Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(3): 1962-1968
Received: 01-03-2019
Accepted: 05-04-2019

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Development and evaluation of terminal velocity apparatus for sorghum grains

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Abstract
Aerodynamic properties of food grains are important factors in harvesting pneumatic conveying, separating, cleaning, transportation and storage of agricultural products. The aerodynamic properties of crop grains influence the selection of design and operational parameters of equipment. These properties are crop variety specific and moisture dependent among the properties, terminal velocity is very important. The terminal velocity of agricultural grains can be measured by using vertical wind column apparatus. In this study, terminal velocity apparatus (vertical wind column) was fabricated by using locally available materials such as M.S sheet, GI sheet, motor, fiber column, blower and speed regulator. The dimensions of this machine were 41.3 × 30 × 141.9 cm and its weight was approximately 19.5 kg. This machine was tested on sorghum (sorghum) grains at eight different moisture content levels viz. 8.96%, 14.37%,17.29%, 20.69%, 23.22%, 25.03%, 27.56% and 29.15 %(w.b.).The terminal velocity values were found 8.83 m/s, 9.11 m/s, 9.28 m/s, 9.32 m/s, 9.46 m/s, 9.54 m/s, 9.62 m/s and 9.71 m/s respectively. The calculated theoretical terminal values were 9.10 m/s, 9.17 m/s, 9.18 m/s, 9.47 m/s, 9.53 m/s, 9.62 m/s, 9.73 m/s and 9.79 m/s respectively at said moisture content levels. There is no significant difference between recorded practical terminal velocity values and calculated theoretical values. Further the study continued on effect of moisture content on terminal velocity, sphericity, and projected area of sorghum grains. It was found that, the terminal velocity of sorghum grains was linearly increased with increase in moisture content. The projected area was also increased with increase in moisture content in linear relationship but sphericity of grains was not depending on moisture content.

Keywords: terminal velocity determination apparatus, terminal velocity, density, projected area

1. Introduction
Information on physical and aerodynamic properties of agriculture products is needed in design of adjustments of machines used during harvesting, cleaning, separating, handling, sorting and storing of agriculture materials and convert them into food, feed and fodder.
Terminal velocity is the highest attainable velocity by an object as it falls through fluid. It occurs when the sum of the drag force and the buoyancy is equal to the downward force of gravity acting on the object since the net force on the object is zero.
In handling and processing of agriculture products, often air is used as a carrier for transport or for separating the desirable products from unwanted materials, therefore the aerodynamic properties such as terminal velocity and drag coefficient needed for air conveying and pneumatic separation of materials. Air velocities greater than the terminal velocity of particles lift particle and to allow fall of a particle, the air velocity must be adjusted just below the terminal velocity.
The terminal velocity is affected by the density, shape, size and moisture content of samples; therefore, it is necessary to determine the aerodynamic properties as a function of different factors such as moisture content, sphericity, density etc. Many valuable research works have been carried out about the aerodynamic properties of agro-food and materials such as; Pistachio nut and its kernel, sunflower seeds, wheat kernel and straw materials, wheat varieties, cotton seeds, garlic and many others.
In fluidized bed drying or freezing, hot air or cold air is passed from below of the bed of material to be dried of frozen. The air speed is kept such that it can keep the material floating in air. So for this purpose, we need to determine the terminal velocity of a product.
Pneumatic separation is the process of using air to lift light, chaffy and dusty materials out of the grain while the heavier materials move downward. So, there we need to determine the terminal velocities of these light and dusty materials.
Sorghum is a major cereal crops in the world, being grown extensively in tropical and subtropical regions of the world. It is an important food crop for a large section of people in Africa and Asia and also the main source of fodder and industrial raw material.

It ranks third in area and production after rice and wheat. Sorghum is also used in production of starch, biscuits, sugar and alcohol. Sorghum grain is a principle source of alcoholic beverages in many countries. Sorghum, the second largest grain crop in India till the green revolution, presently occupies third place among food grains in terms of acreage and production.

