Eco. Env. & Cons. 28 (November Suppl. Issue) : 2022; pp. (S79-S85)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i07s.013

Influence of Blade Types, Cutting Velocity and Stalk Diameter of Sorghum Crop on Cutting Energy and Cutting Force

Raghavendra Veerammanavara[1]*, Veerangouda M[2]., Sushilendra[3]., Vijayakumar Palled[4]., Sharangouda Hiregoudar[5] and Channabasavann A.S[6]

[1]Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, Raichur, Karnataka, India
[2]University of Agricultural Sciences, Raichur, Karnataka, India
[3]Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, Raichur, Karnataka, India
[4]Department of Renewable Energy Engineering, College of Agricultural Engineering, Raichur, Karnataka, India
[5]Centre for Nanotechnology, Department of Processing and Food Engineering, Raichur, India
[6]University of Agricultural Sciences, Bhimarayanagudi, Karnataka, India

(Received 22 March, 2022; Accepted 16 May, 2022)

ABSTRACT

Sorghum (*Sorghum bicolor* L.) popularly known as "Jowar", a cereal grain found in tropical and subtropical climate. India ranks fifth in total sorghum production with 4.7 million tonnes (USDA, 2020). Sorghum is grown in India in an area about 4.82 m ha with production of 4.78 m tonnes and productivity of 989 kg/ha.In Karnataka, it is grown in 0.94 m ha with a production of 0.98 million tonnes and productivity of 945 kg/ha (INDIASTAT, 2020). A designed and fabricated laboratory test-rig of a pendulum impact tester was used to conduct the experiment in the Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, Raichur. The experiment was conducted to determine the engineering properties of sorghum stalk. The independent variables *viz.,* two types of blades (smooth edge and serrated blade), four levels different stalk diameters (12, 16, 20, 24 mm) and three levels of blade cutting velocity (4.40, 6.30, 7.40 m/s) were selected. Results showed that the maximum cutting energy of 35.47 J was recorded at a blade cutting velocity of 4.40 ms^{-1} at 24 mm stalk diameter and the least cutting energy of 5.23 J was recorded for 12 mm stalk diameter at blade cutting velocity of 7.40 m s^{-1} for serrated blade for smooth edge blade and the more cutting energy was recorded of 28.65 J for 24 mm stalk diameter at blade cutting velocity of 4.40 ms^{-1} and the least cutting energy 3.55 J were recorded for 12 m stalk diameter at 7.40 ms^{-1} for serrated cutting blade. The maximum cutting force of 1477.92 N was recorded at a blade cutting velocity of 4.40 ms^{-1} at 24 mm stalk diameter. The least cutting force of 435.81 N was recorded for 12 mm stalk diameter at blade cutting velocity of 7.40 m s^{-1} for smooth edge blade and for serrated cutting blade, the more cutting force was recorded of 1193.75 N for 24 mm stalk diameter at blade cutting velocity of 4.40 ms^{-1} and the least cutting energy 295.84 N were recorded for 12 m stalk diameter at 7.40 ms^{-1}.

***Key words** : Cutting energy, Stalk diameter, Engineering properties.*

([1]Ph.D Scholar, [2]Registrar, [2]Registrar,[3]Assistant Prof. and Head, [4]Associate Prof. and Head, [5]Associate Prof. and Head, [6]Dean, Agri)

Introduction

Sorghum (*Sorghum bicolor* L.) popularly known as "Jowar", a cereal grain found in tropical and subtropical climateIt is the fifth most important cereal crop in the world, after wheat, maize, rice and barley. In India, sorghum is the third cereal crop after rice and wheat (Kumar Charyulu, 2011).Sorghum is nutritionally superior to rice because of its high mineral and fibre content. Starch (60-75%) is the main component of sorghum grain, followed by proteins (7-15%), non-starch polysaccharides (2-7%) and fat (1.5-6%). The average energetic value of whole sorghum grain flour is 356 kcal/100g (Dicko *et al*., 2006).

Sorghum is grown in hot and dry regions where the summers are relatively longer. Most of the sorghum plants take 90-120 days to mature. The boot stage is within 50-60 days, flower stage is within 60-70 days, then with full grain maturity within 120 days. The sorghum is an annual or short-term perennial, culms up to 4 m or more high, sweet except in grain types; panicle is 8-40 cm long, sessile spikelet is 4- 6 mm long. The sorghum grain moisture at the end of the growth period is from 18% to 22% (Anon., 2003).

