EFFECTS OF STEM REGION, MOISTURE CONTENT AND BLADE OBLIQUE ANGLE ON MECHANICAL CUTTING OF MILLET STEMS

/

秸秆部位、含水率和刀片倾斜角对谷子秸秆切割力学性质的影响

As. Ph.D. Stud. Eng. Yanqing Zhang, Prof. Ph.D. Eng. Qingliang Cui*, Prof. Ph.D. Eng. Hongbo Li, M.S. Stud. Eng. Deng Sun, Ph.D. Stud. Eng. Huaming Hou

College of Engineering, Shanxi Agriculture University, Taigu/China

Tel: +86-0354-6289253; E-mail: qlcui@126.com

Keywords: *millet stem, mechanical cutting properties, moisture content; blade oblique angle, stem region*

ABSTRACT

Research has reported that the efficient cutting can improve stem utilisation and lead to energy conservation. In this study, the mechanical cutting properties of millet stems at different stem regions, moisture content and blade oblique angle were investigated. Results showed that cutting stress decreased from stem lower region to upper region, and cutting force and energy were greatly higher in the lower region than in the other areas due to the parameters of the cross section (p<0.05). The cutting force and energy of the nodes were significantly larger than those of the internodes (p<0.05), whereas the cutting stress of the nodes was significantly smaller than that of the internodes due to structural differences （p<0.05）. The cutting stress and specific cutting energy initially increased and then gradually decreased as moisture content increased (10.14% –72.59% [w.b.]). Processing millet stems at high or low moisture content can lead to energy saving. Cutting stress decreased as blade oblique angle was increased. However, specific cutting energy initially decreased and then gradually increased as blade oblique angle was increased. The minimum specific cutting energy values of the internodes and the nodes were reduced by 28.99% and 25.97%, respectively, when 18.8º and 0º blade oblique angles were compared. These findings are useful for further studies on effective stem forage utilisation and mechanical harvesting, deep stem processing.

摘要

切割是秸秆收获加工的主要工序，切割力是衡量秸秆饲料价值的主要指标之一。为高效利用谷子秸秆资源，节省切割能耗，本文对其切割力学性质进行深入研究，分析了茎秆位置、含水率、刀片倾斜角对谷子秸秆切割强度和切割比功的影响。研究结果表明：底部茎秆的切割强度大于顶部秸秆的切割强度；由于秸秆横截面参数的影响，底部秸秆切割力、切割功耗大于顶部茎秆切割力，且差异显著（p<0.05）；茎节切割力、切割功耗远大于秸秆节间切割力、切割比功（p<0.05）；由于结构差异，茎节的切割强度小于秸秆节间的切割强度，且差异显著（p<0.05）。切割强度和切割比功随秸秆含水率的增大先增大后减小（10.14％–72.59％[湿基]），切割过高或过低含水率秸秆可一定程度地减小切割比功。秸秆切割强度随着刀片倾斜角的增大而减小，但切割比功随刀片倾斜角的增大先减小后增大；选用刀片倾斜角 18.8º 切割谷子秸秆时，秸秆节间、茎节切割比功分别减小了28.99％、25.97％。该研究为谷子秸秆资源的高效利用及其收获、加工机械的设计提供理论指导

INTRODUCTION

Millet, a multi-grain crop, is widely grown in the temperate and tropical regions of Eurasia *(Annor et al., 2017).* It has the characteristics of drought resistance, high water use efficiency, wide adaptability and rich nutrition and is considered an ecological crop for sustainable agriculture and human dietary needs *(Devi et al., 2014; Liang et al., 2018)*. Millet stems are rich in fibre, protein and other organic matter, thereby becoming a renewable multi-purpose biological resource *(Zhang, 2012)*. Crushed millet can be used to increase soil fertility in fields, produce forage for ruminants and manufacture fibreboard and other biological building materials through deep stem processing technology.

