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Investigation of parameters affecting cotton waste shredding for as straw mushroom substrates

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Abstract

The objectives of the study were to investigate the effects of shredding parameters on cotton waste reduction for straw mushroom substrate before filling into polyethylene bags. The variables of this study include: rotating knife sets in a spiral shape and V-shape, belt conveyor speeds at 1.4 rpm, 1.7 rpm and 2.33 rpm, rotating knife speeds at 131.6 rpm, 157.1 rpm and 183.1 rpm. It was found that the substrates shredding quantity and capacity depend on all variables, especially the impact of belt conveyor speed, which was consistent with statistical analysis. For the V-shape rotating knives, a belt conveyor speed of 2.33 rpm and rotating knife speed of 183.1 rpm had a high shredding capacity, of about 380 kg/hr, which is the best result for this article.

Keywords: cotton waste, mushroom substrates, shredding

1. Introduction

Mushrooms are organisms that derive their nutritional requirements from complex organic substances and do not having chlorophyll. They cannot generate nutrients by photosynthesis, but instead take nutrients from outer sources [1]. Then the mushroom is defined as “a macro fungus with a distinctive fruiting body, large enough to be seen with the naked eye and to be picked up by hand”[2]. They are rich in protein, some essential amino acids, fiber, potassium, and vitamins and have low cholesterol and fat levels; furthermore, they have benefits to relieve high cholesterol levels, breast cancer, prostate cancer, and diabetes. They also help in weight loss and increase the strength of the immune system [3]. The paddy straw mushroom (*Volvariella volvacea*), commonly known as the straw mushroom or the Chinese mushroom [4], is among the most extensively cultivated mushrooms in tropical and sub-tropical regions [5]. In general, these mushrooms have very limited shelf-life, much like fruits and vegetables that are highly perishable. Thus, they are not suitable for long term storage [6]. The mushrooms can be cultivated on agricultural wastes such as wheat straw, paddy straw, rice straw, rice bran, molasses, coffee straw, banana leaves, tea leaves, cotton straw, saw dust, etc. [7]. The *Volvariella volvacea* has been cultivated successfully on cotton waste, a relatively crystalline cellulose [8]. In addition, cotton waste-based spent mushroom substrate (SMS) is a nutrient-rich organic by-product [9].

Cotton provides an ecologically friendly textile with the bulk of cotton waste coming from the mill process [10]. In Nakhon Ratchasima, Thailand, the ingredients of straw mushroom substrates are 10% cotton waste, 82% mung bean waste, 4% dolomite and 6% fertilizer. After that, all ingredients are mixed and soaked with water on a cement floor, then undergo fermentation for about 4 days (flip-mixing every day). The moisture content of the final mixture was adjusted to 62% (w/w) wet basis, similar with the cotton substrates of oyster mushrooms [11]. The substrate was filled into polyethylene bags by labor and sterilized on steam sterilized cabinets at 95 °C for 4.5

hours. After the substrate was cooled to room temperature, it was inoculated with straw mushroom spawn and kept in a spawn running room under dark conditions. The mycelial growth rate was recorded until the spawn run period to total colonization.

Filling the cotton substrates into polyethylene bags posed a problem in this study because the cotton fiber clumped while packing into the bag. Carding is a mechanical process by which fiber clumps are opened, disentangled, and cleaned for different uses [12]. The efficiency of the machines depends upon the removed plant, plant condition, machine type and forward speed; the number of blades is also an important parameter in the cutting and shredding operation [13]. The objectives of the study were to investigate the effect of shredding parameters on cotton waste shredding.

2. Materials and Methods

2.1 Mushroom Substrate Preparation

The components of the mushroom substrate includes the cotton waste cotton waste 10% cotton waste, 82% mung bean waste, 4% dolomite and 6% fertilizer. The cotton waste was poured on a cement floor as the first layer, followed by the mung bean, fertilizer and dolomite, respectively. The mixing machine or flipping machine mixed all ingredients and soaked with the water for around 3-4 period per cycle, and then underwent fermentation for about 4 days (flip mixing every day), as shown in Figure 1.

Figure 1 Mixing of mushroom substrates.

