

Drying characteristics of kenaf for animal feed using laboratory and commercial dryers

(Ciri-ciri pengeringan kenaf untuk makanan ternakan menggunakan pengering komersial dan di makmal)

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Key words: kenaf (*Hibiscus cannabinus* L.), dryer, drying characteristic, quality, drying cost

Abstract

Mature kenaf is well known for its high quality fibre, however the immature plant has a great potential to be processed for animal feed. Drying has been identified as an appropriate method for handling and storage of kenaf prior to processing for animal feed. Kenaf, which was properly dried using dryer, contained more than 20% protein with the brightness (L*), greenness (a*) and yellowness (b*) values measured at 44.0, –8.0 and 23.0 respectively. Drying of kenaf at 60, 70 and 80 °C using laboratory dryer took 8, 6 and 4 h respectively. Kenaf dried at 80 °C showed no quality difference to the product dried at 60 °C and 70 °C. Drying of 200 kg kenaf using commercial dryer at 80 °C took 15 h. The overall thermal efficiency of evaluated dryer is 63.5% and the drying cost to produce a kilogramme of dried kenaf is about RM2.50.

Introduction

Kenaf (*Hibiscus cannabinus* L.) has been identified as potential crop for animal feed (Mohd. Najib and Noor Ismawaty 2002). It can be planted four times a year and harvested after 80 days of planting with the potential annual dry matter production of about 40.6 t/ha. Kenaf contains various types of nutrient that could benefit the animal. In the USA, researchers found that immature kenaf plants contain up to 20% protein (LeMahieu1 et al. 1991). They also found that kenaf leaf and petiole (non-stalk) portions of the plant are readily consumed by lambs and contain low fibre and high N concentrations. Analysis of the leafy kenaf material showed values of 8.7% neutral detergent fibre (NDF), 3.5% acid detergent fibre (ADF) and 34.0% crude protein (CP).

Contrasted to this, total plant composition levels are 42.9%, 32.6% and 17.1% respectively. Dried kenaf contained 91.8% dried matter, 20.9% CP, 11.1% ash, 46.7% NDF, 33% ADF, 67.5% total digestible nutrient (TDN), 1.1% Ca and 0.22% P. It is safe to store the crop after being converted to hays, pellets and cubes with the moisture content less than 15%.

Fresh harvested kenaf contains 85% moisture and should be dried to 10% moisture content within 48 h or otherwise it would turn mouldy (Mohd. Najib and Noor Ismawaty 2001). Drying of 460 kg kenaf to safe moisture content in forced-hot air box dryer took 24 h with the fuel consumption of about 2.3 litres per hour. The drying was conducted at 70 °C and removed 392 kg water during drying process. The estimated

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overall thermal efficiency for drying of kenaf using box dryer is at about 46% (Ooi and Samsudin 2003). Increasing the airflow and recycling the exhausted air during drying could improve the performance of the dryer.

The drying requirement for locally grown kenaf has not been investigated fully. In this study, experiments were conducted at laboratory and commercial scales to determine the various drying aspects for kenaf:

- The optimum temperature and relative humidity for the drying
- The drying rate at selected temperatures
- The recovery and quality of product
- Estimated cost of drying

Materials and methods

Sample preparation

Kenaf of 70–80 days old was selected for the experiment. The manually harvested crop with weight of about 8 kg were chopped mechanically to approximately 2–3 cm cutting length. Sample weight of about 5 kg was taken from the whole chopped materials. It was packed in a plastic bag and brought to laboratory for drying experiment. The sample preparation was carried out everyday for 9 days to complete the designed laboratory drying trials.

Another batches of kenaf with the weight of 200 kg were harvested twice for two drying trials using commercial size

dryer. The fresh harvested kenaf were chopped, placed in plastic bags and transported to drying place for the drying experiment.

Laboratory drying experiment

Laboratory drying study was carried out using a small dryer with the drying chamber measuring 50 cm long, 40 cm wide and 60 cm high. The dryer was equipped with 2 kW heating element and axial blower (Plate 1). The drying temperature was controlled by thermostat and the quantity of air for drying was regulated to blow at the rate of 15 m³/min.

