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Communiting Characteristics of Dried Water Chestnut Kernel

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The experiments were conducted to study the grinding characteristics of water chestnut in batch grinding process. Power consumption was measured for grinding time ranged from 120 to 360sec at different speed of mill varied from 800 to 1200rpm for the batch sizes of 100, 150 and 200g. For all the batch sizes, it was observed that as the speed of the mill increased, there was an increase in power consumption and found significantly high for the larger batch size. The relation between power consumption and time of grinding was a straight line with negative slope. For a particular batch size and time of grinding, finer the particles were produced in case of higher mill speed. Taking mill speed and time of grinding constant, less fine particles were produced at higher mass size. Harris model was found best suitable to describe the size distribution in batch grinding process.

Keywords: Water chestnut, Batch grinding, Power consumption, Size distribution, Harris model

Introduction

Water chestnut (*Trapa bisinosa Roxburg*) commonly known as *Singhara*, is an annual aquatic warm seasonal crop. Water chestnut belongs to '*Trapaceae*' family. It is cultivated in South Eastern Asia, Malaysia, Srilanka, Taiwan, China, Thailand, Australia and tropical Africa. In India, the two popular species *Trapa bispinosa* and *Trapa quadrispinosa* of water chestnut are widely cultivated. In general, the cultivation of water chestnut is distributed through out the country especially in Punjab, Bihar, Uttar Pradesh Madhya Pradesh, Tamilnadu, Maharastra and in some parts of Uttarakhand. Water chestnut is considered as a cheap source of food and regarded as a poor man's food. In Indian villages, it is generally used in fast. It has significant importance in manufacturing of starch and alcohol. Surprisingly, water chestnut could not draw the attention of the scientists particularly in the area of processing, with the result; valuable and easily available crop could not be used to enrich the food nutritionally and make the balanced daily diet to some extent. Water chestnuts can be used in a variety of recipes because they have a starchy taste that is fairly neutral. Some people claim that their flavor is similar to a bland nut. Water chestnuts also have a firm and crispy texture, which adds to their appeal as an ingredient in stir-fries, salads or any meals where the vegetables to be used must have a crunchy consistency.

Grinding is one of the oldest unit operations and is extensively used in food industry. Though there are few published works available on the grinding of food material, however, workable equipment continues to be designed and used for grinding many types of solid food materials. As far as process of grinding is concerned, power consumption, specific energy consumption and particle size distribution and mill capacity are main considerations, from engineering point of view. The study conducted on modern milling techniques and obtained refined bran free white flour from ragi. The investigation reported 60-70% yield of flour from wet milling process, however the retention of protein, calcium and phosphorous was reported to be low in such flours as compared to those obtained from dry milling process (Kurien and Desikachar, 1962). An abrasive milling process was developed in which 16- 18% of the initial weight of the grain was removed by using an abrasive rice mill (Anderson *et al.*, 1971). The study on kinetics of' breakage of maize in a small laboratory hammer mill was conducted and it was found that breakage was first order function and that the primary breakage distributions were insensitive to mill conditions or moisture content of material. The specific rate of breakage was found to be dependent on particle size (approximately to the third power) and increased as moisture content of the grain was reduced showing that the dried material was more brittle and a minimum rotation speed was necessary to get significant breakage (Jindal and Austin, 1976). The study was conducted on grinding experiment of commercial grade coriander in batch, semi-continuous and continuous grinding in a hammer mill. In batch experiment, the effect of mass size, mill speed and time of grinding on power requirement, energy consumption and particle size distribution was studied. It was found that the case power consumption can be expressed by $P = at^b$ (Gautam, 2002).

Where,

P_c = power consumption, watts and

t = time of grinding, mm

a and b are the coefficient of the equation

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The final ground product should meet the quality standard suggested by the agencies like BIS, FPA and ISO for export trade. Since much of the grinding work was reported on the non-food material there is a need to carry out experimental studies to study the various operations of machine parameters such as mill speed and screen openings on the performance of ground material. Present study was conducted mainly to see grinding behavior of dry water chestnut in hammer mill.