2.2 Deconstruction of the Machine

In the shredder experiment, a lab scale machine was used to reduce the mushroom substrates, as shown in Figure 2. The substrate was put on a conveyor belt and transferred to the incline tray and rotating knife set. The substrate was reduced by the rotating knife set, then fell down to the tray if it could pass 5 millimeters of clearance. This machine can run by motor and transfer power to belts and pulleys. In addition, the rotating knife set has two shapes, a spiral shape set and a V-shape set, which have a 5-millimeter clearance for material passed through.

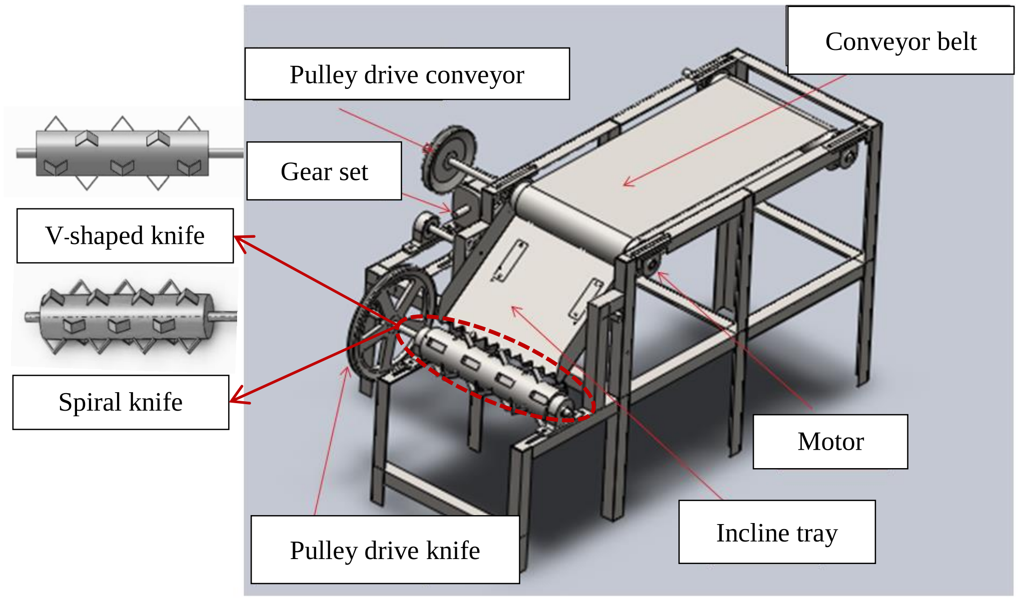

Figure 2 Shredder machine for cotton waste substrates.

2.3 Methods

A completely randomized design was considered for the experiment. The variables of this study include a rotating knife type, conveyor belt speed and rotating knife speed. The rotating knife sets are spiral shaped and V-shaped. The conveyor belt speeds are 1.4 rpm, 1.7 rpm and 2.33 rpm. The rotating knife speeds are 131.6 rpm, 157.1 rpm and 183.1 rpm. The moisture content of the substrates includes a wet basis of about 20±5 % and bulk density of about 0.378±0.050 grams per cubic centimeters; the mass is fixed to1 kg evenly across all tests. Two knife shapes, three speeds of the conveyor belt and three knife speeds gave 18 treatments for the experiment. For each treatment, three replications were done. Therefore, a total of 54 tests were conducted in the experiment. In addition, the experimental method is shown in Figure 3. The indicators are percentage of substrate shredding quantity(or shredding efficiency),percentage of loss quantity and shredding capacity, as shown in equations (1),(2) and (3), respectively.

$$sep(\%) = \frac{m_{sep}}{m_{total}} \times 100 \qquad (1)$$

$$loss(\%) = \frac{m_{loss}}{m_{total}} \times 100 \qquad (2)$$

$$cap(kg/hr) = \frac{m_{sep}}{t} \qquad (3)$$

Where,

sep	=	substrate shredding quantity	(%)
loss	=	substrate loss quantity	(%)
cap	=	shredding capacity	(kg/hr)
m_{sep}	=	mass of substrates shredding	(kg)
m_{loss}	=	mass of substrates loss	(kg)
m_{total}	=	total mass	(kg)
t	=	testing time	(hr)