Three drying temperatures (60, 70 and 80 °C) were selected for the study. The air temperature, relative humidity (RH) and product temperature were measured every minute using data taker model 605. The thermocouple wires and RH sensor were placed at air duct below the drying bed to measure the temperature and relative humidity of heated air for drying. The thermocouple wires were inserted into the material layered on drying bed to measure product temperature. The drying experiment was repeated three times to obtain average moisture reduction, drying rate and product quality on each drying temperature.

Sample received for each drying trial was randomly separated into three portions; a small portion (500 g) was to determine the initial quality (moisture content and colour



Plate 1. Drying of kenaf using small dryer in laboratory



Plate 2. Drying of kenaf using commercial size dryer

of fresh kenaf), another 500 g was placed in measurable drying tray and the big portion (4 kg) was spread on the dryer bed around the measurable drying tray.

The moisture reduction and the drying rate were estimated every hour based on the weight differences of the sample (500 g) placed in measurable drying tray. At the end of drying process, the weight of dried kenaf placed on drying bed was determined, sealed in plastic bags and kept for quality evaluation.

Drying trial using flat bed air recycled dryer

After the initial sample was taken from various bags, the chopped kenaf was weighed and placed in two drying beds with 100 kg load on each layer. The drying material was spread and levelled to cover drying area of about 3 m x 0.48 m with 10 cm thick (*Plate 2*). The drying process was carried out in a closed system. The drying material was placed in drying chamber and heated by forced air from the bottom. The air would pass through and picked the moisture from the product before being discharged or recycled to heat exchanger for further drying process.

The drying process for the experiment was carried out at 80 °C and repeated twice to estimate the average performance of the dryer and the drying cost. The actual temperatures of the air and the product inside the dryer were measured using similar data taker model 605.

Quality analysis of kenaf

Dried samples collected from laboratory and commercial drying trials were ground using hammer mill, packed and labelled separately in 0.08 mm thick polypropylene bags. The colour of dried kenaf was measured using 'Minolta chromameter CR-200'. The L*, a* and b* values indicated the brightness, greenness and yellowness of the samples. About 60 g sample for colour determination was placed in three petri dishes and

measured at three locations along the diameter of the dish.

Small packets of ground kenaf (200 g each) from different treatments were labelled clearly and sent to accredited laboratory to determine nutrient composition (protein, fibre and ash) and mineral content (potassium, calcium and sodium).

Statistical analysis

Statistical analysis was carried out to determine the effective drying temperature for kenaf and to clarify the effect on the quality of product recovered. The moisture content and drying rate of chopped kenaf dried at three drying temperatures and measured every hour were compared by Least Significant Difference (LSD) test, while analysis of variance and Duncan test were carried out for L*, a* and b* values of the samples analysed. Nine readings were taken to determine the average value of sample for the testing parameter.

Results and discussion

Moisture reduction

The moisture content of freshly harvested kenaf was from 85–87%. Laboratory drying of chopped kenaf at 60 °C with an average air relative humidity (RH) of 26% took 8 h to reduce the moisture content to about 10% (*Figure 1*). Similar final moisture content was achieved in 4.5 h and 2.5 h by increasing the air temperature to 70 °C and 80 °C respectively. Increasing the temperature from 60 °C to 70 °C and 80 °C basically reduced the relative humidity of the air in the dryer from 26% to 17% and 12.5% respectively which is 45–47% lower than the average ambient air relative humidity (*Table 1*).

The pattern of moisture reduction at three drying temperatures is represented by exponential curves as shown in *Figure 1*. The moisture content of kenaf on each drying interval was clearly separated. It was significantly different ($p < 0.05$) as a result of increasing the drying temperature by 10 °C. At the end of drying process, the