In regards to area under production of sorghum, during 2019-20, Maharashtra ranked first with 3.94 million hectares (37.86%), followed by Karnataka (20.66%), Tamil Nadu (10.89%) and Rajasthan (6.82 %) (Anon., 2018). In the year 2019-20 and 2020-21, Maharashtra occupied the highest position in production of sorghum with 2.68 million tonnes of production (34.40%) followed by Karnataka (24.11%). Share of other states in production was Tamil Nadu (12.64 %), Andhra Pradesh (7.33%), Uttar Pradesh (4.73%), Madhya Pradesh (3.45%), Telangana (1.18%) and Gujarat (2.10%) (INDIASTAT, 2020).In Karnataka, it is grown in 0.94 m ha with a production of 0.98 million tonnes and productivity of 945 kg/ha (INDIASTAT, 2020). Major sorghum growing districts of Karnataka are Kalaburgi, Raichur, Koppal, Belagavi, Ballari and Vijayapur. In Hyderabad Karnataka is also called as Kalyan Karnataka (Bidar, Gulbarga, Yadgir, Koppal, Raichur and Ballari and Vijayanagara) it is grown in an area of 0.37 m ha with a production of 0.42 m tonnes with productivity of 1194 kg/ha during 2018-2019 (Anon., 2018).

The variation in the physical properties of plant stalks and the resistance of cutting are known in order to understand the behaviour of material with respect to different operating conditions of harvesting. Increased interest in mechanized crop harvesting and commercial use of straw has prompted the need for engineering data on stem properties (Yore *et al.,* 2002). Comparative performance of cutting elements applied in harvester design can be judged by their cutting energy requirements, cutting force and stress applied (Chakraverty *et al.,* 2003). Hence, it is necessary to determine the cutting energy requirements for suitable knife design and also operational parameters (Yilmaz *et al.,* 2008).

The cross sectional area and moisture content of the crop had significant effect on cutting energy and maximum cutting force. Hence, in order to help in the design and development of sorghum harvester, it is essential to investigate the effects of blade parameters such as blade cutting speed and blade type on the cutting characteristics of cereal crop stems, namely cutting energy and cutting force.

In view of this, a pendulum impact tester was fabricated (Sushilendra *et al*., 2016)and the effects of cutting speed of blade, stalk diameter and type of blade on the cutting energy and cutting force requirement of sorghum crop have been studied.

Materials and Methods

Experimental procedure to determine engineering properties of sorghum stalk

In order to design of sorghum harvester requires the knowledge of various crop parameters such as physical, mechanical and frictional properties of crop and crop density (Sawant, 2010). Hence, in order to determine the engineering properties of sorghum stalk test-rig of a pendulum impact tester was fabricated and used to conduct the experiment in Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, Raichur. The experiment was conducted to determine the engineering properties of sorghum stalk. The independent variables *viz.,* two types of blades (smooth edge and serrated blade), four levels different stalk diameters (12, 16, 20, 24 mm) and three levels of blade cutting velocity (4.40, 6.30, 7.40 m/s) were selected as shown in Table 1 and response parameters were recorded and analyzed. During the experiment, stems were fitted firmly in the stalk holder to simulate natural stand of stem in the field as shown in Plate 1. The holder is located at the lowest oscillating point where the equilibrium line is located. The arm is then given an appropriate angular displacement, θ_i when released it gained speed as it moved downwards till it attained maximum speed which corresponds with maximum kinetic energy achieved and recorded as θ_c. The initial angular displacements were fixed and corresponding cutting velocities were determined and all the experiments were replicated three times and the averages of the calculated cutting energy, cutting forcewere analyzed and optimized the independent parameters *viz.*, blade type, cutting velocity and stalk diameter.

Selection of stalks

The mechanical harvesting for sorghum crop is need of the hour. Hence, the sorghum crop was selected and the basic engineering data required for the development of harvester was studied. For determination of cutting energy and cutting force, fifty matured sorghum plant samples were selected randomly in the field and brought to the laboratory study.

