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Effect of mixing speed and time on the homogeneity of multi-particle size sugarcane leaves product in horizontal paddle mixer for pelletized

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Abstract

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The objective of this research study was to examine the effect of mixing speed and time on the homogeneity of multi-particle size sugarcane leaves that were crushed by hammer mill and sieved through mesh sizes of 3, 4, and 5 mm, respectively. The study used a prototype horizontal paddle mixer, with batch operation, built for laboratory studies which was able to mix 4 kg at a time. Mixed materials consisted of randomized samples in nine different positions of the mixer. Sieve analysis was conducted for the multi-particle sizes which remained in 8 class intervals of sieve layers. Mixing indices and coefficient of variation (CV) of mixtures were used as indications of homogeneity. The results showed that the particle size of sugarcane leaves which passed through the three sieve mesh sizes, at a mixing speed of 75 rpm for 4 min, resulted in a homogeneous mixture as the mixing index approached 1 and the CV of mixtures was < 10%.

Keywords: Mixing, Particle size; Sugarcane leaves; Mixing index

Introduction

Mixing is the combination of two or more elements of particles of different components and combining them into a homogeneous mixture (Vaizoğlu, 1999) The particles are homogenized when shaken or vibrated (Behnke, 2005), and the size and shape of the particles has a significant effect on the bulk density and material flow capability. The multi-size particles can have both mixing and de-mixing conditions at the same time when affected by force (Berk, 2019) When pelletized, the product's bulk density will depend on the differences of particle sizes (Harun & Afzal, 2016), but if case particles are not mixed properly, the desired product can be damaged (Cameron et al., 2018). The thesis of Chanin Oupathum studied crushed sugarcane leaves using a hammer mill with a sieve mesh size of 3 mm for pelletizing (Oupathum, 2012), while Nirattisak Khongthon's thesis described the use of a hammer mill with sieve mesh sizes of 1.7 and 3 mm (Khongthon, 2011). Various particle sizes were found after shredding separated the particles of sugarcane leaves, using sieves, into various (unseparated) particle sizes of < 0.25 mm, 0.25-0.42 mm, and > 0.42 mm. Even with the reduction of bagasse size using a hammer mill (51001 Farm King), there were different size particles on sieve analysis (Castro et al., 2013). Particles with similar size and density can create a homogeneous mixture (Bayram, 2008). However, improper mixing can affect the efficiency of the pellets (Bortone et al., 2014), for example, in the pharmaceutical, chemical, or food and agriculture industries (Cho et al., 2017). Therefore, the homogeneity of mixtures is very important.

The study was evaluated the mixture of particle powder using the sieve analysis method (Vaizoğlu, 1999). The evaluated the homogeneity of mixture of sugarcane leaves particles that were sieved through a mesh size of 3 mm for 6 minutes, and then randomly sampled the particles to find the mixing index (M) before pelletizing (Khongthon, 2016). Determined the homogeneity of nutrients in animal feed after 10 minutes mixing using the CV of mixtures before pelletizing using a Quantab chloride test strip (Reese et al., 2017). Tested homogeneity of chicken feed by using salt analysis based on the titrimetric chloride method. Mixing time was 3.75 min, and the CV of mixtures was found to be lower than 10% (Çiftci & Ercan, 2003). Determined the mixing efficiency of an animal feed mixer using rice grain as a homogeneous indicator, with mixing times of 10 and 20 min (Vijayakumar, 2019). When the CV of mixtures is $\leq$ 15%, it can be stated that the mixtures is homogeneous (Matuszek, 2020). Moreover, Studied the powder flow dynamics in a horizontal convective blender: Tracer experiments (Legoix et al., 2018). Developed and performance of a livestock feed mixer using a horizontal mixer (IA, 2018). Studied the 'Effect of Ingredients and Processing Parameters on Pellet Quality' by using a paddle blade for mixing before pelletizing (Briggs et al., 1999). Studied the effects of mixing speeds and timing on the appearance of milk powder using a horizontal mixer (Apsarina et al., 2020). As mentioned above, it was found that mixing time depends on the type of powder material for homogeneity of mixture. Moreover, the horizontal mixer is a common mixer used in commercial factories (Çiftci & Ercan, 2003).

In general experiments, it is difficult to accurately determine the behavior of mixing particles. Mixing two or more powdered mixtures is complicated and requires a proper analysis process. Sieve analysis was performed to analyze the powders suspended in each sieve of 8 class intervals (8 sizes of particle powders) at each point of the mixing tank. Therefore, the objective of this research was to study the effect of mixing speed and time of sugarcane leaves powder. Sugarcane leaves were shredded by hammer mill and sieved through mesh sizes of 3, 4 and 5 mm, respectively, which affected the homogeneity of mixture at each point of the mixing tank. The mixing index and CV of mixtures were indications of homogeneity. Proper mixing can increase the mixing potential to benefit the quality of the pelletizing process.

Materials and Method

This research was conducted at the Department of Agricultural Engineering. Faculty of Engineering, Khon Kaen University, Thailand. Sugarcane leaves used in the study were Khon Kaen 3 cultivar, which is a popular variety in northeast Thailand due to its high yield, and because it can adapt to rainfall.