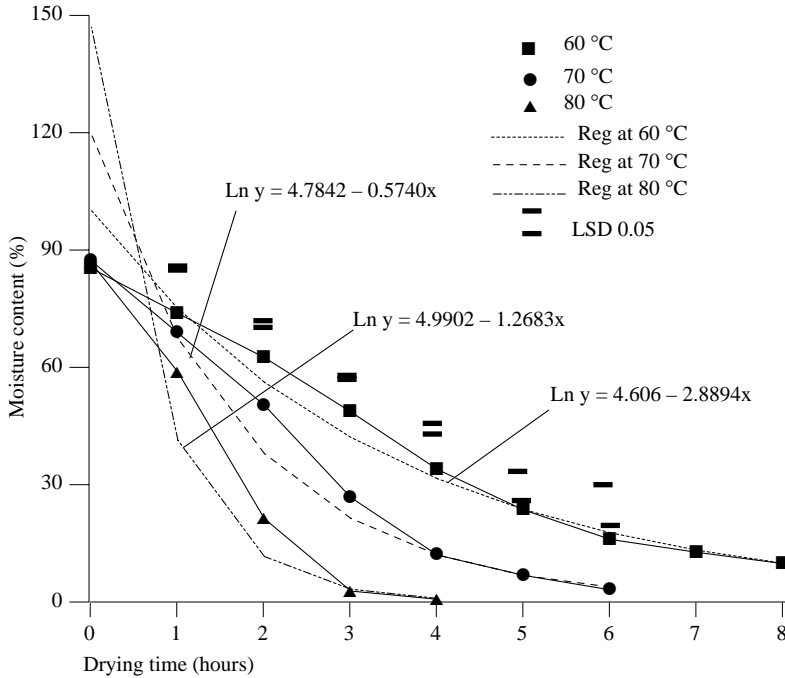


Figure 1. Moisture reduction of kenaf during drying using laboratory dryer

Table 1. Temperature and relative humidity (RH) recorded during drying of kenaf

Heated air for drying		Ambient		Product temperature (°C) av. (range)
Temperature (°C)	RH (%) av. (range)	Temperature (°C) av. (range)	RH (%) av. (range)	
60	26.3 (21.6–50.1)	33.4 (27.2–36.7)	70.1 (60.5–85.3)	57.0 (28.7–61.2)
70	16.9 (13.5–32.3)	34.8 (29.4–38.6)	63.7 (57.6–66.8)	63.8 (29.6–73.5)
80	12.5 (9.5–22.3)	37.5 (32.7–40.9)	57.5 (49.2–74.0)	74.8 (28.9–83.8)
80*	14.3 (8.7–22.7)	31.7 (29.3–35.5)	71.6 (66.1–83.0)	68.0 (28.6–82.9)

*Commercial drying trials

final moisture content after 8, 6 and 4 h drying were 10, 4 and 2% respectively. Further drying of samples up to 6–12 h would end up with the equilibrium moisture content of 4.5, 2.4 and 1.6% respectively.

Drying rate

Drying rate could be measured by determining the rate of water removed per hour. It was obviously high at higher temperature especially at the initial stage of drying process. Drying of kenaf at 80 °C produced drying rate of 0.340 kg/h at first hour of drying (Figure 2). It was 35% and

13% higher compared with the drying rate produced by heated air at 60 °C and 70 °C respectively.

The drying rate at various drying intervals was significantly different ($p < 0.05$) as a result of the temperature difference, except on the second hour of drying time, the drying rates were almost similar i.e. at about 0.08 kg/h. The average drying rates for the three drying temperatures (60, 70, 80 °C) for the whole drying process were 0.052, 0.072 and 0.1085 kg/h respectively.