The main objective of this study was to develop a terminal velocity apparatus in laboratory scale to determine the aerodynamic properties of agricultural grains and also to determine the aerodynamic properties of sorghum food grains to develop appropriate technologies in designing and adjustment of machines used during harvesting, separating, cleaning, handling and storing of agriculture materials and convert them food, feed and fodder.

The present study has the following objectives

1. Fabrication of terminal velocity apparatus.
2. Evaluation of Terminal velocity apparatus on sorghum grains
3. Effect of moisture content on terminal velocity
4. Effect of moisture content on sphericity and projected area of sorghum grains

2. Materials and Methods

2.1 Fabrication

The apparatus is simple in operation, consisting of following parts.

1. Casing
2. Blower
3. Electric motor
4. Speed regulator
5. Stand
6. Sieves
7. Fiber column
8. Anemometer

i) Casing

Casing may refer to an enclosing shell, tube, or surrounding material. Casings are rigid structures. The casing serves the purpose of increasing pressure. But, pressure should decrease with an increase in cross sectional area as pressure is inveresely related to the cross sectional area.

Casing is made up of GI sheet and the diameter and thickness of casing sheet is 30 cm and 3 mm thickness respectively. The casing is in circular shape as shown in fig.6. One side of casing is provided with a hole to place shaft of the motor, which makes the blower to rotate. This casing may direct the air flow or increase safety by increase safety by preventing objects from contacting the fan blades.

The operations used in the making of casing are marking, cutting, welding, grinding and drilling.

Fig 1: Marking for casing

Fig 2: Cutting of metal

Fig 3: Grinding of metal

Fig 4: Welding

Fig 5: Drilling

Fig 6: Casing

Fresh well matured and ripened fig fruits were procured from nearby garden, Sangareddy, Telangana State. These fig fruits were washed with chlorinated water (50ppm) to remove any traces dirt particles. The fruits were cut into slices along its diameter approximately 1.0 cm thickness using knifes.

ii) Blower

Blower is a mechanical device for moving air or other gases. The term fan and squirrel cage fan, are frequently used as synonyms. A blower consist of a rotating elements of blades which act on the air. Usually, it is contained with in some form of housing or casing. It is powered by electric motor. These blowers increase the speed and volume of air stream. The kinetic energy of the blowers are used to increase the volume of air stream. Blower displaces the air radially, changing the direction of air flow. This is sturdy, quiet and corrosion resistance.

The blower is circular in shape and forward curved. It is made up of plastic and of diameter 20 cm. It is double inlet having 36 blades on each side. It is connected to the shaft of motor and rotates along with the rotation of shaft. The circumference of blower is 62.83 cm as shown in fig.7.

iii) Electric motor

An electric motor is an electric machine that converts electrical energy into mechanical energy, usually rotation. It can be powered by direct current sources (D.C) or alternating current sources (A.C). The motor consists of a shaft which is protruded through the hole made on one side of casing. The purpose of motor is to rotate the blower which is placed on its shaft.

The motor used is of 1400 rpm, 230 volts, power of 105 watts and frequency of 50Hz. It is shown in figure 8.

Fig 7: Blower

Fig 8: Electric Motor

iv) Speed regulator

A regulator is a crucial component that serves to increase or decrease speed of blower according to our needs. The regulator controls the voltage that makes the current flow less or more. Lower the voltage lower the speed of blower. It is shown in figure 9.

v) Stand

Frames are rigid structures. They maintain their shapes with or without external forces. Frame designed to support loads are usually stationary, fully constrained structures. The frame supports the parts of the apparatus which provides balance and reducing vibrations of the machine while in operation. It is subjected to direct weight(or) load of other members of the machine.

The stand is made up of GI angular bars and the height of the stand is 80 mm. The frame is square in shape with a side of 150mm. Four angular bars of height 80mm is connected to the frame for standing purpose. The electric motor is attached to the stand for the purpose of support while operating as shown in figure 10.