Experiments

Sugarcane leaves were harvested in Phu Khiao District, Chaiyaphum Province, Thailand (16° 28'49.3 "N 102° 05'11.5" E) during the summer of harvest year 2018–2019, and the fresh leaves naturally dried for 1 month. The dried leaves were then chopped and reduced in size using a hammer mill, installed with hammer mill screen sizes. Three different mesh sizes of 3 mm, 4 mm, and 5 mm were used. A crushing speed of 1000–1100 rpm produced three different sizes of sugarcane leaves powder, consisting of particles passed through mesh sizes of 3 mm (TP1$\leq$3 mm), 4 mm (TP2$\leq$4 mm), and 5 mm (TP3$\leq$5 mm), respectively. The moisture content of the crushed sugarcane leaves was obtained by oven–drying at a temperature of 101º ± 2ºC for 24 ± 2 hours, in accordance with the Standard of the American Society for Testing and Materials (ASAE S487). The moisture content of the crushed sugarcane leaves was 11.55% w.b., and the bulk density after crushing was 76.13 kg/m^3 (3 mm), 94.56 kg/m^3 (4 mm), and 83.62 kg/m^3 (5 mm), respectively. Powder materials for each mesh size were kept in a laboratory in the same condition and stored in a closed tank to prevent the mixing of powder of other mesh sizes before the mixing process began.

Devices

The experiments were conducted using a prototype horizontal mixer, with batch operation, built for laboratory studies, and able to mix up to 4 kg of material at a time (Figure 1). The components of the mixer consisted of a screw conveyor (Figure 1a) to convey materials and initially mix them into the mixing tank, and control dust inside the screw conveyor to prevent its spread. The materials then flowed into a hopper (Figure 1b) for collection and facilitate their flow into the mixing tank. The mixing tank had two paddles installed in opposing directions to thoroughly mix the powder materials. The machine used a 3-phase electric motor with a capacity of 2.2 kW (3 horse power) (Mitsubishi, SF-JR, Thailand) (Figure 1c), and a power inverter (Delta, Ms300, Thailand) to control the rotation speed. The water control unit, used to humidify the material, was controlled by two ball valves and two spray nozzles (Figure 1d) to adjust pressure and flow rate for the same water volume in every mixing process. During the mixing process, the volume of powder mixture should be higher than the mixing shaft, and the paddles should be above the powder mixture to obtain a

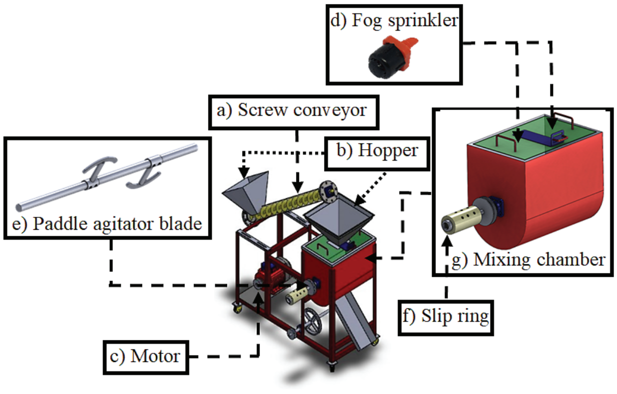

Fig. 1. Mixing machine

good mix of materials (Cullen, 2009). In a horizontal mixer, excessive mixture results in improper mixing and the inability to mix the ingredients in the upper area of the mixer, either ribbon or paddle agitator (Çiftci & Ercan, 2003). Mixing below 50% mixing capacity is not recommended (Manufacturing, n.d.).

For proper mixing, mixture samples must be collected periodically. The horizontal mixer can estimate the optimal mixing time by blending for two minutes. The mixer is then stopped and 9 samples collected from the specified sampling positions. After that, the samples are mixed for a further two minutes before the mixer is stopped. Then, the samples are collected from the same position as the previous sampling (Manufacturing, n.d.). Mixing times are important for the homogeneity of mixtures for each mixer to obtain the desired uniformity (Çiftci & Ercan, 2003). The best way to determine the proper mixing time is to test the homogeneity of the mixer by studying the distribution of particles in the mixing tank.

The study of homogeneity of the horizontal paddle mixer for mixing the multi-particle size sugarcane leaves sieved through different mesh sizes

The homogeneity test of the horizontal paddle mixer was conducted by studying the distribution of particles in the mixing tank. This experimental design was a Factorial in Experiments Randomized Complete Block Design (RCBD) with three replications per test, as illustrated in Table 1. Factors tested in the study included three levels of mixing speeds (50 rpm, 75 rpm, and 100 rpm) and three mixing periods (4 min, 6 min and 8 min), as shown in Table 1. The studied factors were compared among 3 sizes of powdered particles, namely TP1, TP2 and TP3 (referring to particles sieved through mesh sizes of 3 mm, 4 mm, and 5 mm, respectively) to achieve the desired humidity level. Sieved particles of all three mesh sizes were mixed by adding water using a moisture weight relationship (Tavakoli et al., 2009) to obtain 40–45% moisture content, according to the condition of biomass pellet production from sugarcane leaves (Khongthon et al., 2016), to increase the adhesion force, and prevent material flow causing separation (Vaizoğlu, 1999):

$$.m_w = \frac{m_i(M_{wf} - M_{wi})}{1 - M_{wf}}, \tag{1}$$

where: m_w is mass of water added to sample (g), m_i is initial mass of sample (g), M_{wf} = is final desired moisture content of sample (% w.b.) and M_{wi} = is initial moisture content of sample (% w.b.).