Materials and Methods

Commercial grade of water chestnut procured from local market of Pantnagar was used as the basic raw material for the study. The kernels were cleaned and stored in poly bags at room temperature. For the grinding operations a hammer mill (Willey mill) with fixed blades was used.

The mill consisted of a hopper grinding section, base sieve and an outlet the grinding section comprised of a disc carrying four fixed hammers, with sharpened ends to cutting edges. Four blades were attached to the inner periphery of the grinding chamber and the clearance between these blades and the cutting edge of hammer could be adjusted and was kept constant at 0.2mm. Whole kernels were fed to the mill through top feed hopper. Kernels entering the grinding zone were struck by hammers, shattered into pieces and finally rubbed into powder by the hammers inside the mill casing. A base sieve was provided at the bottom through which product passed and was collected at the outlet. The base sieve was having average whole size of 0.5 mm, 1.00mm and 2mm. A Ro-tap sieve shaker was used to obtain size distribution of ground material. The sieve shaker was provided with a timer to control the sieving time and operated electrically. A set of 5 standard sieves of size (1.00, 0. 710, 0.500, 0.250 and 0.125mm) and pan were used for the sieve analysis of ground material.

To study the effect of different operational conditions of a hammer mill on the power requirement and particle size distribution of the ground material, the experiment were planned to observe the grinding behavior of water chestnut kernels. Mill speeds, batch size and time of grinding were considered as batch grinding test was performed at 10% moisture content using a blind screen at appropriately fitted to the outlet of the grinding section to stop the mill out flow. At first no load power consumption was recorded by running the hammer mill using a watt meter at every setting of speed of operation of the mill. Power consumption and particle size distribution were taken as dependent variables for grinding (Table 1).

Statistical analysis: Communiting characteristics of dried water chestnut kernels were observed by conducting experiments in three levels of speed of operations (800, 1000 and 1200 rpm) with three levels of time of grinding (120, 240 and 360 seconds) and three levels of sample size (100, 150 and 200 g). The observed variables for experiments were power requirement, particle size distribution and average particle size diameter. The experimental data for grinding of dried water chestnut kernel was statistically and graphically analyzed with the help of Minitab 3.2 and spread sheet (EXCEL) software packages on personal computer.

Results and Discussion

Power consumption: In batch grinding the effect of mill speed, sieve size and batch size was observed on the power consumption. Full second order models were fitted for the variation of power consumption with the independent parameters. The relationships obtained are as follows:

$$P_c=56.52-8.21B-12.96S+5.32T-0.25B^2+0.03S^2+0.11T^2+2.38BS-0.46ST-0.3BT \quad (1)$$

Where,

Pc = power consumption;

B = batch size;

S = speed of mill (rpm) and

T = time of grinding

The results of analyses of variance (ANOVA) for second order model at 5% level of significance showed that the F- value for fitted model was 257.37, which was more than the tabular value. The coefficient of determination (R^2) had a value of 99.27 %, thus the model is acceptable.

Table 1. Experimental plan

Experimental variable	No. of levels	Levels	
		Coded	Uncoded
		B1	100
Batch size(gm)	3	B2	150
		B3	200
		S1	800
Speed of mill(rpm)	3	S2	1000
		S3	1200
		T1	120
Time of grinding(sec)	3	T2	240
		T3	360