Plate 1. Determination of cutting energy requirement of crop by pendulum impact tester

Blade velocity

When the blade is released, its initial velocity is zero. But when it reaches the stem placed vertically downward position, it has the highest velocity based on physics laws on cutting moment. The relation between peripheral velocity (Vc) and initial angle (dropping angle) of a pendulum arm at the impact moment was calculated from the following equation (Koloor and Borgheie, 2006).

$$V_c = \sqrt{\frac{2W_t R(1-\cos\theta)}{I}} \text{ x } L$$

Where,

V_c = linear velocity of the blade at cutting point, m/s
W_t = Weight of pendulum, kg
R = Distance between the rotational center and center of gravity, m
I = Moment of inertia, kg m^2
L = Length of pendulum, m.
θ = Angle of pendulum at initial position, degrees

Cutting energy of sorghum stalk

The sorghum stalk to be cut was placed at the point of maximum kinetic energy of the swinging arm and held by the stalk holder. When the arm was released, it gains speed till it meets and cuts the material placed in the path of the knife. The difference in the angle before and after cutting will be directly related to energy consumed for cutting of the stalk. The energy required for cutting of sorghum plant stalk was determined by the difference between è and θ_o. Expressions for determiningcutting energy requirement and peripheral knife speed were given

Table 1. List of variables considered for pendulum type impact tester

Crop	Independent parameters	Levels	Performance parameters
Sorghum	Blades	B-1 (Smooth edged blade) B-2 (Serrated blade)	Cutting energy (J) Cutting force (N)
	Velocity	V-1 (4.4 m/s) V-2 (6.3 m/s) V-3 (7.4 m/s)	
	Diameter of stalks	12 mm (Selected) 16 mm (Selected) 20 mm (Selected) 24 mm (Selected)	

as stated by Alizadeh (2011).

$$E_c = WR(\cos\theta_2 - \cos\theta_1)$$

Where, Ec = Cutting energy, J
W=Weight of the pendulum, kg
R = Radial length to centre of gravity, m and
θ_1 = Angle of pendulum at initial position, degrees
θ_2 = Angle of pendulum after cutting, degrees

Cutting force of sorghum stalk

Cutting force was calculated by measuring the cutting energy and dividing length of which is equivalent to diameter of the stalk.

$$F_C = \frac{E_C}{D}$$

Where,
F_c = Cutting force, N
E_c = Cutting energy, J
D = Diameter of the stem, m

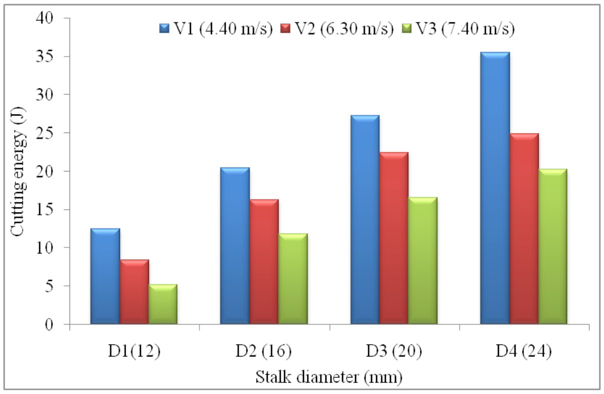
Results and Discussion

The influence of stalk diameter, blade cutting velocity and blade types on cutting energy were conducted as per the procedure explained in materials and method section. The influence of stalk diameter, blade cutting velocity and types of blades on the cutting energy and cutting force were determined and recorded. The experiments were conducted at sorghum stalk moisture of 31.60 % (w. b.).The results it was found that, for smooth cutting blade, the maximum cutting energy of 35.47 J was recorded at a blade cutting velocity of 4.40 ms^{-1} at 24 mm stalk diameter. The least cutting energy of 5.23 J was recorded for 12 mm stalk diameter at blade cutting velocity of 7.40 m s^{-1}. For serrated cutting blade, the more cutting energy was recorded of 28.65 J for 24 mm stalk diameter at blade cutting velocity of4.40 $ms^{-1}$and the least cutting energy 3.55 J were recorded for 12 m stalk diameter at 7.40 ms^{-1} as shown in Table 2.