Table 1. Parameters tested for mixing multi-particle size sugarcane leaves

Parameters	Description
Blade speed, rpm	50, 75, 100
Mixer run time, min	4, 6, 8

Method of mixing

The mixer was cleaned before starting the experiment. The materials were weighed in a container of known dimensions. As the mixer started to operate, the hopper was opened at the top of the mixer between the discharging funnel and the center of the mixer. Powder particles were poured into the mixing tank and the materials began to mix. When the mixer stopped working after the determined mixing time, 100 g of sugarcane leaves powder were randomly sampled (Yeow et al., 2011) from nine different positions in the mixer (Figure 2d). Normally, the sampling position of the horizontal mixer is accessible from the top, from where samples can be directly collected (Manufacturing, n.d.) using a food scoop or shovel (Çiftci & Ercan, 2003), as shown in Figure 2e. Collected samples were stored in packaging bags at laboratory room temperature. Samples were then oven-dried for 24 hours to reduce their moisture content, in accordance with the Standard of American Society for Testing and Materials (ASAE S487) (American Society of Agricultural Engineers., 1984). After that, the particle samples were analyzed by Sieve Analysis (Figure 2g) to determine the percentage of powder particles that remained in the sieve – a critical process before the analysis (Patience, 2012) (Figure 3). Samples were separated by sieve shaker (Retsch 200 model) with mesh sizes of 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, 75 µm and 38 µm, respectively, in each layer. It is commonly used to quantify the powder fineness of material by stacking sieves mesh, and then shake or vibrate them using a mechanism for a period of time. The powder particles remaining in each sieve were weighed and the quantity recorded (Berk, 2019), as shown in Figure 3, according to the Method of Determining and Expressing Fineness of Feed Materials by Sieving (ASAE S319.3, 2007)(American Society of Agricultural Engineers., 2007). In order to determine the homogeneity of the powder particles, the indication method, based on the evaluation of the main ingredients in the animal feed to determine the homogeneity of the ingredients (Matuszek, 2020), was used.

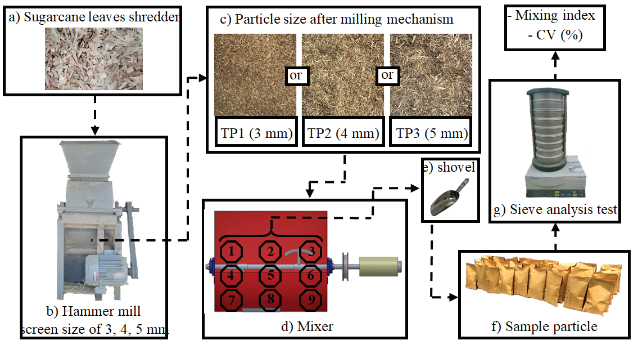

Fig. 2. Particles mixing testing method

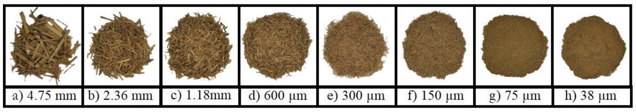

Fig. 3. Size of particles remaining in each sieve layer

Mixing Index

Many researchers have provided the definitions and methods for mixing index calculations of various particle sizes, using different mixing indices in various literatures. The Lacey mixing index can be easily calculated (Wen et al., 2015) and is frequently used (Cho et al., 2017). The index was developed using statistical analysis and standard deviation to study the proportional variation of components of each randomized sample. The samples were then calculated for the mixing index, as per Equation 2 (Lacey, 2007). The quality of particle mixing is completed when the mixing index (M) = 1, or approaches 1, at which time the mixing process continues. The mixing index demonstrates the relationship between mixing time and quality (Berk, 2019):

$$M = \frac{S_0^2 - S^2}{S_0^2 - S_R^2}, \tag{2}$$

where: S_0^2 represents the variance at the time when the components of the mixture are completely segregated, S_R^2 denotes the variance at the time when they are fully mixed, and S^2 is the variance for a mixture between fully random and completely segregated mixtures., which can be respectively defined as:

$$S^2 = \left[\frac{1}{(N-1)}\right]\left[(X_1-\bar{X})^2+(X_2-\bar{X})^2+\ldots+(X_n-\bar{X})^2\right] \tag{3}$$

$$S_0^2 = \bar{X}(1-\bar{X}) \tag{4}$$

$$S_R^2 = \frac{[\bar{X}(1-\bar{X})]}{n} \tag{5}$$

where: N represents the number of cells, n is the average number of particles in each cell, while $\bar{X}$, $X_{1,2,\ldots n}$ respectively represent the average number fraction of white particles and the number fraction of white particles in each cell. Lacey index depends on the amount of the cells. Lacey index would be higher when divided into more cells.

Coefficient of variation (CV) of mixtures

The homogeneity of mixture is determined by using Pearson's coefficient of variance (CV) (Dantuma, 2018). The CV of collected samples was determined as 10% or lower, which is considered to be an acceptable level of mixing (Manufacturing, n.d.), (Patience, 2012) and (Mccoy et al., 1994) indicating that the mixture is almost homogeneous. The coefficient of mixing can be calculated as per Equation 6 (Reese et al., 2017) and (Patience, 2012):

$$cv(\%) = \frac{\text{standard deviation (s)}}{\text{mean}} \times 100 \tag{6}$$

$$s = \frac{\sqrt{\sum(x_i-\bar{x})^2}}{n-1} \tag{7}$$

Herrman & Behnke (1994) (Manufacturing, n.d.) interpreted the results of homogeneity testing and improvement in the mixing process, as shown in Table 2.

Power consumption in mixing multi-particle size sugarcane leaves

The power consumption in mixing was determined from the torque of the mixing shaft. Torque can be realized by installing a TTS Torque Transducer which measures deformation of materials. A strain gauge (Figure 4a) (Tokyo Measuring Instruments Laboratory Co. Ltd., rg = 350 ohms, gauge factor = 2.09) is commonly used as a signal sensor. The gauge was attached to the power shaft to reflect the mechanical properties of the material by converting the mechanical energy into electrical energy. An electrical signal was then transmitted from the circuit attached to the

Table 2. Interpretation of Mixer Tests

CV	Rating	Corrective Action
<10%	Excellent	None
10-15%	Good	Increase mixing time by 25–30%
15-20%	Fair	Increase mixing time 50%, look for worn equipment, overfilling, or sequence of ingredient addition
>20%	Poor	Possible combination of all the above. Consult extension personal or feed equipment manufacturer