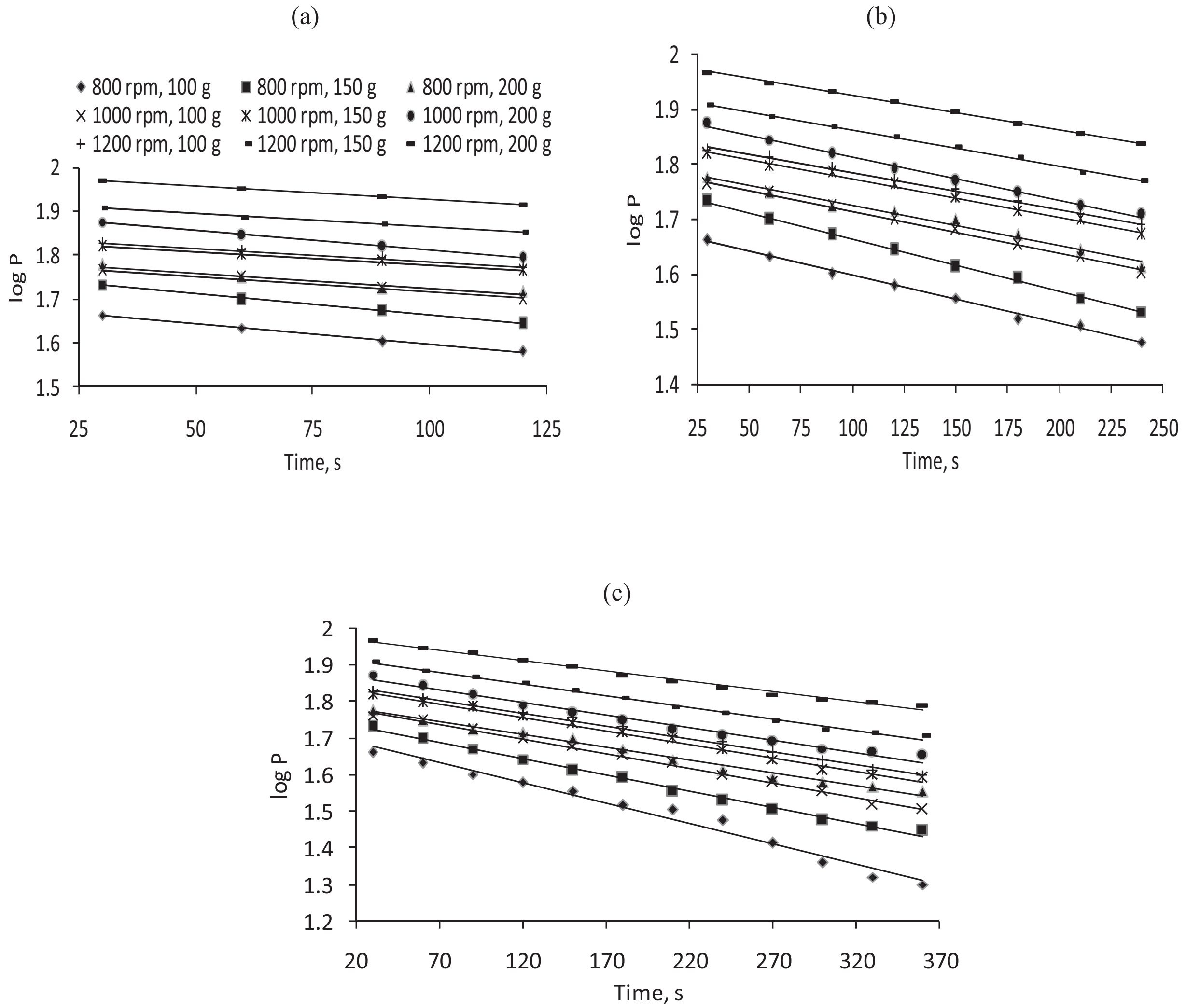

Figure 1. Variation of power consumption with grinding time (a) 120sec, (b) 240sec and (c) 360sec at different mill speeds and batch sizes

Power consumption was measured for a period of time ranging from 120 sec to 360sec at different speeds of the mill and batch sizes. Figure 1 exhibits power consumption at 1(a) 120sec, 1(b) 240sec and 1(c) 360sec time of grinding.