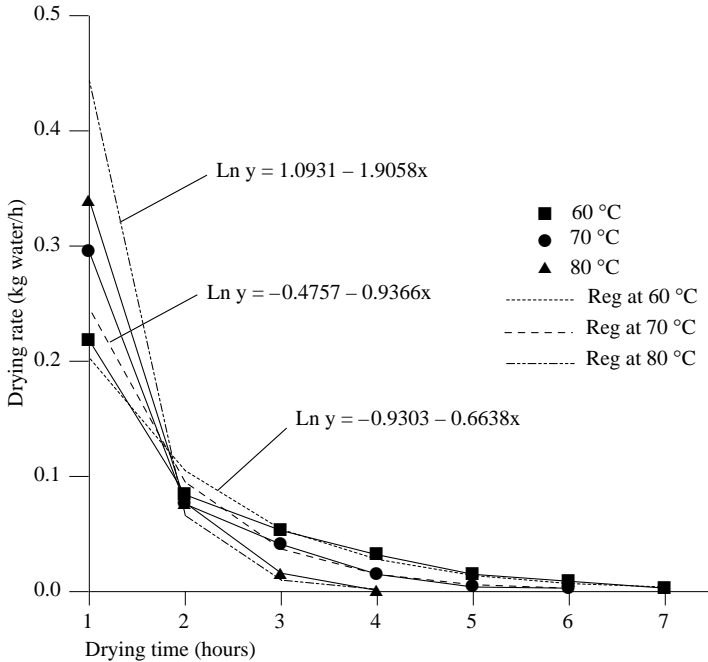


Figure 2. Drying rate of kenaf during drying using laboratory dryer

Drying equations

The moisture ratio (MR) is another mean to express the drying characteristic of product at different drying conditions. For the kenaf, it was derived from moisture content correlation in Figure 1 and the measured equilibrium moisture content at the end of drying process. The Ln MR of kenaf at three drying temperatures is illustrated in Figure 3.

The simple drying equations of kenaf at 60, 70 and 80 °C are expressed as follows:

- MR = 1.5144e^{-0.385t} for 60 °C.....eqn. 1
- MR = 2.9955e^{-0.8874t} for 70 °C.....eqn. 2
- MR = 5.8709e^{-1.903t} for 80 °C.....eqn. 3

The high constants (5.8709 and 1.903) as indicated in equation 3, shows that better drying performance could be obtained by drying at 80 °C compared to the other two drying temperatures conducted.

The study (moisture reduction, drying rate and drying equation) showed that kenaf was suitable to dry at high temperature. The

produce was not hardened as compared to sensitive product that could resist moisture migration during drying. Kenaf, after being exposed to high temperature (80 °C) tend to be loosen and lighter that could accelerate the drying process. Probably, the chopped kenaf was a good thermal conductivity. It could absorb heat vary fast starting from 29 °C at the initial stage up to slightly lower drying temperature at the end of drying process. The average product temperature recorded at laboratory drying trials at 60, 70 and 80 °C were 57, 64 and 75 °C respectively (Table 1).

Colour changes of dried kenaf

Colour is a measurable property to determine the quality of dried product. Drying parameters such as temperature and drying rate could influence the quality of the end product. Some products might be discoloured as a result of too high drying temperature or become spoiled (fermented) because of very slow drying process. The effect of drying on the colour of dried kenaf