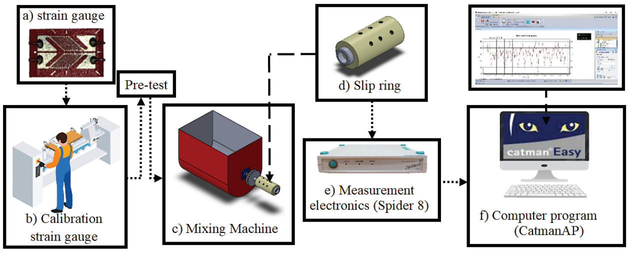

Fig. 4. Power consumption in mixing

shaft by connecting the signal between the stationary and rotating parts, using a Slip Ring (Figure 4d). The signal was then transmitted to the Spider 8 receptor (Figure 4e), and data transferred to the Catman AP program (version 3.1) installed on a computer (Figure 4f) to interpret the digital signal into the torque value. This was used to calculate the power consumption in the mixing process (IA, 2018) (see Equation 8).

Results and Discussion

Results of homogeneity of the horizontal paddle mixer for mixing the multi-particle size sugarcane leaves sieved through different mesh sizes

Mixing index

The relationship between mixing speed and time revealed that the mixing speeds of 50 rpm, 75 rpm, and 100 rpm, and mixing times of 4 min, 6 min, and 8 min resulted in a different mixing index in each sieve layer, with a significance level of 99%. The relationship between parameters was also found, as illustrated in Table 3.

Table 4 and Figure 5 display the comparison of mixing indices of the particle size TP1 in the study of mixing speed and time for mesh sizes 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, 75 µm and 38 µm, respectively. At mesh size 4.75 mm, the mixing index was not different, except for the mixing speed and time of 50-4, 50-6, and 75-6, which had mixing indices of 0.7525, 0.9329, and 0.9341

Table 3. Analysis of variance on the effects of mixing speed and time

Particl Size, mm	Source	df	F-value							
			4.75 mm	2.36 mm	1.18 mm	600 µm	300 µm	150 µm	75 µm	38 µm
3 (TP1)	Block	2	0.279^{ns}	0.640^{ns}	0.875^{ns}	0.519^{ns}	0.080^{ns}	0.032^{ns}	0.646^{ns}	0.940^{ns}
	Speed	2	35.322**	72.349**	153305.348**	1493.331**	3080.064**	3722.389**	41.255**	75.739**
	Time	2	8.758**	142.393**	360109.648**	1619.217**	5664.172**	4543.137**	40.043**	81.229**
	Speed * Time	4	17.771**	137.801**	1645629.843**	4367.200**	10455.682**	6468.123**	285.753**	73.349**
	Error	70								
	Total	80								
4 (TP2)	Block	2	0.624^{ns}	1.038^{ns}	0.441^{ns}	0.642^{ns}	1.704^{ns}	0.616^{ns}	0.016^{ns}	3.197*
	Speed	2	98.101**	566.400**	31745.999**	1320.971**	1816.740**	19241.974**	336.783**	146.313**
	Time	2	48.178**	113.605**	18469.428**	1220.833**	1810.732**	13333.815**	237.320**	2.444*
	Speed * Time	4	11.407**	224.094**	15460.037**	1728.075**	2406.117**	13104.120**	488.205**	31.978**
	Error	70								
	Total	80								
5 (TP3)	Block	2	1.225^{ns}	1.022^{ns}	0.796^{ns}	1.816^{ns}	0.479^{ns}	2.290^{ns}	1.799^{ns}	2.371^{ns}
	Speed	2	36.151**	181602.885**	76345.484**	705.762**	2317.945**	24249.811**	166.352**	11.626**
	Time	2	18.226**	40042.917**	25190.612**	838.874**	5927.915**	6397.488**	77.685**	19.680**
	Speed * Time	4	22.241**	35509.159**	12415.207**	1699.196**	1241.277**	1734.286**	442.183**	20.255**
	Error	70								
	Total	80								

** Highly significant at 1%, * Significant at 5%, ^{ns} Non significant

Table 4. Comparison of average mixing speed and time that affected the mixing index of various particle sizes