The trend showed that as the speed of the mill increased, there was an increase in power consumption. For bigger batch size the power requirement was significantly high. In all the cases, initially power consumption was in higher range and gradually as time continues the power requirement reduced to some extent. It may be due to the reason that initially to break the whole grain or its broken fractions large power is required since the grain offer more resistance to breakage. After initial breakage the liner particle offers less resistance to breakage resulting lesser power consumption. When batch size is more, naturally initial power requirement to overcome the resistance of grain is more. The graphs show that relation between power consumption and time of grinding is a straight line. The variation of power consumption for different batch sizes and speed of operation could he represented by the following equation (Gautam, 2002);

$$P_b = A + BT \quad \ldots (2)$$

The value of coefficient of correlation lies in the range from 0.9796 to 0.9990 with the standard error of experiment varying in the range from 0.2649 to 0.4326. The coefficient 'A' and 'B' were found in range of 1.6856 to 1.9881 and -0.0006 to -0.0011 respectively (Table 2).

Particle size distribution: The size distribution of the water chestnut kernel for different speed and time of grinding and different batch size was obtained by sieve analysis. Full second order models were fitted for the variation of average particle diameter with the independent parameters. The relationships obtained are as follows:

Table 2. Values of standard error, coefficient of correlation and coefficients of equation for power consumption

Batch size (g)	Mill speed (rpm)	Time (sec)	SE	R^2	A	B
100	800	120	0.3185	0.9953	1.6896	-0.0009
		240	0.3267	0.9952	1.6856	-0.0009
		360	0.3572	0.9796	1.7114	-0.0011
	1000	120	0.2946	0.9883	1.7880	-0.0007
		240	0.2894	0.9957	1.7917	-0.0008
		360	0.3745	0.9965	1.7964	-0.0008
	1200	120	0.3942	0.9888	1.8471	-0.0006
		240	0.4123	0.9960	1.8506	-0.0007
		360	0.4326	0.9963	1.8554	-0.0007
150	800	120	0.3321	0.9979	1.7602	-0.0010
		240	0.3156	0.9987	1.7580	-0.0009
		360	0.2649	0.9945	1.7503	-0.0009
	1000	120	0.2698	0.9936	1.8375	-0.0006
		240	0.2745	0.9960	1.8439	-0.0007
		360	0.3489	0.9938	1.8473	-0.0007
	1200	120	0.3265	0.9969	1.9261	-0.0006
		240	0.3741	0.9970	1.9284	-0.0007
		360	0.3835	0.9939	1.9258	-0.0006
200	800	120	0.3965	0.9477	1.7942	-0.0007
		240	0.3289	0.9820	1.7986	-0.0007
		360	0.2984	0.9863	1.7934	-0.0007
	1000	120	0.2785	0.9990	1.9014	-0.0009
		240	0.3018	0.9955	1.8932	-0.0008
		360	0.2961	0.9814	1.8795	-0.0007
	1200	120	0.3561	0.9965	1.9863	-0.0006
		240	0.3267	0.9988	1.9881	-0.0006
		360	0.3364	0.9884	1.9813	-0.0006

$$D_p = 31.17 - 0.0056B + 0.02476S + 0.011T - 0.00043B^2 + 0.0017S^2 + 0.0024T^2 - 0.002BS + 0.0045ST - 0.0005B \quad \ldots (3)$$

From analyses of variance (ANOVA) for second order model, the F-value for fitted model was 16.52, which was more than the tabular value at 5% level of significance and the coefficient of determination (R^2) had a value of 89.74 %. Thus the model is acceptable.

The effect of time for grinding, batch size and speed of operation of mill on particle size distribution is shown in Figure 2. It shows that as the time of grinding increased, the peak of the curves shifted towards the left magnitude also increased. This reveals that finer particles were produced with time. The mill speed had a definitive effect on particle size distribution of the resultant ground particle. It is clear that for a particular batch size and time of grinding finer particles were produced in case of higher mill speed. Taking mill speed and time of grinding constant, it shows that at higher mass size, less fine particles were produced. However, when speed of the mill was increased finer particles were generated.