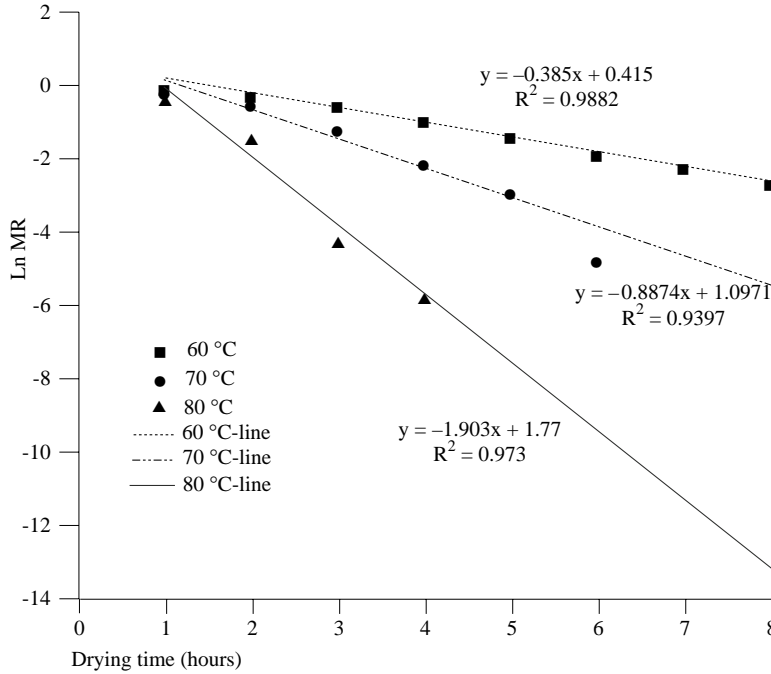


Figure 3. Moisture ratio of kenaf at drying temperatures of 60, 70 and 80 °C

Table 2. Colour [brightness(L*), greenness(a*) and yellowness(b*)] of kenaf

Drying temperature (°C)	Fresh kenaf			Dried kenaf		
	L*	a*	b*	L*	a*	b*
60	40.11	-14.01	20.68	45.54a	-7.92cd	23.33e
70	40.73	-14.46	20.93	44.41ab	-8.56c	23.31e
80	38.70	-13.75	19.70	44.31ab	-7.79cd	20.02f
80**	38.68	-14.93	22.30	42.80b	-6.95d	22.91e

**Drying using commercial size dryer

Values with the different letters in each column are significantly different ($p < 0.05$) based on DMRT

at three drying temperatures is illustrated in Table 2. Drying clearly changed the colour profile of fresh kenaf. Fresh kenaf has a dark green colour with average L*, a* and b* values of 38.69 to 40.73, -13.75 to -14.46 and 19.70 to 22.33 respectively. Drying has changed the colour significantly towards brighter and more yellowish with L*, a* and b* values at the average of 44.75, -8.09 and 22.22 respectively. The L*, a* and b* values of laboratory dried samples were not much different except when they were compared with the product from commercial dryer.

Nutrient composition of dried kenaf

Previous analysis showed that dried kenaf contains 91.8% dried matter, 20.9% CP, 11.1% ash, 46.7% NDF, 33% ADF, 67.5% TDN, 1.1% Ca and 0.22% P (Mohd. Najib and Noor Ismawaty 2002). The nutrient composition of dried kenaf gathered from the drying experiment at three drying temperatures and commercial dryer are illustrated in Table 3.

Crude protein content of kenaf dried at 70 °C and 80 °C was about 20%, which was 3% lower than protein content in sample dried at 60 °C. Increasing drying

Table 3. Nutrient content of kenaf dried at 60, 70 and 80 °C

Drying temperature (°C)	Content (g/100 g)				Content (mg/100 g)		
	Moisture	Crude protein (N x 6.25)	Ash	Crude fibre	Potassium	Calcium	Sodium
60	6.75	23.47	7.68	23.06	1917.00	423.66	16.56
70	4.65	20.29	8.22	23.66	2118.82	360.12	12.89
80	3.56	20.40	8.53	23.56	2089.60	414.25	15.33
80*	3.67	19.70	10.36	23.30	2433.00	321.97	29.45

*Drying using commercial size dryer

temperature by 10 °C had slightly affected the crude protein content in the product. This might be due to the protein break down or denatured as a result of heating process during the drying. However, the ash and crude fibre content were maintained at 8% and 23% respectively except on commercially dried sample which contained 2% extra ash compared to laboratory dried samples.

The main nutrient contents of dried kenaf were potassium (2–2.4 g), calcium (0.2–0.4 g) and sodium (13–29 mg) in 100 g sample. They were not affected when drying at 70 °C and 80 °C except for calcium content which was lower compared to sample dried at 60 °C.

Drying cost

Drying cost was estimated based on two drying trials on 200 kg kenaf, each using batch air recycled dryer. The drying bed of the dryer has a floor area of 3.0 m x 0.48 m made of perforated sheet where the air can pass through at the rate of about 0.25 m/s. The amount of air circulated inside the dryer was at the rate of 21.6 m³/min where 30% was discharged out and 70% was recycled and reheated together with the fresh intake air.

Air inside the dryer was heated using diesel burner. The fuel burnt inside the heat exchanger and transferred to pass through air by convection process. The drying trial was set at 80 °C, but the actual monitored temperature was recorded fluctuating from 76 °C to 84 °C. The relative humidity was in the range of 12–15% throughout the drying process. The whole drying process took 15 h to reduce the moisture content of

kenaf from 85% to about 9% with about 33 kg of final product recovered.

About 167 kg of water was removed during the drying process. It required about 445 890 kJ energy to evaporate water inside the fresh kenaf. Total energy from burning of 26 litres of diesel for the whole drying process was estimated around 702 000 kJ. The comparison between energy utilized and energy supplied for drying resulted in the estimated overall drying efficiency of about 63.5%. This high drying efficiency indicated that the heating system of the dryer was very good and the drying material tested (kenaf) was relatively easy to dry. This drying efficiency could be improved by increasing drying capacity and air flow rate of the dryer.