Size, mm	Speed, rpm	Time, min	Sieve (Mixing Index)							
			4.75 mm	2.36 mm	1.18 mm	600 µm	300 µm	150 µm	75 µm	38 µm
3 (TP1)	50	4	0.7525^{c}	0.9290^{d}	0.9838^{d}	0.9964^{b}	0.9911^{h}	0.9627^{f}	0.9933^{a}	0.9655^{b}
		6	0.9329^{b}	0.9478^{c}	0.9415^{i}	0.9814^{d}	0.9984^{b}	0.9986^{b}	0.9371^{d}	0.9980^{a}
		8	0.9432^{ab}	0.9917^{a}	0.9949^{c}	0.9975^{a}	0.997^{d}	0.9997^{a}	0.9962^{a}	0.9979^{a}
	75	4	0.9859^{ab}	0.9916^{a}	0.9958^{a}	0.9969^{ab}	0.9989^{a}	0.9992^{a}	0.9970^{a}	0.9979^{a}
		6	0.9341^{b}	0.9564^{c}	0.9726^{g}	0.9826^{c}	0.9966^{e}	0.9979^{c}	0.9962^{a}	0.9980^{a}
		8	0.9670^{ab}	0.9617^{bc}	0.9768^{f}	0.9969^{ab}	0.9952^{g}	0.9920^{e}	0.9741^{b}	0.9980^{a}
	100	4	0.9890^{a}	0.8220^{e}	0.9453^{h}	0.9919^{b}	0.9972^{c}	0.9972^{d}	0.9483^{c}	0.9968^{a}
		6	0.9811^{ab}	0.9734^{b}	0.9951^{b}	0.9974^{a}	0.9988^{a}	0.9979^{c}	0.9962^{a}	0.9977^{a}
		8	0.9814^{ab}	0.9787^{ab}	0.9805^{e}	0.9595^{e}	0.9956^{f}	0.9969^{d}	0.9979^{a}	0.9980^{a}
4 (TP2)	50	4	0.9639^{d}	0.9801^{a}	0.9802^{c}	0.9976^{b}	0.9986^{ab}	0.9988^{c}	0.9940^{d}	0.9978^{b}
		6	0.9767^{c}	0.9655^{c}	0.9940^{b}	0.985^{f}	0.9981^{b}	0.9980^{d}	0.9912^{e}	0.9968^{d}
		8	0.9393^{f}	0.9673^{b}	0.9226^{e}	0.9067^{h}	0.9982^{b}	0.9993^{a}	0.9809^{g}	0.9968^{d}
	75	4	0.9965^{a}	0.9924^{a}	0.9966^{a}	0.9977^{a}	0.9990^{a}	0.9988^{c}	0.9969^{a}	0.9979^{a}
		6	0.9943^{ab}	0.9441^{d}	0.9641^{d}	0.9973^{c}	0.9604^{e}	0.9991^{b}	0.9962^{b}	0.9980^{a}
		8	0.9897^{b}	0.7328^{g}	0.8727^{h}	0.9976^{b}	0.9981^{b}	0.9993^{a}	0.9892^{f}	0.9977^{bc}
	100	4	0.9863^{b}	0.6390^{h}	0.9089^{g}	0.9966^{d}	0.9968^{c}	0.9903^{f}	0.9896^{f}	0.9976^{c}
		6	0.9729^{c}	0.8618^{e}	0.8492^{i}	0.9454^{g}	0.9989^{a}	0.9991^{b}	0.9787^{h}	0.9978^{b}
		8	0.9542^{e}	0.7931^{f}	0.9154^{f}	0.9892^{e}	0.9933^{d}	0.9974^{e}	0.9946^{c}	0.9978^{b}
5 (TP3)	50	4	0.9891^{ab}	0.9182^{h}	0.9488^{g}	0.9954^{ab}	0.9975^{d}	0.9967^{f}	0.9940^{c}	0.9966^{c}
		6	0.9530^{c}	0.9839^{e}	0.9758^{e}	0.9930^{b}	0.9979^{c}	0.9987^{e}	0.9962^{b}	0.9976^{b}
		8	0.9784^{b}	0.9249^{g}	0.9194^{h}	0.9338^{d}	0.9968^{e}	0.9978^{h}	0.9979^{a}	0.9977^{b}
	75	4	0.9815^{ab}	0.9946^{b}	0.9959^{a}	0.9976^{a}	0.9990^{a}	0.9993^{a}	0.9978^{a}	0.9980^{a}
		6	0.9937^{a}	0.9898^{d}	0.9889^{b}	0.9932^{b}	0.9990^{a}	0.9996^{b}	0.9962^{b}	0.9976^{b}
		8	0.9876^{ab}	0.9907^{c}	0.9870^{c}	0.9943^{b}	0.9957^{f}	0.9998^{c}	0.9962^{b}	0.9975^{b}
	100	4	0.9241^{c}	0.9955^{a}	0.9958^{ua}	0.9959^{ab}	0.9986^{b}	0.9978^{g}	0.9979^{a}	0.9978^{ab}
		6	0.9452^{c}	0.9934^{bc}	0.9803^{d}	0.9386^{c}	0.9958^{f}	0.9984^{d}	0.994^{c}	0.9977^{b}
		8	0.9908^{ab}	0.9776^{f}	0.9694^{f}	0.9962^{ab}	0.9938^{g}	0.9982^{i}	0.9936^{d}	0.9979^{ab}

respectively. At mesh size 2.36 mm, the mixing speed and time of 50-8, 75-4, and 100-8 had no difference in mixing indices, which were between 0.9787-0.9917. At mesh size 1.18 mm, mixing speed and time of 75-4 had the highest mixing index at 0.9958. At mesh size 600 µm, mixing speed and time of 50-8, 75-4, 75-8, and 100-6 had no difference in mixing indices, which were between 0.9969-0.9975. At mesh size 300 µm, mixing speed and time of 75-4 and 100-6 had similar mixing indices at 0.9988 and 0.9989. At mesh size 150 µm, mixing speed and time of 50-8 and 75-4 had the highest mixing indices at 0.9992 and 0.9997. At mesh size 75 µm, mixing speed and time of 50-4, 50-8, 75-4, 75-6, and 100-6 had no difference in mixing indices, which were between 0.9933-0.9970. At mesh size 38 µm, there were no differences in mixing indices, except the mixing speed and time of 50-4, which had the lowest mixing index at 0.9655.

Table 4 and Figure 6 show the comparison of mixing index of the particle size TP2 in the study of mixing speed and time for mesh size of 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, 75 µm, and 38 µm, respectively. At mesh size 4.75 mm, the mixing speed and time of 75-4 and 75-6 had high mixing indices at 0.9965 and 0.9943. At mesh sizes 2.36 mm, 1.18 mm and 600 µm, the mixing speed and time of 75-4 had the highest mixing indices at 0.9924, 0.9966, and 0.9977, respectively. At mesh size of 300 µm, mixing speed and time of 75-4 and 100-6 had high mixing index at 0.9989-0.9990. At mesh size 150 µm, mixing speed and time of 50-8 and 75-8 had highest mixing index at 0.9993. At mesh size of 75 µm, the mixing speed and time of 75-4 had the highest mixing index at 0.9969. At mesh size of 38 µm, mixing speed and time of 75-4 and 75-6 had high mixing indices at 0.9979-0.9980.