Modeling of the particle size distribution of the ground product was attempted with the help of fitting computer software available. The criteria employed for model selection was the value of correlation coefficient, standard error of estimate as well as rationality of the model. Since the software employed had auto fitting ability to rank a particular equation, the criteria for a selection of model was based on the average rank over the whole set of experimental observation. The following equation called Harris Model was found to have the best fitting ability amongst the equation available, which satisfactorily correlated the commutative mass fraction with size of the ground material.

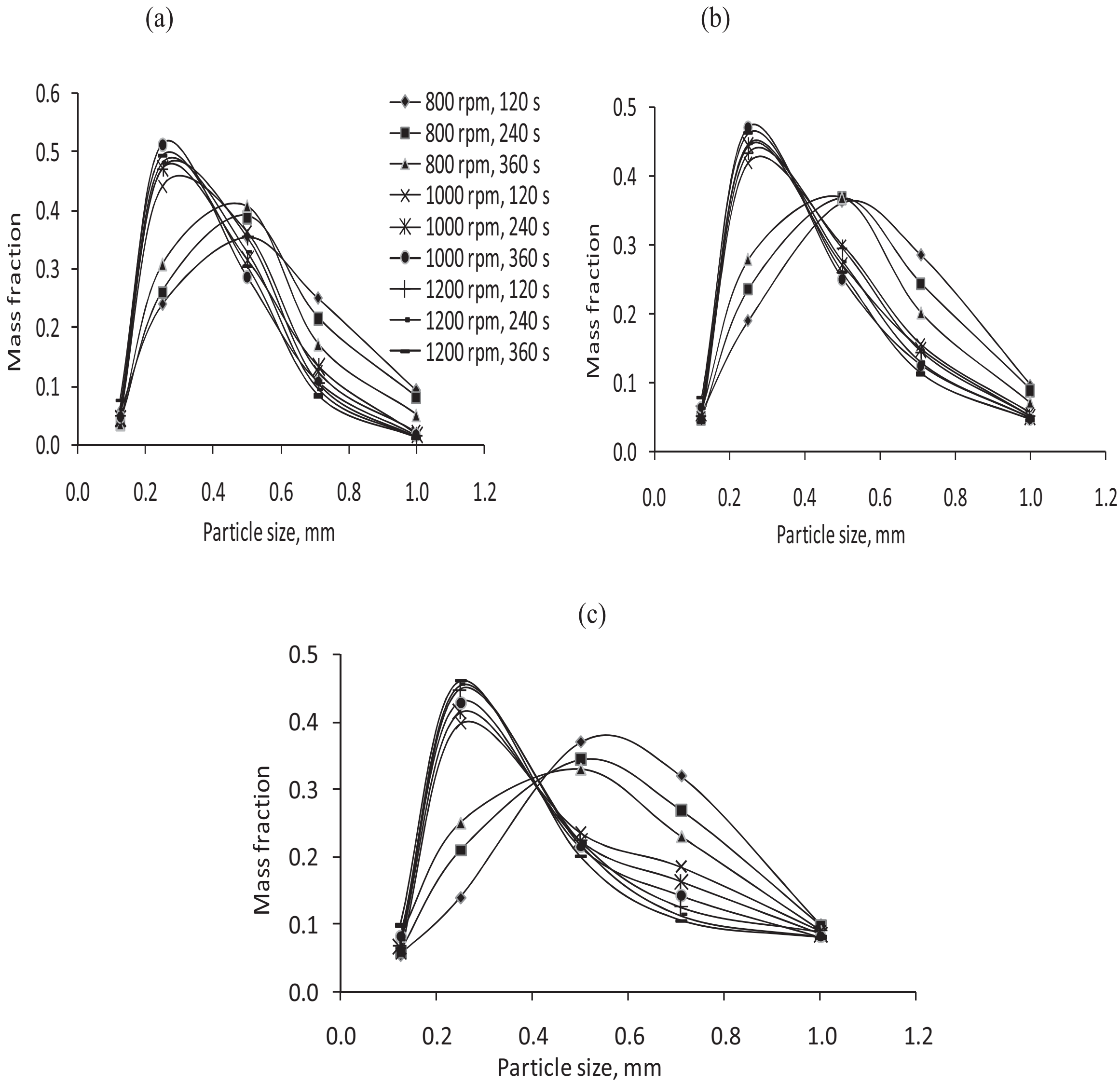

Figure 2. Variation in particle size distribution for (a) 100g, (b) 150g and (c) 200g batch size at different mill speeds and grinding times