Cutting is an indispensable step in mechanical harvesting technology and deep stem processing. Meanwhile, cutting force is an index of the chewiness of forage for ruminants *(Chen et al., 2007; Zhou et al. 2012)*. The mechanical cutting properties of millet stems should be researched to improve the utilisation of such stems. Limited research on the mechanical cutting properties of millet stems has been conducted in recent years, whereas the mechanical cutting properties of wheat stems, corn stalks and rice straws have been studied. The mechanical cutting properties of stems vary depending on stem region, moisture content and cutting form. A study on sunflower stalks showed that the cutting stress and specific cutting energy are higher in the lower region than in other areas *(İnce et al., 2005)*. A study on corn stalks reported that the cutting force and the total cutting energy of internodes and nodes vary significantly due to structural heterogeneity *(Igathinathane et al., 2010)*. Moisture content affects the mechanical properties of stalks. Researches about barley and safflower stalks were carried out to determine the effects of moisture content and stalk position on mechanical properties *(Özbek O. et al., 2009; Tavakoli H., 2009)*. For kenaf stalk cutting, the maximum cutting force and cutting energy were 1584.55 N and 8.75 J, respectively, at 35% moisture content and 694.86 N and 3.50 J, respectively, at 72% moisture content *(Dauda et al., 2014)*. In addition to these factors, the blade oblique angle also affects the mechanical cutting properties of stems. *Mathanker et al. (2015)* found that choosing an optimised blade oblique angle can result in significant savings in cutting energy and improvement of cutting quality for energycane stems. Results from a study of *Miscanthus x giganteus* stems revealed that the cutting energy at 60º blade oblique cutting angle is lower than that at 0º blade oblique cutting angle *(Johnson et al., 2012)*. *Zuoli Fu et al.* (2011) found that the best blade oblique angle to cut alfalfa stems was 10° for energy saving.

Considering the above points, this study focuses on discovering the variations in cutting stress and specific cutting energy with changes in stem regions, moisture content and blade oblique cutting angles. Results can provide basic data for the study of mechanical harvesting and processing of millet stems.

MATERIALS AND METHODS

Millet variety and sample preparation

Zhangza 10 is a fine-grained millet variety. It was planted in Taigu County, Shanxi Province in China (112º55′ E, 37º43′ N), and the sampling date was October 20, 2017.

Stems without lodging, pests and diseases were randomly selected. The average height of the millet stems was 110.9 cm. Leaf sheaths were removed, and the samples were divided into three millet stem height regions, namely, upper (S1), middle (S2) and lower regions (S3) (Fig.1). To prepare stem samples with different moisture content, the millet stems were naturally dried at an average room temperature of 25°C and moisture content was measured using a standard method (ASABE, 2008). Tests were conducted at five moisture content levels of 10.14%, 24.60%, 41.33%, 55.27% and 72.59% (w.b.).

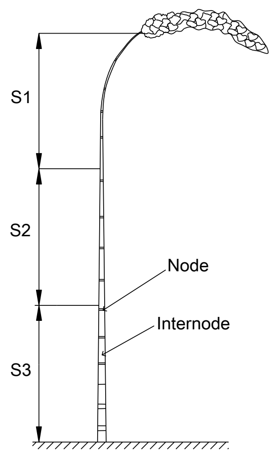
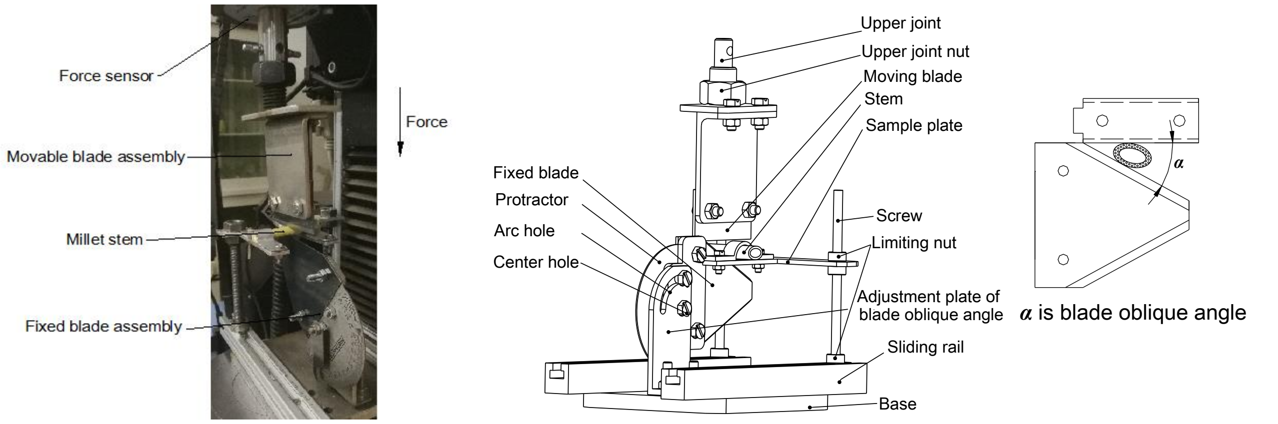