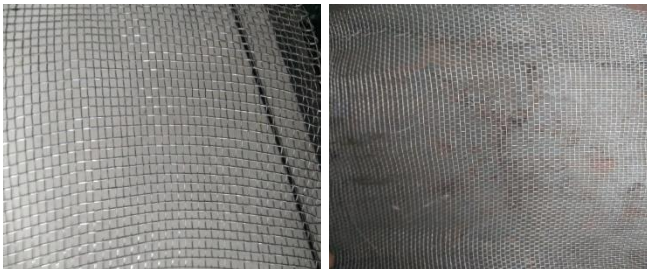
The operations used in the making of frame and stand are marking, cutting, welding and grinding. Half of the frame is used for placing of motor and half of it is used for switch board connections.

Fig 9: Speed Regulator

Fig 10: Stand with electric motor connected

vi) Sieves

The main purpose of sieve is to hold the grain samples. Different sizes of seives are used for different grains. The sieves are made up of stainless steel. Here, the seives are replaced according to the grain sizes. Two sizes of sieves are used with percentage open area of 64.8% and 79% were shown in fig.11(a) and (b) respectively. The sieve is placed between the air outlet end and fiber column.



(a) **(b)**

Fig 11: Sieves of different sizes

vii) Fiber column

The fiber column is fixed above the air outlet end. It is made up of poly acrylic material with length of 600 mm, diameter of 82mm and wall thickness of 3 mm. It is transparent in nature so that we can be able to see the grains when suspended in air while operating the machine. It is shown in figure 12.

Viii) Anemometer

An anemoneter is the device used for measuring the speed of air and is also a common weather station instrument. In this experiment, the sample was dropped into the air stream from the top of the air column, and air with varying velocity was blown till the seeds stayed suspended in the air stream. The air velocity near the location of the seed suspension was measured by hot air anemometer having a least count 0.01 m/s.

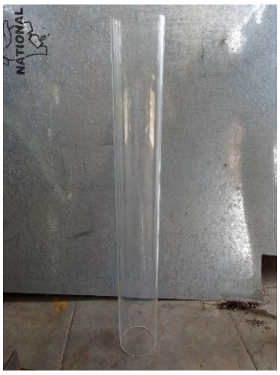


Fig 12: Fiber column

Fig 13: Anemometer

2.2 Raw materials

Sorghum grains of different moisture content levels viz. 8.96%, 14.37%, 17.29%, 20.69%, 23.22%, 25.03%, 27.56% and 29.15 % (w.b.) were selected to conduct experiment with developed terminal velocity apparatus.

2.3 Physical parameters of food grains

2.3.1 Determination of moisture content

The moisture content of wet basis of dried grains were determined by hot air oven method for sorghum done by putting 25-30 g of grains 105 °C for 6 h. The average moisture content of the samples was calculated to obtain the moisture content of the samples using the relationship below

$$\text{M.C. (w.b)\%} = \frac{W_w - W_d}{W_w} \times 100$$

Where,

W_w= weight of wet grains, g

W_d=weight of dried sample, g

2.3.2 Geometric mean diameter

The legth, width and thickness (a,b,c) of sorghum grains were determined by a vernier caliperse of an accuracy of 0.02 mm. The geometric mean diameter can be calculated from following equation.

$$d_g = (abc)^{\frac{1}{3}}$$

Where,

d_g = geometric mean diameter

a = diameter along X-axis, mm

b = diameter along Y-axis, mm

c = diameter along Z-axis, mm

2.3.3 Sphericity of grains

The sphericity sorghum grains was calculate by using the following formula

$$\text{Sphericity } S_p = \frac{(LWT)^{\frac{1}{3}}}{L}$$

Where,

L= length of the sorghum grain, mm

W=width of the sorghum grain, mm

T=thickness of sorghum grain, mm

2.3.4 Density

Density is determined by placing/ dropping seeds of known weight into fluid of volume 500 ml. The displacement of volume was recorded three times and then averaged.

$$\text{Density}(\rho) = \frac{\text{average weight}}{\text{displaced volume}}$$

2.4 Operation procedure

The electrial operated terminal velocity determination apparatus was installed on level and hard surface. The sorghum grains were fed from the top of fiber column onto

the sieves and distributed uniformly on the sieves. The seives can be changed according to the different type of grains.
The rotating blower creates an air stream. The air stream which was created makes the sample placed on the sieve to get suspended in the air column. The air flow rate should be adjusted in such a way that the grains must suspend in the air which was regulated by using regulator and also through the suction provided. The air velocity near the location of the seed suspension was measured by the anemometer. The obtained velocity is considered as the terminal velocity of those grains.