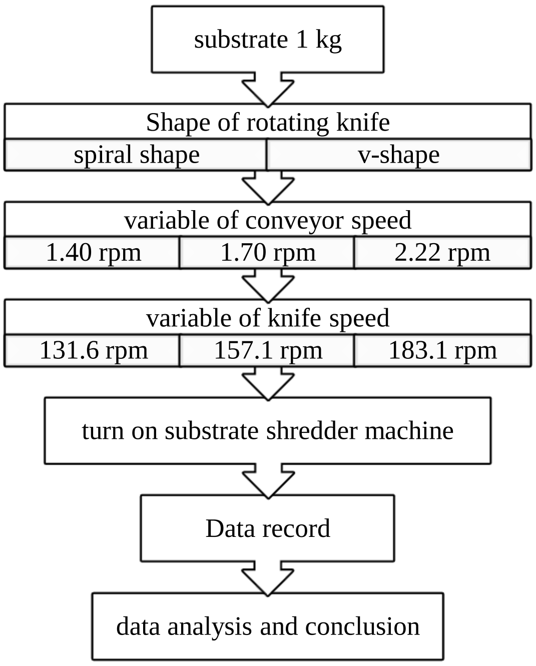

Figure 3 Experiment methods

The completely randomized design (CRD) [14] refers to the random assignment of experimental units to a set of treatments. It is essential to have more than one experimental unit per treatment to estimate the magnitude of experimental error and to make probability statements concerning treatment effects. The experimental model is shown in equation (4).

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \tag{4}$$

Where μ is the baseline mean, and α_i and β_j are the main factor effects for conveyor speed and knife speed, respectively. $(\alpha\beta)_{ij}$ is the two-factor interaction effect, and ε_{ijk} is the random error of the observation from the (i, j) treatment.

3. Results and Discussion

The percentage of mushroom substrate shredding and loss proportion is shown in Figure 4. It was found that the spiral shaped rotating knife has a similar substrate shredding quantity for all conveyor belt speeds and knife speeds of 96.66%,95.03% and 96.01% for maximum, minimum and average quantities, respectively. In addition, the range of substrate loss is 3.04%-4.97% and has 3.99% for average loss. For the V-shaped rotating knife, the trends are not similar, which as a result of not relation of variables. On the other hand, the average shredding quantity is 96.24%, a little higher than the V-shaped knife, which the maximum and minimum values are 98.31% and 93.86%, respectively. Meanwhile, the average quantity of substrates loss is 3.76%. The V-shaped rotating knife has the highest shredding quantity at 98.31 % and the lowest of quantity of loss at1.69%, at 2.33 rpm for conveyor belt speed and 131.6 rpm of rotating knife speed.

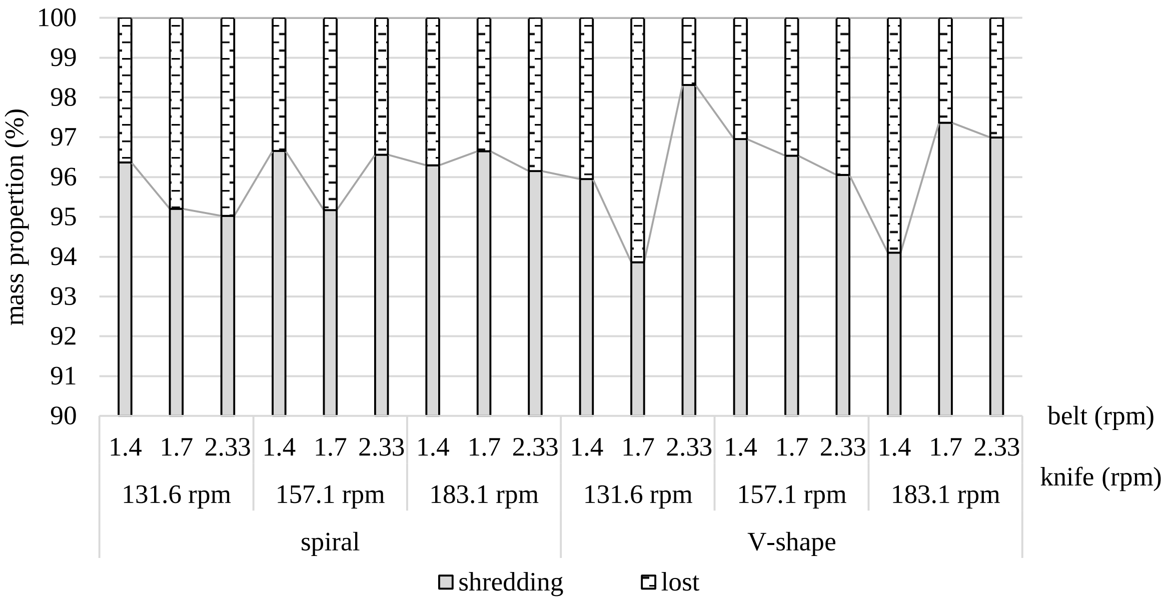

Figure 4 Shredding quantity and loss quantity

The trends of shredding capacity for the spiral shaped knife increase when the conveyor belt speed and rotating knife speed have higher values, as shown in Figure 5. The shredding capacity at a conveyor belt speed of 2.33 rpm and rotating knife speed of 131.6 rpm is about 350 kg/hr.