Fig.1 - The millet stem regions evaluated in the cutting test:
(S1) upper region, (S2) middle region, (S3) lower region

Testing instrument

The test device used to measure the cutting force was a 5544 universal material testing machine (Instron, United States) with a maximum load of 2 kN. The instrument used to measure moisture content was a DHG-9023A drying oven (*Wuxi Three Xin Seiko Test Equipment Co. Ltd., China*) with a temperature adjustment range of 50°C–200°C. Other instruments utilised included an electronic analytical balance (0.001 g accuracy), a vernier calliper and a custom-made cutting test apparatus.

The custom test apparatus, which includes a fixed blade assembly and a movable blade assembly, can conduct cutting tests with different blade oblique angles (Fig.2a). The movable blade assembly primarily includes an upper joint, an upper joint nut and a moving blade. The fixed blade assembly mainly includes a fixed blade, an adjustment plate for the blade oblique angle, a protractor, a sample plate, a screw, a limiting nut, a sliding rail and a base (Fig.2b). Before the test, the upper joint was fastened on the material testing machine through the upper joint nut. The adjustment plate of the blade oblique angle has a central hole and a 90° arc hole. Rotating the position of the bolt in the arc hole with the centre hole bolt can change the angle between the moving and fixed blades. To ensure that the sample is placed at the moving blade edge line, the position of the sample plate can be adjusted by the limiting nut. During the test, the material testing machine drove the movable blade assembly to move vertically and cut the stem samples.



a. Physical map of test apparatus *b. Structure diagram of test apparatus* *c. Cutting diagram*

Fig. 2 - The cutting test

Cutting test

The mechanical cutting properties of the internodes and the nodes were measured due to structural heterogeneity. Before the test, the long and short axes of each sample were measured with the vernier calliper. Then, each sample was placed on the sample plate, with the midpoint of the sample positioned in the blade edge line. Millet stems are viscoelastic materials thus, the blade velocity was maintained at 300 mm·min^{-1} for all cutting tests *(Zhou et al., 2012)*. Each sample was cut, and its wall thickness was measured. Each treatment had six stems. After the tests, the cutting force and cutting energy were recorded by the testing machine at a certain frequency, and the cross-sectional areas, cutting stress and specific cutting energy were calculated as follows:

$$A = \frac{\pi}{4}\left[D_1 x D_2 - \left(D_1 - 2T\right) x \left(D_2 - 2T\right)\right] \quad (1)$$

$$E_t = \int_0^S F\left(s\right) ds \quad (2)$$

$$\tau = \frac{F}{A} \quad (3)$$

$$E_{ts} = \frac{1000 \cdot E_t}{A} \quad (4)$$

where: D_1 is the long axis of the stem cross section, [mm];
D_2 is the short axis of the stem cross section, [mm];
T is wall thickness of the stem cross section, [mm];
A is the area of the stem cross section, [mm^2];
E_t is the cutting energy, [J];
s is the cutting displacement of millet stem, [mm];
F is the cutting force, [N];
τ is the cutting stress, [MPa];
E_{ts} is the specific cutting energy, [mJ·mm^{-2}].