Table 4 and Figure 7 show the comparison of mixing indices of particle size TP3 in the study of mixing speed and time for mesh sizes 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, 75 µm, and 38 µm, respectively. At mesh size 4.75 mm, the mixing speed and time of 50-4, 75-4, 75-6, 75-8, and 100-8, respectively, had no difference in mixing

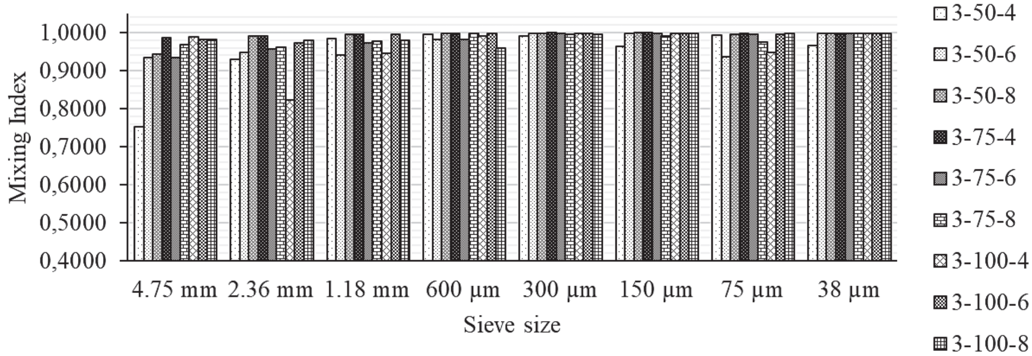

Fig. 5. The relationship between particles at mesh size 3 mm and mixing index at different mixing speed and times

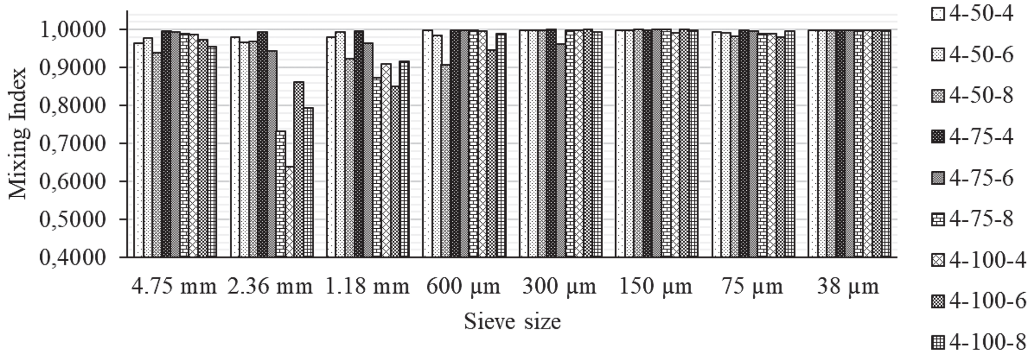

Fig. 6. The relationship between particles at mesh size 4 mm and mixing index at different mixing speed and times

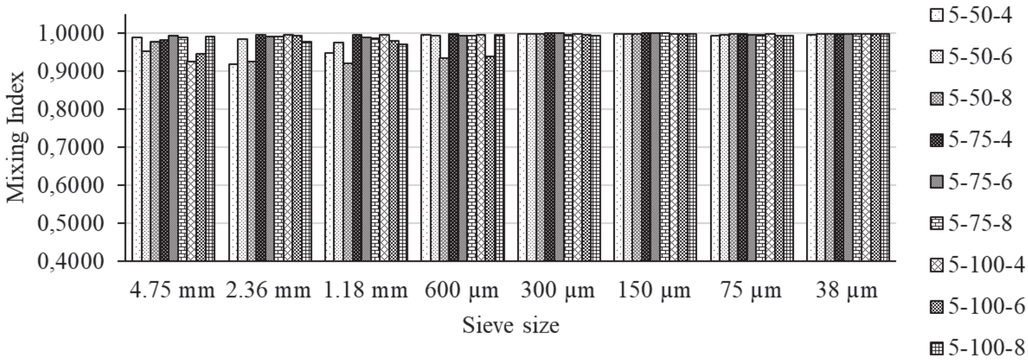

Fig. 7. The relationship between particles at mesh size 5 mm and mixing index at different mixing speeds and times

indices, which were between 0.9815-0.9937. At mesh size 2.36 mm, the mixing speed and time of 100-4 had the highest mixing index at 0.9955. At mesh size 1.18 mm, mixing speed and time of 75-4 had the highest mixing index at 0.9959. At mesh size 600 µm, mixing speed and time of 50-4, 75-4, 100-4, and 100-8 had high mixing indices of between 0.9954-0.9976. At mesh size 300 µm, mixing speed and time of 75-4 and 75-6 had the highest mixing indices at 0.9990. At mesh size 150 µm, mixing speed and time of 75-4 had the highest mixing index at 0.9993. At mesh size 75 µm, mixing speed and time of 50-8, 75-4, 75-6 and 100-4 had high mixing indices of between 0.9978-0.9979. At mesh size 38 µm, mixing speed and time of 75-4, 100-4 and 100-8 had high mixing indices of between 0.9978-0.9980.

Coefficient of variation (CV) of mixtures

The multi-particle size sugarcane leaves were categorized into 8 sizes by sieve analysis method. The portion of each size was calculated as a percentage of weight remaining in the sieve. The percentage of coefficient of variation (% CV) of mixtures of particles on mesh sizes 3, 4, and 5 mm are shown in Table 5. The CV of mixtures of powder particles was largely < 10%.