Fig 14: Working on terminal velocity determination apparatus

2.5 Perfomance evaluation
Terminal velocity is the highest velocity attainable by the grains as it falls through air. It occurs when the sum of the drag force and the buoyancy is equal to the downward force of the gravity acting on the grains.

$$V_t = \left[\frac{2w(\rho_p - \rho_f)}{\rho_p \rho_f A_p C}\right]$$

Where,
V_t = terminal velocity, m/s
C= overall drag coefficient
g = acceleration due to gravity, m/s^2
m_p= mass of the particle, kg
ρ_p= mass density of particle, kgs^2/m^4
ρ_f = mass density of fluid, kgs^2/m^4
A_p= Projected area of particle in perpendicular direction of motion, m^2
w= weight of particle, kg

2.6 Cost estimation
Cost estimation may be defined as the process of forecasting the expenses that must be incured to manufacture a product. These expenses take into a consideration all expenditure involved in a design and manufating with all related to service facilities such as pattern making, tool, making charges

Basically the cost estimation is of two types.
- Material cost
- Machining cost

2.6.1 Material cost
Material cost gives the total amount requiired to collect tge rawmaterial whichhas to be processed or fabricated to desired size and functioning of the component. These materials are divided into categories.

a. **Material for fabrication:** The material is obtained is raw conditioned and is manufatured or processes to finished size for proper functioning of the component.
b. **Standard purchased parts:** This includes the parts which was readily available in the market like motor, blower, fiber column etc.,

2.6.2 Machining cost
This cost includes manufacturing cost apart from material cost, which includes labour, material and factory services required to produce the required part.

3. Results and Discussion
The terminal velocity determination apparatus were tested on sorghum grains. The results were analysed for terminal velocity of sorghum at different moisture content levels and physical parameters of sorghum grains.

3.1 Experimental determination of terminal velocity
A vertical air tunnel was used to determine the experimental terminal velocity of grains. 25 g of sorghum seeds at different moisture content levels were randomly selected for measurement terminal velocity. The seed sample was placed on a mesh screen in vertical tube. The air velocity was adjusted by increasing the speed of motor untill the seed began to float. The air velocity near where the seed became suspended was measured with anemometer with 0.1 m/s accuracy.
The following values were recorded for sorghum grains at differenet moisture content levels as shown in table 1.

Table 1: Experimental terminal velocity values of sorghum grains at different moisture levels

S.No.	Moisture content (%w.b.)	Average terminal velocity (m/s)
1	8.96	8.83
2	14.37	9.11
3	17.29	9.28
4	20.69	9.32
5	23.22	9.46
6	25.03	9.54
7	27.56	9.62
8	29.15	9.71

The average terminal velocity values for sorghum grains were found as 8.83m/s, 9.11m/s, 9.28m/s, 9.32m/s, 9.46m/s, 9.54m/s, 9.62m/s and 9.71m/s at 8.96%, 14.37%, 17.26%, 20.69%, 23.22%, 25.03%, 27.56% and 29.15% on wet basis respectively. It was observed that with increase in moisture content of grains results in increase in terminal velocity of grains.

3.2 Theoretical determination of terminal velocity
The calculated terminal velocity values were shown in table 2

for sorghum grains at different moisture content levels.

Table 2: Theoretically calculated terminal velocity values of sorghum grains at different moisture levels

Moisture Content (%wb)	Projected area(mm^2)	Drag coefficient	Terminal velocity(m/s)
8.96	11.92	0.32	9.10
14.37	12.26	0.34	9.17
17.29	13.01	0.31	9.18
20.69	13.45	0.33	9.47
23.22	14.06	0.34	9.53
25.03	14.52	0.33	9.62
27.56	15.01	0.31	9.73
29.15	15.47	0.307	9.79

The terminal velocity values for sorghum grains were calculated as 9.10 m/s, 9.17 m/s, 9.18 m/s, 9.47m/s, 9.53 m/s, 9.62 m/s, 9.73 m/s and 9.79 m/s at 8.96%, 14.37%, 17.26%, 20.69%, 23.22%, 25.03%, 27.56% and 29.15% on wet basis respectively.