Data analysis

Data analysis was conducted using SAS 9.2. ANOVA test and Duncan's multiple comparison test were used to analyse the effect of the stem region on the mechanical cutting parameters, and $p<0.05$ represents that a factor (stem region) of a certain level is significantly different at the 5% levels of significance using the Duncan's multiple comparison test. Polynomial regression analysis was adopted to create a correlation model among the mechanical cutting properties, moisture content and blade oblique cutting angle.

RESULTS

Cutting force–deformation characteristics of millet stem

Millet stems are composite materials composed of multiple tissues, and the laws of deformation and failure are determined by their structure. The overall structure of the internodes and the nodes in this work was similar (Fig.3). The force–deformation curve was divided into two processes, namely, extrusion and cutting (Fig.4). During the extrusion process, the cutting force increased with an increase in displacement. The rate of change in the cutting force was initially slow in the extrusion process and then accelerated, followed by a high peak. The blade had a squeezing effect on the stem due to the stem's hollow core structure. Afterwards, the cutting force dropped abruptly, followed by a second low peak during the cutting process. Experimental observation showed that the blade cut into the stem, and the thick wall mechanical tissue, the fundamental soft tissue and medullary cavity tissue were destroyed in turn. Finally, the cutting force was gradually reduced to 0 N, and the cutting was completed. The blade squeezed the stem during the cutting process.

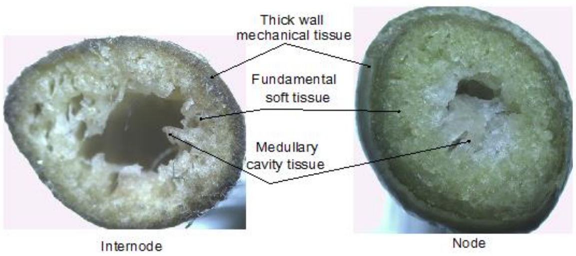


Fig. 3 - The cross-sectional stem structure

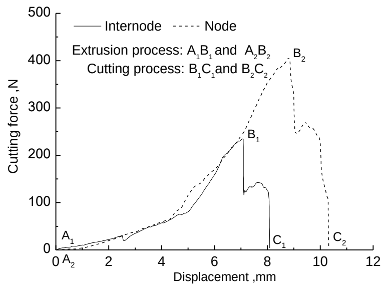


Fig. 4 - The cutting force–displacement curve of the millet stem internodes and nodes

Effects of stem region and material variation on mechanical cutting properties

The mechanical cutting properties between internodes and nodes among different stem regions are shown in Table 1. With internodes, the cutting stress decreased from stem lower region to upper region probably because the accumulation of more mature fibres in the lower region *(İnce et al., 2005)*. The cutting force and energy were higher in the lower region than in the upper region and significantly differed, and *p* value of cutting force and cutting energy were 0.0021 and 0.0029, respectively (p<0.05). The main reason was that the long axis, short axis and cross-sectional area decreased from the lower region to the upper region, and the reduced size parameters of the cross section decreased the cutting force and energy of the millet stem. These results were similar to those of cotton stalks in a previous work *(Aydın et al., 2018)*. The pattern of the mechanical cutting properties of nodes between stem regions was similar to that of the internodes.

Table 1

Effect of stem region on the mechanical cutting parameters during millet stem cutting

Physical properties		Stem region					
		Internodes			Nodes		
		S1	S2	S3	S1	S2	S3
Size parameters	D_1 [mm]	6.22cA	7.43bB	9.14aB	7.93bA	10.23aA	11.56aA
	D_2 [mm]	5.13bA	5.49bB	6.692aB	5.98bA	7.96aA	9.34aA
	A [mm^2]	17.50bB	27.69bB	35.54aB	43.47bA	64.72bA	88.490aA
Cutting force [N]		248.41bA	386.64aB	451.30aB	395.86bA	497.47bA	679.94aA
Cutting energy [J]		0.45bB	0.64bB	0.79aB	1.35bA	1.78abA	2.27aA
Cutting stress [MPa]		12.16aA	14.07aA	14.89aA	7.63aB	8.09aB	9.91aB
Specific cutting energy [mJ·mm^{-2}]		23.61aA	23.24aA	24.16aA	30.55aA	28.80aA	30.18aA

Note: moisture content of stem was 72.59%; blade oblique angle was 0°; values presented are mean from the original data; different letters (a, b, c) in the same line represent significant differences among stem region (p<0.05); and different letters (A, B) represent significant differences between internodes and nodes (p<0.05).