The particles which passed through the mesh size of 3 mm at a mixing speed of 50 rpm and a mixing time of 8 min had a CV of mixtures of between 0.59-45.79, which was lower than those of 4 and 8 min. The particles at a mixing speed of 75 rpm and a mixing time of 4 min had a CV value of between 0.67-16.77, which was lower than those of 6 and 8 min. The particles at a mixing speed of 100 rpm and a mixing time of 6 minutes had a CV value of between 0.66-35.35, which was lower than those of 4 and 8 min.

The particles which passed through mesh size of 4 mm at a mixing speed of 50 rpm and a mixing time of 4 min had a CV of mixtures of between 0.92-17.12, which was lower than those of 6 and 8 min. The particles at a mixing speed of 75 rpm and a mixing time of 4 min had a CV value of between 0.58-6.82, which was lower than those of 6 and 8 min. The particles at a mixing speed of 100 rpm and a mixing time of 4 and 6 min had a CV value of 1.20-26.33, which was lower than those of 8 min.

The particles which passed through the mesh size of 5 mm at a mixing speed of 50 rpm and a mixing time of 6 min had a CV of mixtures of between 1.38-37.44, which was lower than those of 4 and 8 min. The particles at a mixing speed of 75 rpm and a mixing time of 4 min had a CV value of between 1.04-12.12, which was lower than those of 6 and 8 min. Lastly, the particles at a mixing speed of 100 rpm and a mixing time of 4 min had a CV value of 0.82-29.29, which was lower than those of 6 and 8 min.

Overall, it was found that, at a mixing speed of 75 rpm, the particles which passed through mesh sizes 3, 4 and 5 mm produced the lowest CV values when compared with mixing speeds 50 and 100 rpm. A mixing speed of 75 rpm was a suitable speed since it was not too fast or too slow, and resulted in a thorough mixing of materials, so the powder particles did not coagulate. Therefore, the particles of sugarcane

Table 5. The effects of mixing speed and time on CV variation of mixtures of the particle size

Particle size, mm	Sieve size	Mixing speed								
		50 rpm			75 rpm			100 rpm		
		4 min	6 min	8 min	4 min	6 min	8 min	4 min	6 min	8 min
3 (TP1)	4.75 mm	51.22	45.01	45.79	16.77	39.55	31.42	16.45	35.35	31.36
	2.36 mm	10.88	6.55	2.72	4.45	8.50	9.06	22.22	4.83	4.37
	1.18 mm	1.21	2.31	0.68	0.64	1.57	1.47	2.20	0.66	1.33
	600 µm	1.56	3.20	1.19	1.46	3.41	1.43	2.35	1.25	5.07
	300 µm	2.71	1.13	1.55	0.97	1.65	1.96	1.50	0.98	1.88
	150 µm	9.45	1.36	0.59	0.66	1.11	2.07	1.23	1.56	1.86
	75 µm	5.54	15.87	3.63	3.46	4.04	9.57	12.94	3.49	2.47
	38 µm	20.14	5.79	5.55	2.21	5.72	4.99	7.62	5.24	4.56
4 (TP2)	4.75 mm	17.12	24.26	36.44	6.82	8.02	11.39	12.44	26.33	30.29
	2.36 mm	3.12	4.89	4.66	1.94	5.75	12.90	13.59	8.19	10.49
	1.18 mm	1.35	0.61	2.21	0.58	1.53	2.84	2.90	3.26	2.38
	600 µm	1.60	3.84	9.58	1.58	1.65	1.57	1.88	7.43	3.35
	300 µm	1.40	1.53	1.51	1.19	7.20	1.59	2.02	1.20	3.01
	150 µm	0.92	1.85	1.08	0.92	1.31	1.08	2.51	1.27	2.18
	75 µm	6.35	6.02	8.48	4.85	4.06	6.61	8.19	9.35	4.60
	38 µm	10.70	7.60	7.07	2.48	6.00	5.95	8.52	6.64	6.01
5 (TP3)	4.75 mm	12.56	37.44	27.39	16.88	12.12	14.75	29.29	30.08	13.02
	2.36 mm	3.49	1.38	3.01	0.92	1.04	1.01	0.85	0.86	1.61
	1.18 mm	2.93	1.97	3.59	0.85	1.42	1.53	0.82	1.81	2.23
	600 µm	2.65	3.09	9.32	1.94	3.09	2.81	2.44	9.36	2.39
	300 µm	2.53	2.11	2.66	1.62	1.44	3.09	1.80	3.16	3.78
	150 µm	1.63	2.08	2.67	0.75	1.08	0.73	1.33	2.31	2.43
	75 µm	8.62	5.58	4.00	5.41	5.53	5.29	5.07	6.96	6.90
	38 µm	12.24	5.58	9.74	2.47	8.43	7.96	7.60	10.86	8.92

leaves powder had a homogenous mixture. Mixing speeds of 50 and 100 rpm, at some mixing times and sieve layers, produced high CV values which caused inhomogeneity of particles of sugarcane leaves powder. The particles can coagulate if the mixing speed is too slow, while too-fast a mixing speed can upset the mixing due to the separation of particles. While the mixing time of 4 minutes was suitable for mixing powder particles, it can reduce time in the mixing process and produce a low CV value.

Mixing speed and time had an effect on the mixing index of the multi-particle size sugarcane leaves sieved through different mesh sizes which determines the suitable conditions of mixing for further production. i.e.: pelletizing for fuel production. The studied particles were passed through 3 levels of mesh size: TP1, TP2 and TP3 (referring to the particles sieved through mesh sizes 3 mm, 4 mm and 5 mm, respectively). Those particles were tested with 3 levels of mixing speeds (50 rpm, 75 rpm and 100 rpm) and 3 levels of mixing time (4 min, 6 min and 8 min). All three types of particles had the best mixing index and CV value when the mixing speed was 75 rpm and the mixing time 4 min. This was a shorter mixing time compared to other times, and increases the mixing efficiency.