Estimated cost of drying (operational) of kenaf was RM63 per batch, that including the cost of fuel, electricity, labour, repair and maintenance (*Table 4*). The total drying cost increased to about RM83.40 after fixed cost such as depreciation value, interest, tax and insurance were counted for the whole drying process. The drying cost to produce one kilogramme of dried kenaf was around RM2.50 based on 33 kg end product recovered after drying process. The drying cost could be reduced slightly by increasing drying capacity to 400 kg. Although the drying time has to be extended, the product recovered was double and the drying cost could be reduced quite significantly.

Conclusion

Kenaf contains more than 20% protein, rich in minerals and suitable for animal feed. It

Table 4. Drying cost of 200 kg kenaf using commercial dryer at 80 °C (67–84 °C)

Item	Rate	Cost (RM)
Repair and maintenance	15 h	5.00
Labourer :		
a. Loading and unloading – 2 person	2 h	20.00
b. Supervision – 1 person	2 h	10.00
Electricity	24 kW h	7.20
Diesel	26 litres	20.80
Overall operation cost		63.00
Fixed cost		20.40
Overall drying cost		83.40

can be processed to silage for temporary storage or converted to hay or dried material to be more convenient and safe for long term storage. Kenaf need to be mechanically dried because it contains very high moisture and easily spoiled if drying is delayed.

At the drying temperature of 80 °C, the chopped kenaf can be dried in the laboratory in 3 hours. However, it took 15 hours for 200 kg crop to dry using commercial size dryer. About 33 kg of dried product or 16.5% of initial weight of fresh kenaf recovered at the end of drying process. The drying cost to produce dried kenaf using dryer is estimated around RM83.40 per batch or RM2.50 per kg.

Abstrak

Kenaf yang matang terkenal sebagai sumber serat yang bermutu, manakala yang muda berpotensi untuk dijadikan makanan ternakan. Pengeringan ialah kaedah terbaik untuk mengendali dan menyimpan kenaf sebelum diolah menjadi makanan ternakan. Kenaf yang dikeringkan secara terkawal menggunakan alat pengering, mengandungi tidak kurang daripada 20% protein dan mempunyai warna dengan ukuran kecerahan (L*), kehijauan (a*) dan kekuningan (b*) masing-masing pada 44.0, –8.0 dan 23.0. Pengeringan di peringkat makmal pada suhu 60, 70 dan 80 °C masing-masing mengambil masa 8, 6 dan 4 jam. Pengeringan pada suhu 80 °C didapati tidak menunjukkan perbezaan kualiti yang ketara berbanding dengan suhu 60 °C dan 70 °C. Pengeringan dengan alat pengering komersial, pada suhu 80 °C dengan kapasiti 200 kg mengambil masa 15 jam. Kecekapan penggunaan haba alat pengering yang diuji ialah 63.5% dan kos pengeringan bagi menghasilkan sekilogram kenaf kering adalah sekitar RM2.50.

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Appendix 1. Assumption for the estimation of drying cost using commercial size dryer

Estimation of operational cost:

- a. Repair and maintenance is based on 3% of dryer cost, utilized for 180 days/year and drying is completed within a day.
Cost incurred is RM900/year or RM5/drying/day
- b. Labour cost rate at RM5/h
- c. Electricity rate at RM0.30/kW h
- d. Diesel cost at RM0.80/litre

Estimated fixed cost for operating RM30 000 dryer:

- e. Depreciation value of the machine operating for 10 years at the rate of 5%.
Cost incurred is RM2 850/year
- f. Interest at 4% = $0.5 \times \text{RM}30\,000 \times 4\% = \text{RM}600/\text{year}$
- g. Tax and insurance at 1.5% = $0.5 \times \text{RM}30\,000 \times 1.5\% = \text{RM}225/\text{year}$
- h. Total estimated fixed cost/year = RM3 675
- i. Estimated fixed cost/day/process at utilizing rate of 180 days/year and one process/day is about RM20.40