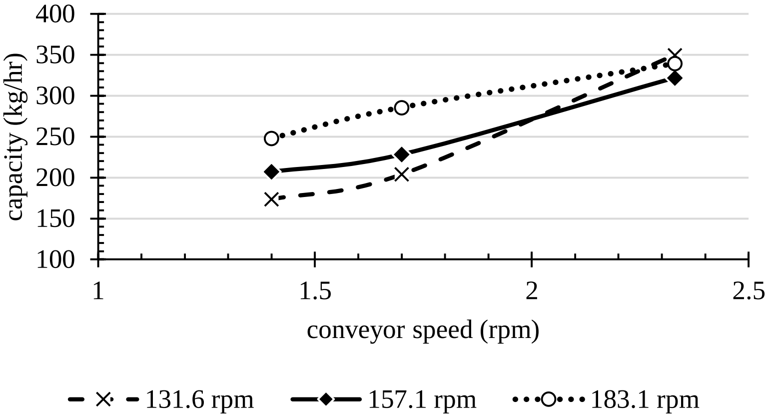

Figure 5 Shredding capacity of the spiral shaped knife

The trends of shredding capacity for the V-shaped knife increase when the conveyor belt speed and rotating knife speed have higher values, as shown in Figure 6. When the conveyor belt speed is 2.33 rpm and the rotating knife speed is 183.1 rpm, the shredded capacity is at about 380 kg/hr. Although the amount of shredding is not maximum, but when considering the highest shredding capacity, so it can give the small substrates so high about 370 kg/hr.

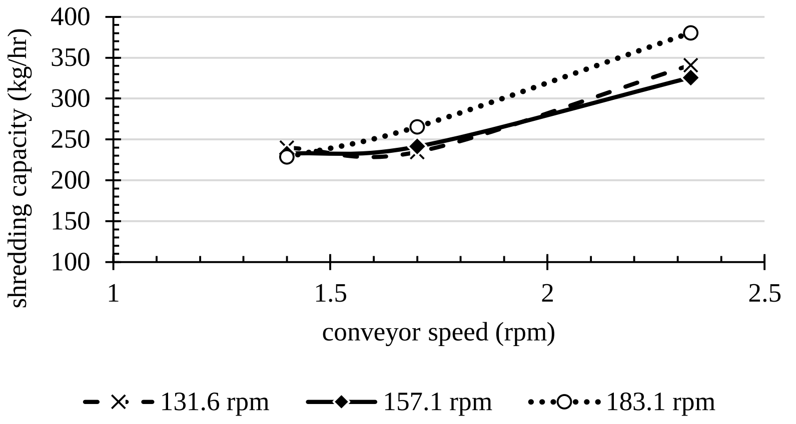

Figure 6 Shredding capacity of the V-shaped knife

For the shredding performance comparison between spiral shaped and V-shaped knives, it was found that the spiral shaped knife has a shredding performance lower than the V-shaped knife, except at a rotating knife speed of 183.1 rpm, as shown in Figure 7.In addition, the effect of increasing the conveyor speed is a higher shredding performance, especially for the V-shaped knife with a 183.1 rpm knife speed and 2.33 rpm conveyer speed; this has a highest shredding performance at about 369 kg/hr. This is consistent with the research of Pattarachai Vichaiya[15] that the effects of increasing the rotating speeds are an increasing effect to the higher shredded water hyacinth efficiency.