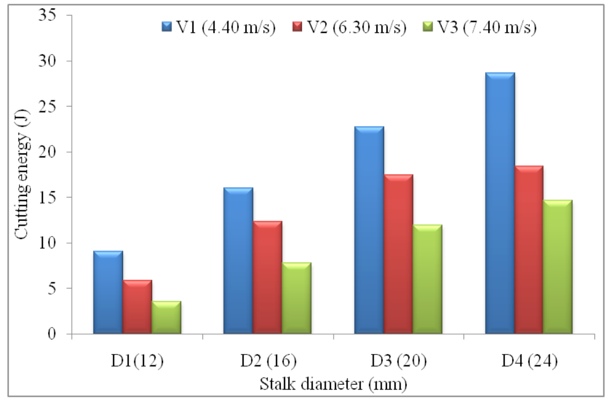
From the ANOVA of cutting energy shows that, the statistical model is significant at 1% level of significance. The independent parameters like types of blades, stalk diameter and blade cutting velocity had effect on cutting energy at 1 % level of significance. The interactions of independent variables also significant at 1 % level of significance. It was found that, as the diameter of stalks increases, the cutting energy also increases at all the levels of blade and all the levels of cutting velocity as shown in from the Fig. 1 and 2. It was observed that, as the cutting velocity increases, the cutting energy decreases for smooth and serrated blade, this could have been fact as the cutting velocity increases, the stalks does not become flattened or crushed and at higher cutting velocity due to less resistive force lower cutting energy had observed. At lower cutting velocity the stalks become flattened, crushed and more resistive force observed at lower cutting velocity. Hence, cutting energy increases as cutting velocity decreases. As the diameter of the sorghum stalks increases, the cutting energy increases, It is due to the fact that, at less diameter stalks the plant material to cut is very less but as diameter of stalks increases the blade has to cut more plant material. Hence, cutting energy increase as the diameter of the stalks increases. The more resistive force observed at higher cross sectional area of the stalks. These trends were in agreement with the findings of Sushilendra *et al.* (2016) and Zhang *et al.* (2019). The selected two different types of blades, the serrated blades requires less cutting energy compared to the

Table 2. Pattern of cutting energy (J) for different cutting velocity, diameter of stalks and blade type for sorghum crop

Blade type	Diameter (mm)	Cutting energy (J)		
		Cutting velocity (m/s)		
		V1 (4.4)	V2 (6.3)	V3 (7.4)
Smooth edge blade	D1(12)	12.52	8.45	5.23
	D2 (16)	20.42	16.25	11.86
	D3 (20)	27.23	22.43	16.58
	D4 (24)	35.47	24.89	20.25
Serrated blade	D1(12)	9.06	5.85	3.55
	D2 (16)	16.05	12.35	7.82
	D3 (20)	22.75	17.45	11.95
	D4 (24)	28.65	18.45	14.65



Effect of stalk diameter (D) and cutting velocity (V) on cutting energy using serrated blade for sorghum crop



Effect of stalk diameter (D) and cutting velocity (V) on cutting energy using smooth blade for sorghum crop

smooth blade. It is due to the fact that, in case of serrated blade, the serrations contains in the serrated blade which aids in holding the crop thereby it avoids the slippage of stalks. Hence, cutting energy required for cutting the sorghum stalk decreases but in case of smooth edge blade, the cutting energy requirement to cut the stalk is more. It's due to the fact that, less stalk holding tendency and more slippage. Similar findings reported by Pekitkan *et al.,* (2018) and Sushilendra *et al.* (2020).

Effect of diameter of stalks, cutting velocity and types of blades on cutting force for sorghum crop stalks

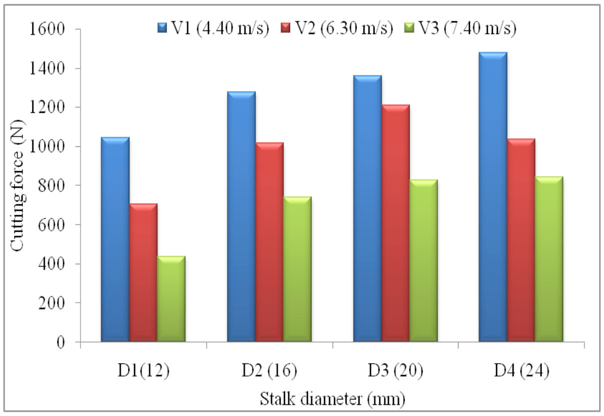
The influence of stalk diameter, blade cutting velocity and types of blades on the cutting force data is presented in the Table 3.

The cutting force required to cut the sorghum stalks is ranged from 435.81 to 1477.92 N. From the results it was found that, for smooth cutting blade, the maximum cutting force of 1477.92 N was recorded at a blade cutting velocity of 4.40 ms^{-1} at 24 mm stalk diameter. The least cutting force of 435.81 N was recorded for 12 mm stalk diameter at blade cutting velocity of 7.40 m s^{-1}. For serrated cutting blade, the more cutting force was recorded of 1193.75 N for 24 mm stalk diameter at blade cutting velocity of 4.40 ms^{-1} and the least cutting energy 295.84 N were recorded for 12 m stalk diameter at 7.40 ms^{-1}.

