocity, and other data, the drag coefficient (C_d) of jafra seed was calculated using the following formula.

$$C_d = \frac{2\, m\, g\, (\rho_p - \rho_a)}{v_t^2 \rho_a \rho_p\, A}$$

Where,

m = mass of a single kernel, kg

g = acceleration due to gravity, m/s^2

ρ_p = particle or true density of jafra seed, kg/m^3

ρ_a = density of air, kg/m^3 (from psychrometric chart)

v_t = measured terminal velocity, m/s

A = projected area of a particle, m^2 = $\frac{\pi}{4} GMD^2$

The experiment at each moisture content was repeated for five kernels, and average of five kernels data at each moisture content level was reported.

3. RESULTS AND DISCUSSION

3.1 Size and shape

A summary of the axial dimensions namely major (a), intermediate (b) and minor (c) dimensions of jafra seeds are presented in Table 1. The regression relationships of size and shape (sphericity) parameters as a function of moisture content in the experimental range are presented in Table 2. The physical parameters mentioned above increased with an increase in moisture content. The major (a), intermediate (b) and minor (c) dimensions of jafra seeds increased from 4.434 mm to 4.823 mm, from 3.014 to 3.501 mm, and from 2.072 to 2.991 mm, respectively with an increase inmoisture content from 11.71% d.b. to 35.08% d.b. Correspondingly, the calculated Geometrical mean diameter (GMD) increased from an initial value of 3.025 at 11.71% d.b. moisture content to 3.693 mm at 35.08% d.b. Similarly, the calculated sphericity of jafra seeds increased from 0.682 to 0.766 with an increase in

Comment [EA7]: The regression analysis was not mentioned in the introduction neither was it mentioned in in the methodology moisture content from 11.71% d.b. to 35.08% d.b.The sphericity values of jafra seeds are similar to that of kenaf seeds [19].

The physical parameter values as a function of moisture content were fitted with linear regression equations and presented in Table 2. All the values fitted well with high coefficient of determination, R^2 values (Table 2). The increasing trend in physical parameter values with an increase in moisture content is due to the filling of capillaries and voids upon absorption of moisture and subsequent swelling of kernel. The increase in physical dimensions is common for most of the biological materials especially for dry seeds and it is in conformity with the findings reported in the literature for other seeds and grains [3, 4, 17]. The minimum and maximum values of sphericity at minimum and maximum moisture content values falls within a range of 0.32 to <1.00 which is the general range for the agricultural commodities [2]. Similar regression equations were also reported for raw and parboiled rough rice [3],Quinoa seeds [18], sorghum seeds [11], kenaf seeds [19], etc.

Table 1 Size and shape paramters for jafra seed at five different moisture content levels (values in parenthesis represent the standard deviation)

S. No.	Moisture content, % d.b.	Major dimension (a), mm	Intermediate dimension (b), mm	Minor dimension (c), mm	Geometrical mean diameter (GMD), mm	Sphericity (ϕ)
1.	11.71	4.434 (0.732)	3.014 (0.586)	2.072 (0.598)	3.025 (0.458)	0.682 (0.092)
2.	19.49	4.568 (0.859)	3.261 (0.528)	2.422 (0.528)	3.304 (0.482)	0.723 (0.100)
3.	25.09	4.678 (0.420)	3.423 (0.429)	2.529 (0.260)	3.434 (0.197)	0.734 (0.054)
4.	29.09	4.687 (0.077)	3.482 (0.569)	2.708 (0.444)	3.535 (0.486)	0.754 (0.080)
5.	35.08	4.823 (0.766)	3.501 (0.505)	2.991 (0.546)	3.696 (0.464)	0.766 (0.121)

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Comment [EA9]: The table has not been scientifically done. That is only 3 rows must appear. Pls change all the others i.e. Tables 1-5. Meanwhile under this table, there is no key to explain what is in the bracket. What is in the heading must be in the bottom of the table. Same as table 3

Table 2 Regression equations for various parameters of jafra seed as a function of moisturecontent (M) in the experimental moisture content range from 11.71% d.b. to 35.08% d.b

Property	Relationship with moisture content (M)	R^2
Major dimension (a), mm	0.0165 M+4.3734	0.96
Intermediate dimension (b), mm	0.0214 M+2.9938	0.95
Minor dimension (c), mm	0.039 M+1.913	0.98
Geometrical mean diameter (GMD), mm	0.0287 M+2.939	0.95
Sphericity (ϕ)	0.0036 M+0.6741	0.97
Thousand grain mass, g	0.24 M+0.2936	0.99
Bulk density, kg/m^3	-1.0432 M+653.31	0.94
True density, kg/m^3	-2.9988 M+1422.2	0.99
Angle of repose, °	1.2895 M+39.394	0.99

Property	Relationship with moisture content (M)	R^2
Terminal velocity, m/s	0.1087 M+9.1628	0.94

M is moisture content, % d.b; R^2 coefficient of determination

3.2 Thousand grain mass

The thousand grain mass of jafra seeds varied from 32.10 to 37.60 g as the moisture content increased from 11.71% d.b. to 35.08% d.b. (Table 3). The regression equation showing the relationship between moisture content and thousand grains mass is presented in Table 2. The density of moisture (water) is higher than that of the dry matter of biological materials. As the moisture content of biological materials increases the mass of biological materials increases for a constant number of grains mass. The thousand grain mass is similar to the values reported for the kenaf seed [19].