Table 3: Difference between experimental and theoretical terminal velocity values

Moisture content(%wb)	Experimental Terminal velocity (m/s)	Theoretical terminal velocity (m/s)	Difference
8.96	8.83	9.10	0.27
14.37	9.11	9.17	0.06
17.29	9.28	9.18	0.1
20.69	9.32	9.47	0.15
23.22	9.46	9.53	0.07
25.03	9.54	9.62	0.08
27.56	9.62	9.73	0.11
29.15	9.71	9.79	0.08

The difference values between the theoretical and experimental terminal velocity vales at different moisture content levels were meager and not significant.

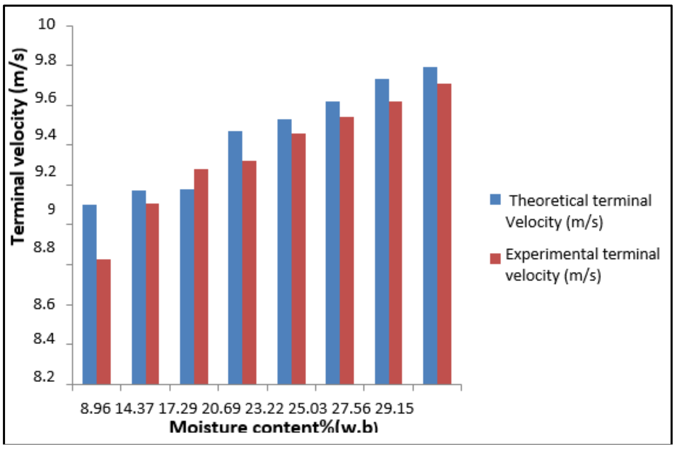


Fig 15: Difference between theoretical and experimental terminal velocities

3.3 Effect of moisture content on terminal velocity

When sorghum grains moisture content was increased from 8.96% (w.b.) to 29.15% (w.b.). The experimental terminal velocity also increased from 8.83 m/s to 9.71 m/s. Regression modeling for sorghum grains had shown the correlation between the moisture content and terminal velocity as follows

$$V_t = 0.041M_c + 8.494 \text{ with } R^2 = 0.986$$

There was a linear relationship between terminal velocity and moisture content of sorghum grains as shown in fig. 16.

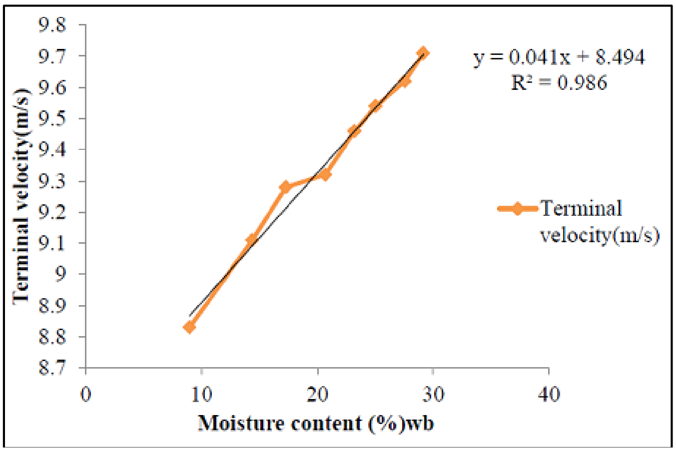


Fig 16: Effect of moisture content on Terminal velocity

3.4 Effect of moisture content on projected area of sorghum grains

The sorghum grains moisture content was increased from 8.96% (w.b.) to 29.15% (w.b.), the projected area also increased from 11.92 mm^2 to 15.47 mm^2

Regression modelling for sorghum grains had shown the correlation between the moisture content and projected area as follows

$$A_p = 0.182M_c + 9.920 \text{ with } R^2 = 0.969$$

There was a linear relationship between projected area and moisture content of sorghum grains as shown in fig. 17.