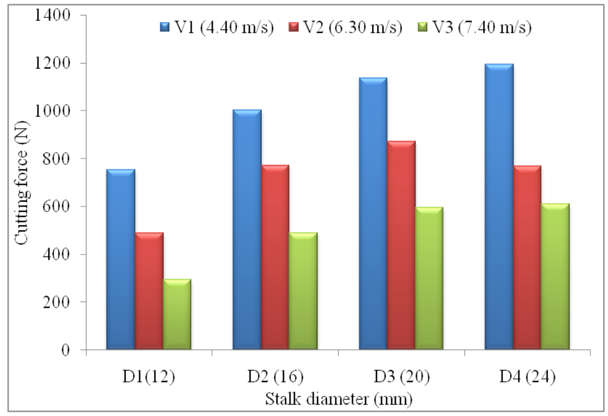
The ANOVA of cutting force shows that, the statistical model is significant at 1% level of significance. The independent parameters like types of blades, stalk diameter and blade cutting velocity had effect on cutting force at 1 % level of significance. The interactions of independent variables also significant at 1 % level of significance. The diameter of stalks increases, the cutting force also increases at all the levels of blade and all the levels of cutting velocity as shown in from the Fig. 3 and Fig. 4. It was observed that, as the cutting velocity increases, the cutting force decreases for smooth and serrated blade, this might be due to the fact that, at lower cutting velocity the blade fail to cut the sor-

Table 3. Pattern of cutting force (N) for different cutting velocity, diameter of stalks and blade type for sorghum crop

Blade types	Diameter (mm)	Cutting force (N)		
		Cutting velocity (m/s)		
		V1 (4.4)	V2 (6.3)	V3 (7.4)
Smooth edge blade	D1(12)	1043.34	704.16	435.84
	D2 (16)	1276.25	1015.62	741.25
	D3 (20)	1361.50	1211.50	829.00
	D4 (24)	1477.92	1037.08	843.75
Serrated blade	D1(12)	755.00	487.50	295.84
	D2 (16)	1003.12	771.88	488.75
	D3 (20)	1137.50	872.50	595.5
	D4 (24)	1193.75	768.75	610.42



Effect of stalk diameter (D) and cutting velocity (V) on cutting force using serrated blade for sorghum crop



Effect of stalk diameter (D) and cutting velocity (V) on cutting force using smooth blade for sorghum crop

ghum stalk due to less impact on the sorghum stalk. But with the increase in cutting velocity, cutting force decreases due to less resistive forces at higher cutting velocity. As the diameter of the sorghum stalks increases, the cutting force increases, It is due to the fact that, at less diameter stalks the plant material to cut is very less but as diameter of stalks increases the blade has to cut more plant material.Full mature plants cellulose became compact and hard so the force required to cut was increased as diameter increased. Hence, cutting force increases as the diameter of the stalks increases. The more resistive force observed at higher cross sectional area of the stalks. These trends were in agreement with the findings of Dange *et al.* (2010) and Azadbakht *et al.* (2014). The selected two different types of blades, the serrated blades requires less cutting force compared to the smooth blade. It is due to the fact that, in case of serrated blade , the serrations contains in the serrated blade which aids in holding the crop thereby it avoids the slippage of stalks. Hence, cutting force required for cutting the sorghum stalk decreases but in case of smooth edge blade, the cutting force requirement to cut the stalk is more. It's due to the fact that, less stalk holding tendency and more slippage. Similar findings are reported by Pekitkan *et al.* (2020) and Sushilendra *et al. (*2020).

Conclusion

The engineering properties of sorghum stalk are important for design of cutting unit and conveying unit of sorghum harvester. Hence, in order to design of cutting unit of sorghum harvester, it was necessary to determine the influence of cutting blades, blade cutting velocity on the engineering properties of sorghum stalks viz., cutting energy, cutting force and average cutting velocity. The maximum cutting energy of 35.47 J was observed at a cutting velocity of 4.40 ms^{-1} at 24 mm stalk diameter. The minimum of cutting energy of 5.23 J was obtained at a cutting velocity of 7.40 m s^{-1} at 12 mm stalk diameter for smooth edge blade. The maximum cutting energy of 28.65 J was recorded at a cutting velocity of 4.40 ms^{-1} at stalk diameter of 24 mm whereas the minimum cutting energy 3.55 J was obtained at cutting velocity of 7.40 ms^{-1} at 12 mm stalk diameter for serrated blade. The maximum cutting force of 1477.92 N was recorded at a cutting velocity of 4.40 ms^{-1} at 24 mm stalk diameter while the minimum cutting force of 435.84 N was observed at a cutting velocity of 7.40 ms^{-1} at 12 mm stalk diameter for smooth edge blade. The maximum cutting force of 1193.75 N was recorded at a cutting velocity of 4.40 ms^{-1} at 24 mm stalk diameter while the minimum cutting force of 295.84 N was observed at a cutting velocity of 7.40 ms^{-1} at 12 mm stalk diameter for serratedblade

References

Alizadeh, M. R. Fatemeh, R. A. and Dabbaghi, A. 2011, Cutting energy of rice stem as influenced by internodes position and dimensional characteristics of different varieties. *Aust.J.Crop. Sci.* 5(6) : 681-687.