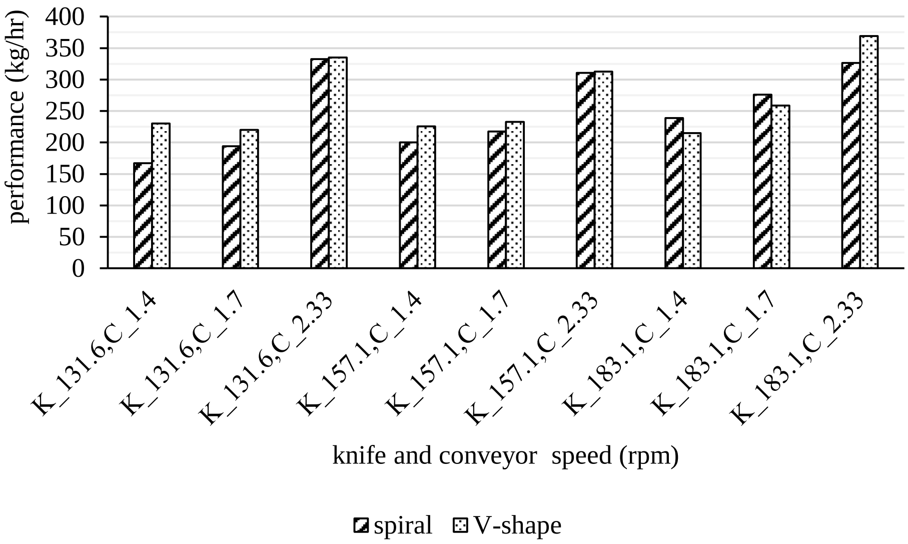

Figure 7 Comparison of shredding performance

Statistical analysis was used to analyze the data for shredding method. Multiple factorial analyses were done. Analysis of variance (ANOVA) was carried out to see the level of significance of each factor and their interaction. A further t- test was conducted to see which factors vary significantly from others. The statistical results are shown in Tables1-3 for the spiral shaped knife and Table4-6s for the V-shaped knife.

Table 1. Regression statistics of the spiral shaped knife.

Regression Statistics	
Multiple R	0.947859019
R Square	0.89843672
Adjusted R Square	0.864582293
Standard Error	23.75916864
Observations	9

Table 2.ANOVA of the spiral shaped knife.

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	29961.56571	14980.78285	26.53823457	0.001047635
Residual	6	3386.988568	564.4980947		
Total	8	33348.55427			

Table 3. Coefficients of the spiral shaped knife.

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-139.5008912	70.28553198	-1.984773925	0.094397271
Knife speed (rpm)	0.944044537	0.37667913	2.50623	0.046137809
Conveyer speed(rpm)	139.789981	20.43501774	6.84070759	0.000479685

Table 4. Regression statistics of the V-shaped knife.

Regression Statistics	
Multiple R	0.947035046
R Square	0.896875378
Adjusted R Square	0.862500505
Standard Error	21.14852787
Observations	9

Table 5.ANOVA of the V-shaped knife.

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	23338.94756	11669.47378	26.09101585	0.001096698
Residual	6	2683.561387	447.2602312		
Total	8	26022.50895			

Table 6. Coefficients of the V-shaped knife.

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-18.58063013	62.56260707	-0.296992581	0.776485537
Knife speed(rpm)	0.383954222	0.335289892	1.14514106	0.295765113
Conveyer speed (rpm)	129.7351648	18.18963234	7.132368726	0.000382488

The statistical analysis tables show conveyor belt speed and rotating knife speed are related to substrate shredding capacity. For the spiral shaped knife, the multiple correlation coefficient is 0.948 and R-square is 89.94%. The V-shape has a multiple correlation coefficient of 0.947 and R-square is 89.96%.

The conveyor belt speed and rotating knife speed affect shredding quantity, loss quantity and capacity ($p<0.05$), or statistically significant at 0.05. Consider equation (4) for the spiral shaped knife and equation (5) for the V-shaped knife; the conveyor belt speed affects capacity more so than the rotating knife speed.

$$y_1 = 0.994x_1 + 139.790x_2 \quad (5)$$

$$y_2 = 0.384x_1 + 129.735x_2 \quad (6)$$

Where,

y_1 = shredding capacity of the spiral shape

y_2 = shredding capacity of the V-shape

x_1 = speed of belt conveyor

x_2 = speed of rotating knife

4. Conclusion

The substrates shredding quantity and capacity depend on rotating knife type, rotating knife speed and conveyor belt speed. Higher speeds had an effect on all results, especially the impact of the conveyor belt speed, which is consistent with statistical analysis. If the conveyor belt speed is high, it affects the substrate transferring to the rotating knife and compression force, which results in a high substrate shredding capacity.

5. Acknowledgement

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