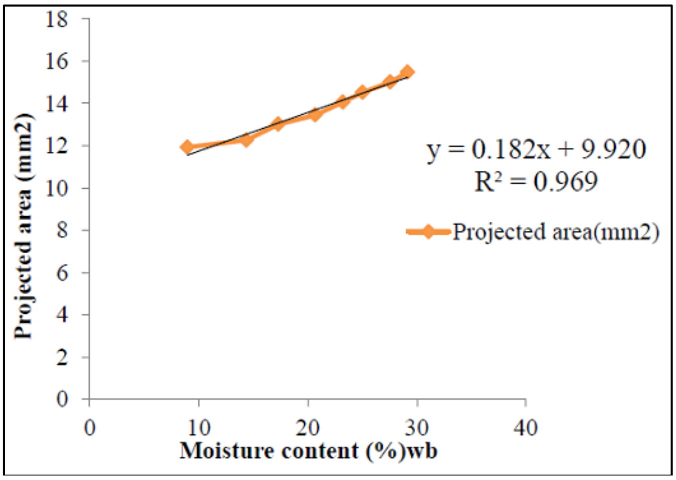


Fig 17: Effect of moisture content on projected area

3.5 Effect of moisture content on Sphericity of sorghum grains

When the sorghum grains moisture content was increased from 8.96% (w.b.) to 29.15% (w.b.), the sphericity also increased from 0.798 to 0.808 but the increased values in sphericity is not significant. Regression modelling for sorghum grains had shown the correlation between the moisture content and sphericity as follows

$$\text{Sphericity } (\varnothing) = 0.000M_c + 0.792 \text{ with } R^2 = 0.948$$

This above equation showed that sphericity of sorghum grains is not depending on moisture content of grains. Sphericity is a moisture independent variable. It depends only on length, width and thickness of grains.

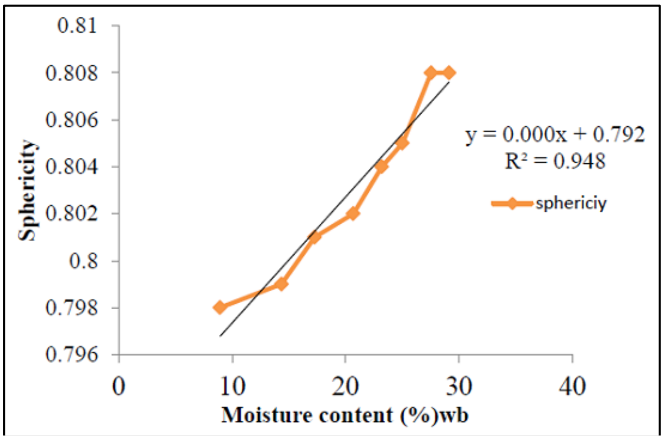


Fig 18: Effect of Moisture content on Sphericity

3.6 Cost of machine
The machine cost details are as follows

Table: The machine cost details are as follows

S. No	Items	Cost in Rs.
1	Motor	1200
2	Blower	700
3	Fiber column	700
4	L- Angle(stand)	300
5	Metal sheet(casing)	300
6	Regulator& Switch board	250
7	Shaft	100
8	Drilling	100
9	Grinding and filling	150
10	Welding	500
11	Painting	250
12	Circular pipe	150
13	Sieves	200
14	Miscellaneous	500
Total		Rs. 5,400/-

4. Conclusion
The terminal velocity determination apparatus has been fabricated with locally available materials. The terminal velocity determination apparatus has been developed and fabricated keeping in mind the constraints and requirements of small scale industries to find out the terminal velocity of different agricultural grains at different moisture content levels in laboratory method. It can be used for determination of terminal velocity of all sizes of food grains i.e., of mustard to maize by using different screens. The operation of this machine is quite simple. The moisture content of sorghum grains effect the terminal velocity i.e. with increase in moisture content, terminal velocity of grains get increased. The regression model has shown the relationship between moisture content and terminal velocity as V_t = 0.041Mc + 8.494 with R^2 = 0.986. The projected area of sorghum grains increased with increase of moisture content. The regression model has shown the relationship between moisture content and projected area as Ap = 0.182Mc + 9.920 with R^2 =0.969. The sphericity of grains does not depend on moisture content.

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