$$\Phi = \frac{1}{(a + bD^{c})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The values of correlation coefficient for the above equation were more than 0.96 in most of the cases. The value of standard error of estimate ranged from 0.05 to 0.07. The values of the coefficient 'a' increased from 1.09 to 1.01 and values of coefficient 'b' increased in a range from 403261 to 754515 as the time of grinding and speed of mill increased. The value of the coefficient 'c' increased with of increase of speed of mill and time of grinding for a constant batch size and the value of 'c' ranged from 9.01 to 12.89 (Table 3).

Table 3. Values of standard error, coefficient of correlation and coefficients of equation for cumulative mass fraction in batch grinding process (Harris model)

Mass size, g	Speed, rpm	Time, sec	SE	R^2	a	b	c
100	800	120	0.0523	0.9863	1.0236	403261	9.0123
		240	0.0516	0.9754	1.0369	412545	9.0664
		360	0.0602	0.9862	1.0136	425653	9.0865
	1000	120	0.0623	0.9785	1.0135	488955	10.369
		240	0.0609	0.9965	1.0236	456452	10.236
		360	0.0596	0.9954	1.0359	458523	10.259
	1200	120	0.0576	0.9754	1.0426	499363	10.986
		240	0.0581	0.9621	1.0563	563695	11.125
		360	0.0654	0.9721	1.0569	598566	11.346
150	800	120	0.0669	0.9632	1.0599	469654	10.356
		240	0.0695	0.9965	1.0612	498656	10.656
		360	0.0603	0.9542	1.0689	495663	10.699
	1000	120	0.0635	0.9687	1.0699	635256	12.361
		240	0.0596	0.9699	1.0724	584955	11.265
		360	0.0621	0.9987	1.0756	698475	12.896
	1200	120	0.0635	0.9954	1.0788	684525	12.568
		240	0.0647	0.9822	1.0812	698545	12.654
		360	0.0649	0.9961	1.0698	632215	12.153
200	800	120	0.0632	0.9932	1.0896	615254	11.965
		240	0.0594	0.9822	1.0985	635963	11.695
		360	0.0602	0.9755	1.0956	754515	14.366
	1000	120	0.0594	0.9632	1.0998	712415	14.126
		240	0.0654	0.9698	1.0965	696444	13.652
		360	0.0579	0.9758	1.0986	532656	11.699
	1200	120	0.0536	0.9625	1.0956	521564	11.789
		240	0.0699	0.9935	1.0975	656535	13.104
		360	0.0710	0.9941	1.0962	563541	11.489

Conclusion

For batch grinding, power consumption was measured for a period of time ranging from 120 to 360sec at different speed of the mill varied from 800 to 1200rpm for the batch sizes of 100, 150 and 200g. The effect of mill speed, sieve size and feed rate were observed on the power consumption. Full second order model was fitted for the variation of power consumption with the independent parameters. As the speed of the mill increases, there was an increase in power consumption. In all the cases, the initial power consumption was in higher range and gradually as time continues the power requirement reduces to some extent. The relation between power consumption and time of grinding was a straight line.

The size distribution of the water chestnut kernel for different speed, time of grinding and different batch size was obtained by sieve analysis. Full second order model was fitted for the variation of average particle diameter with the independent parameters. For a particular batch size and time of grinding, finer particles were produced in case of higher mill speed. Taking mill speed and time of grinding constant, less fine particles were produced at higher mass size. Harris Model was found to be the best fitting for the particle size distribution of ground product.

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