Table 3 Thousand grain mass of jafra seeds at various moisture content levels (values in parenthesis represent the standard deviation)

Moisture content, % (d.b.)	Thousand grain mass, g
11.71	32.10(0.12)
19.49	34.10(0.15)
25.09	35.30(0.20)
29.09	36.68(011)
35.08	37.60(0.14)

3.3 Bulk and true densities

The bulk and true densities of "jafra" seeds at different moisture contents are presented in Table 4. The regression equations showing the relationship between the densities and moisture content in the moisture content range of 12.26 to 37.73 % d.b. for jafra seeds are presented in Table 2. The bulk density of jafra seeds decreased with an increase in moisture content. Bulk density of jafra seeds decreased from initial value of 645 ~~kg/m^3~~ to 615 kg/m^3 with an increase in moisture content from 11.71% d.b. to 35.08% d.b. The decrease in bulk density with an increase in moisture content is mainly due to the increase in volume was more than the corresponding increase in mass of the material [20]. It facilitates the same weight of material to occupy more volume of the cylinder thus decreasing the bulk density. Regression analysis shows that bulk density is linearly dependent on moisture content and is negatively correlated (Table 2).

Similarly, true density of jafra seeds also decreased with an increase in moisture content with in the experimental limit. The true density decreased from 1385.43 kg/m^3 to 1309.05 kg/m^3 with an increase in moisture content from 11.71% d.b. to 35.08% d.b. The decrease in true density is due to an increase in volume of the kernel (more than weight increase). Regression analysis shows that true density is negatively correlated and depicts the linear dependency of true density on moisture content

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(Table 2). True density values reported in the literature for jafra seeds were slightly lower than that of the values obtained in this study [6]. Similar decreasing trend in bulk density and true density for various grains and seeds as a function of increasing moisture content were reported in the literature [11, 18,21,22].

The calculated porosity of jafra seeds as a function of moisture content are presented in Table 4. The porosity values of jafra seeds remain unchanged with an increase in moisture content in the experimental moisture content range of 11.71% d.b. to 35.08% d.b. The average porosity for jafra seeds is 53.57 %. The porosity values of jafra seeds are lower than that of the values for raw and parboiled paddy [3].

Table 4 Bulk and true densities, porosity and angle of repose of jafra seeds at various moisture content levels (values in parenthesis represent the standard deviation)

Moisture content, % d.b.	Bulk density, kg/m^3	True density, kg/m^3	Porosity, %	Angle of repose, °
11.71	645.0 (0.82)	1385.43 (4.68)	53.44	40.69 (0.51)
19.49	638.5(0.47)	1383.13(2.24)	53.84	41.98(0.17)
25.09	635.0(0.81)	1376.35(3.98)	53.86	43.24(0.19)
29.09	628.6(0.51)	1356.80(4.78)	53.67	44.52(0.12)
35.08	615.0(0.90)	1309.05(3.23)	53.02	45.87(0.32)

3.4 Angle of repose

The angle of repose of jafra seeds as moisture content are presented in Table 4. The regression equations are presented in Table 2. The angle of repose of jafra seed increased with an increase in moisture content. It increased from 40.69^0 to 45.87° with an increase in moisture content from 11.71% d.b. to 35.08% d.b. The regression equation exhibiting the relationship between angle of repose of jafra seeds and moisture content is presented in Table 2. The linear increase in angle of repose as a function of moisture content was also reported by various researchers for various biological materials [11, 18,19].

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3.5 Terminal velocity and drag coefficient

The terminal velocities and drag coefficients of jafra seeds at different moisture content levels are presented in Table 5. The regression relationship between moisture content and terminal velocity of jafra seed is presented in Table 2. The terminal velocity of jafra seed increased with an increase in moisture content in the experimental range. It increased from 11.10 m/s to 13.34 m/s with an increase in moisture content from 11.71% d.b. to 35.08% d.b. The increase in terminal velocity with an increase in moisture content can be attributed to the increase in mass of seed per unit frontal area presented to the airflow. The terminal velocities in this study are in the range of terminal velocities reported for wheat grain [1].

As presented in Table 5, the drag coefficient of jafra seeds increased with an increase in moisture content. It increased from 0.0123 to 0.0102 with an increase in moisture content from 11.71% d.b. to

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35.08% d.b. The reason for increasing the drag coefficient is that, it varies inversely with the square of terminal velocity and directly with the diameter of the particle. The diameter of the particle increases with an increase in moisture content. The determined drag coefficient values are lower than the values reported for groundnut kernels and soybean [1].

Table 5Terminal velocity and drag coefficient (C_d) of the jafra seeds at various moisture levels (values in parenthesis represent the standard deviation)

S. No.	Moisture content, % d.b.	Terminal Velocity, m/s	Drag Coefficient
1	11.71	11.099(0.694)	0.0123
2	19.49	11.140(0.604)	0.0121
3	25.09	12.019(0.725)	0.0113
4	29.09	12.584(0.367)	0.0190
5	35.08	13.339(0.856)	0.0102

4. SUMMARY AND CONCLUSIONS

The knowledge of physical and aerodynamic properties isimportant in the design of various processes and equipment. Jafra which is also known as “annatto” or “achiote” undergoes various processing operations before it is being utilized. Hence, the physical and aerodynamic properties of the jafra seeds such as size and shape, thousand grain weight, bulk density, true density, and angle of repose were measured. The terminal velocity was measured and the drag coefficient was calculated. The above physical and aero dynamic properties of jafra seeds were measured as a function of moisture content in the range of 11.71% d.b. to 35.08% d.b. Most of the physical properties of jafra seeds were increased with an increase in moisture content in the experimental moisture content range. However, the bulk density, true density, and Drag Coefficient of jafra seeds were decreased with an increase in moisture content. Regression equations for various parameters of jafra seed as a function of moisture content (M) in the experimental moisture content range were fitted. The regression relationships have high coefficient of determination. The physical and aerodynamic property data in the present research will help in design of the processes and process equipment for jafra seed processing.

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