Anonymous, 2003. Annual report 2003-2004, National Cooperative Development Corporation, New Delhi.

Anonymous,2018.https://aps.dac.gov.in/APY/Public_Report1.aspx.

Ashok, K. Avdash, K. Kalay, K. and Devesh, K. 2017. Performance evaluation of harvesting and threshing methods for wheat crop. *Int. J. Pure App. Biosci*. 5(2):

604-611.

Azadbakht, M. Esmaeilzadeh, E. and Mostafa, E. S. 2014. Energy consumption during impact cutting of canola stalk as a function of moisture content and cutting height. *J. Saudi Soci. Agril Scie.*,http://dx.doi.org/10.1016/j.jssas.2013.10.002

Chakraverty, A. Singh, P. R. Raghavan, G. S. V. and Ramaswamy, H. S. 2003. *Handbook of Postharvest Technology.* 1st edn., Marcel Dekker Inc, New York.

Dange, A. R. and Thakare, S. K. 2010. Force and energy required for cutting Pigeon pea stems. *Int.J.Ag. Engg.* 3(2): 272-274.

Dicko, M. H. Gruppen, H. Zouzouho, O. C. Traore. A. S. Berkel, W. J. and Voragen, A. G. J. 2006. Effect of germination on amylases and phenolics related enzymes in fifty sorghum varities grouped according to food-end use properties. *J. Sci. Food Agric*. 86(1): 130-143.

INDIASTAT. 2020. India sorghum production, New Delhi, Available https://www.indiastat.com/data/agriculture/jowar-great-millet/datayear/2020.

Koloor, T. R. and Borgheie, A. 2006. Measuring the static and dynamic cutting force of stems for Iranian rice varieties. *J. Agri. Sci.Tech.* 8(3) : 193-198.

Kumara Charyulu, D. Bantilan, M. C. S. Nedumaran, S. and Deb, U.K. 2011. Development and diffusion of improved sorghum cultivars in India: impact on growth and variability in yield. *In: 7th ASAE Conference, Vietnam*.

Pekitkan, F. G., Esgici, R., Elicin, A. K. and Sessiz, A. 2018. The Change of Shear force and energy of cotton stalk depend on knife type and shear angle. *Sci. Papers-Series A, Agron*. 61(1): 360-366.

Sawant, B. P. Sawant, S. A. and Munde, P. A. 2010. Effect of moisture content on selected physical properties of pulses. *Int. J. Agric. Engg.* 2(2) : 270-272.

Sushilendar., Veerngouda, M. Bhavya and Manjunath, K. 2020. Cutting velocity and stalk cross sectional area of black gram stalks on cutting energy and cutting force. *Int. J. Curr. Microbiol. App. Sci.* 9(6): 650-659.

Sushilendra. Veerangouda, M. Anantachar, M. Prakash, K. V. Desai, B. K. and Vasudevan, S. N. 2016. Effect of blade type, cutting velocity and stalk cross sectional area of chickpea stalks on cutting energy, cutting force and specific energy. *Int. J. Agril. Sci.* 8(53) : 2658-2662.

United states Department of Agriculture, 2020. https://www.fas.usda.gov/data/search ?reeports%.

Yilmaz, D. Akinci, I. and Cagiran, M. I. 2008. Effect of some threshing parameters on sesame separation. *Agric.Engg. Int.: CIGR E-J*, 10: 1-8.

Yore, M. W., Jenkins, B. M. and Summers, M. D. 2002. Cutting properties of rice straw. ASAE. Annual Int. Meeting / CIGR XV the World Congress. USA, 28-31 July: 1-9.

Zhang, C.Liqing, C.Junfang, X. and Jumin, Z. 2019. Effects of blade sliding cutting angle and stem level on cutting energy of rice stems. *Int. J. Agril. Biol. Engg*. 12(6): 75-81.