The cutting force and energy of the nodes and the internodes were significantly different, and p value of cutting force and cutting energy were 0.0022 and 0.0001, respectively (p<0.05), because the cross-sectional parameters of the nodes were larger than those of the internodes. Although the cutting force, cutting energy and specific cutting energy of the nodes were larger than those of the internodes, the cutting stress of the nodes was significantly smaller than that of the internodes (p<0.05). The thick-walled mechanical tissue and fundamental soft tissue could be the main factor that determined its mechanical properties *(Zhao et al., 2011)*.

Since the nodes also had more fundamental soft tissue than did the internodes, the more fundamental soft tissue resulted in a reduced cutting stress for the whole structural organisation of the nodes.

Effect of moisture content of millet stems on mechanical cutting properties

Moisture content is an important factor that affects the mechanical properties of crop stems. In this study, the cutting stress of the upper, middle and lower regions were 10.31–16.97, 12.66–18.17 and 13.57–27.32 MPa, respectively, at 10.14%–72.59% moisture content for the stem internodes.

The cutting stress values of the stem nodes were 7.1–14.67, 9.04–15.5 and 10.43–26.09 MPa, respectively. Fig.5a–5b presents the polynomial relationship between cutting stress and moisture content for the internodes and the nodes, whose r^2 values were larger than 0.82 and 0.73, respectively. The millet stem cutting stress increased with the moisture content when the latter was 10.14%–41.33%. However, the cutting stress of the stem decreased with the increase of the moisture content when the moisture content was higher than 41.33%. This finding could be attributed to the change in density at different moisture content levels *(Dauda et al., 2014)*. Results from the sunflower stalk study were consistent with ours *(Kocabıyık et al., 2004)*. During harvest period, the range of moisture content of millet stems was 45%–73%. Millet stems of lower cutting stress should be harvested at high moisture content to improve the utilisation rate of stem forage.