Results of power consumption in mixing multi-particle size sugarcane leaves

The studied particles were passed through 3 levels of mesh size: TP1, TP2 and TP3 (referring to the particles sieved through mesh sizes 3 mm, 4 mm and 5 mm, respectively). Those particles were tested with 3 levels of mixing speed (50 rpm, 75 rpm and 100 rpm) and 3 levels of mixing time (4, 6 and 8 min). The torque of the mixing shaft was measured and the results are shown in Table 6. It was found that the power consumption in the mixing process increased as the mixing speed increased (Figure 8).

Figure 9 shows the relationship between the mixing speed and torque of the mixing shaft at mixing times of 4,

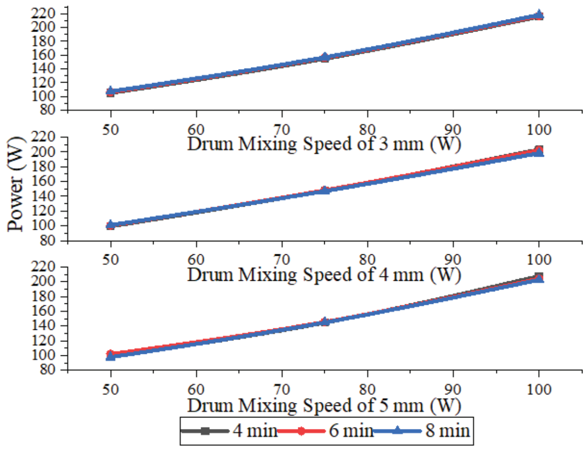

Fig. 8. The power of mixing shaft in mixing the particles passed through mesh sizes 3 mm, 4 mm and 5 mm

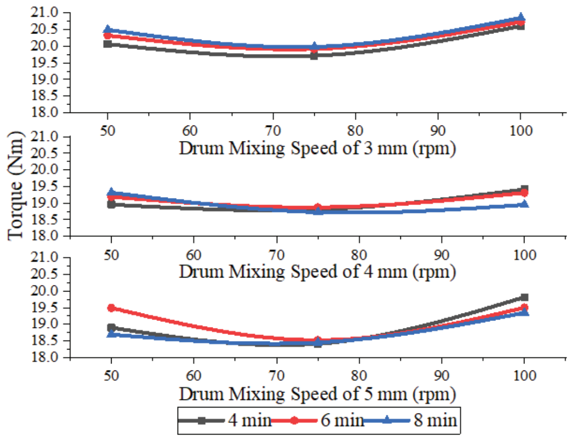

Fig. 9. Torque of mixing shaft in mixing the particles passed through mesh sizes 3 mm, 4 mm and 5 mm

Table 6. The effect of mixing speed and time on power consumption in the mixing of the particles passed through different mesh sizes

Particle size, mm	Torque (Nm) (Avg)								
	50 rpm			75 rpm			100 rpm		
	4 min	6 min	8 min	4 min	6 min	8 min	4 min	6 min	8 min
3 (TP1)	20.06	20.32	20.50	19.71	19.92	19.98	20.61	20.73	20.85
4 (TP2)	18.96	19.19	19.32	18.81	18.87	18.73	19.42	19.31	18.95
5 (TP3)	18.90	19.49	18.70	18.41	18.52	18.45	19.82	19.50	19.35
Power (W) (Avg)									
3 (TP1)	105.05	106.42	107.32	154.83	156.44	156.96	215.82	217.11	218.39
4 (TP2)	99.27	100.48	101.14	147.73	148.23	147.08	203.34	202.23	198.44
5 (TP3)	98.94	102.07	97.89	144.61	145.49	144.92	207.52	204.22	202.60

6 and 8 min as the particles passed through different mesh sizes. At every size of particle, the torque of the mixing shaft tended to decrease, and then increase. The torque of particles TP1, TP2 and TP3 at a mixing speed of 75 rpm and mixing times of 4, 6 and 8 min, tended to decline:

TP1 (19.71 Nm. 19.92 Nm. 19.98 Nm),
TP2 (18.81 Nm. 18.87 Nm. 18.73 Nm) and
TP3 (18.41 Nm. 18.52 Nm. 18.45 Nm), respectively.

While at a mixing speed of 100 rpm, the torque of the mixing shaft tended to increase:

TP1 (20.61 Nm. 20.73 Nm. 20.85 Nm),
TP2 (19.42 Nm. 19.31 Nm. 18.95 Nm) and
TP3 (19.82 Nm. 19.50 Nm. 19.35 Nm). Nm), respectively.

Conclusions

This study focused on the particle size, mixing speed and mixing time that affected the homogeneity of mixtures and can be summarized as follows:

Particles TP1 (3 mm), TP2 (4 mm) and TP3 (5 mm) at mixing speeds of 50 rpm, 75 rpm and 100 rpm and mixing times of 4, 6 and 8 min, significantly affected the Mixing Index of each sieve layer. The Coefficient of Variation (CV) of mixtures of each sieve layer was mostly high (< 10%), indicating that the particles were thoroughly mixed.

The energy consumption in mixing sugarcane leaves of different mesh sizes was measured. It was found that as the mixing speed increased, the energy consumption in mixing also increased. The lowest mixing energy was 99.27 kW and the highest 218.39 kW. Torque tended to decrease at mixing speed of 75 rpm, with torque values ranging between 19.71-19.98 Nm.

Therefore, the particle sizes of TP1 (3 mm), TP2 (4 mm) and TP3 (5 mm) at a mixing speed of 75 rpm and a mixing time of 4 min resulted in a homogeneous mixture. As the Mixing Index approached 1 the CV of mixtures was < 10%. Suitable mixing conditions can shorten the mixing process, increase its potential, and reduce energy consumption. Good mixing conditions can be used in the production of high quality biomass pellets with homogeneous materials.

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