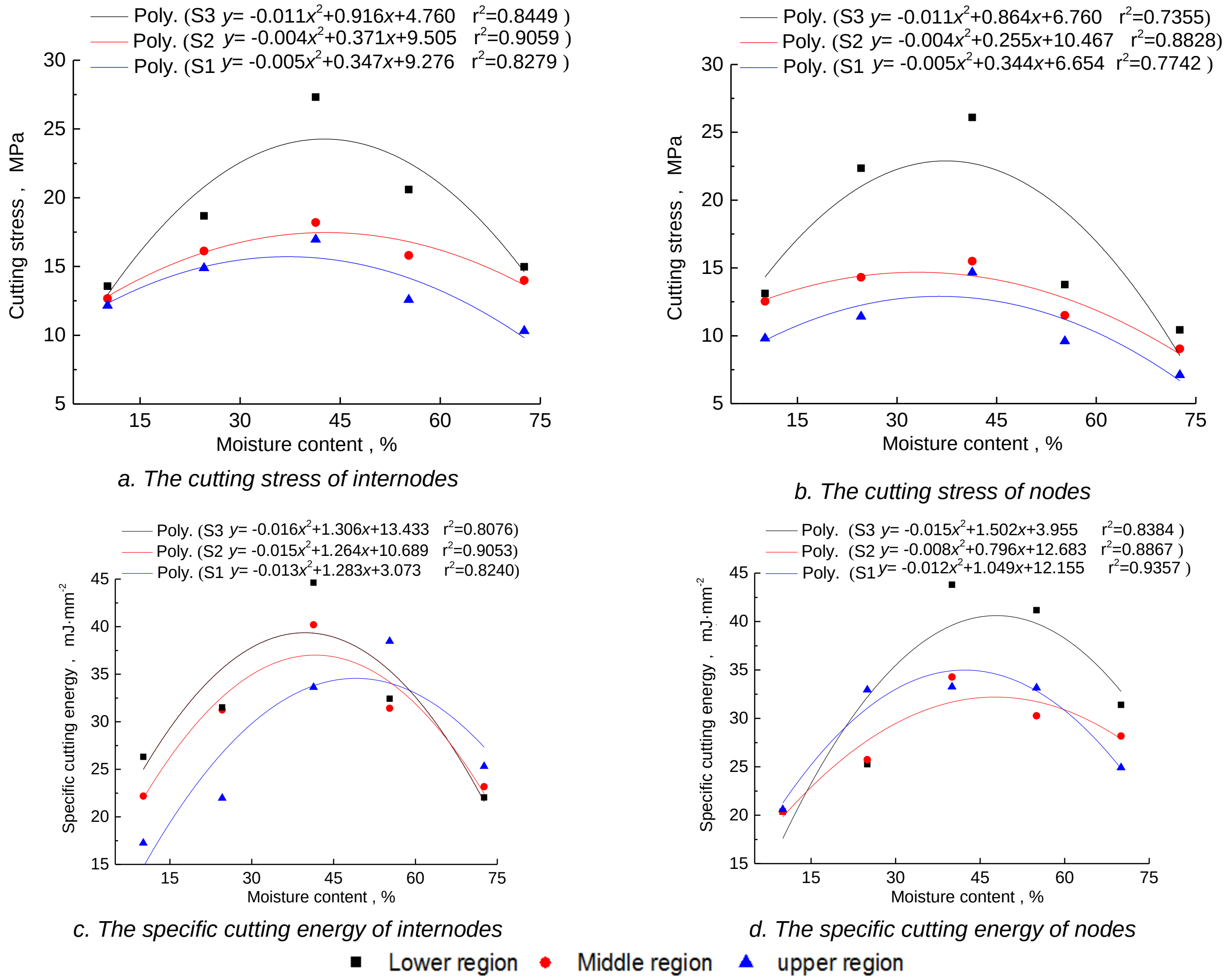


Fig. 5 - The relationship between mechanical cutting properties and moisture content

The specific cutting energy values of the upper, middle and lower regions were 17.25–38.47, 22.17–40.20 and 22.04–44.61 mJ·mm^{-2}, respectively, at 10.14%–72.59% moisture content for the stem internodes, and those of the stem nodes were 20.36–43.80, 20.38–34.27 and 20.59–33.26 mJ·mm^{-2}, respectively. Fig.5c–5d shows the polynomial relationship between specific cutting energy and moisture content, whose r^2 values were larger than 0.80 and 0.83, respectively.

The specific cutting energy initially increased and then gradually reduced with the increase in moisture content. These results differed from those of other stem materials, such as sunflower stems (*İnce et al., 2005*). The reason may be that cutting energy is related to maximum cutting force *(Zhou et al., 2012)*, and high-cutting-stress stems require additional energy to be cut. To save energy, millet stems with approximately 41.33% moisture content should not be cut during mechanical harvesting and deep stem processing.

Effect of blade oblique angle on mechanical cutting parameters of millet stems

Tests were conducted at five blade oblique angles of 0º, 12º, 24º, 36º and 48º. The cutting stress of stems decreased as blade oblique angle was increased (Fig.6a–6b). The cutting stress of upper, middle and lower region for internodes were reduced 49.51%, 47.82% and 46.01% respectively compared 48º to 0º blade oblique angle, and those of nodes were reduced 38.32%, 39.37% and 23.82% respectively. These findings were consistent with those for legume forage in a previous work *(Zhao et al., 2009*). In conclusion, the blade oblique angle has a strong influence on millet stem cutting stress and selecting the suitable blade oblique angle can reduce the cutting stress.

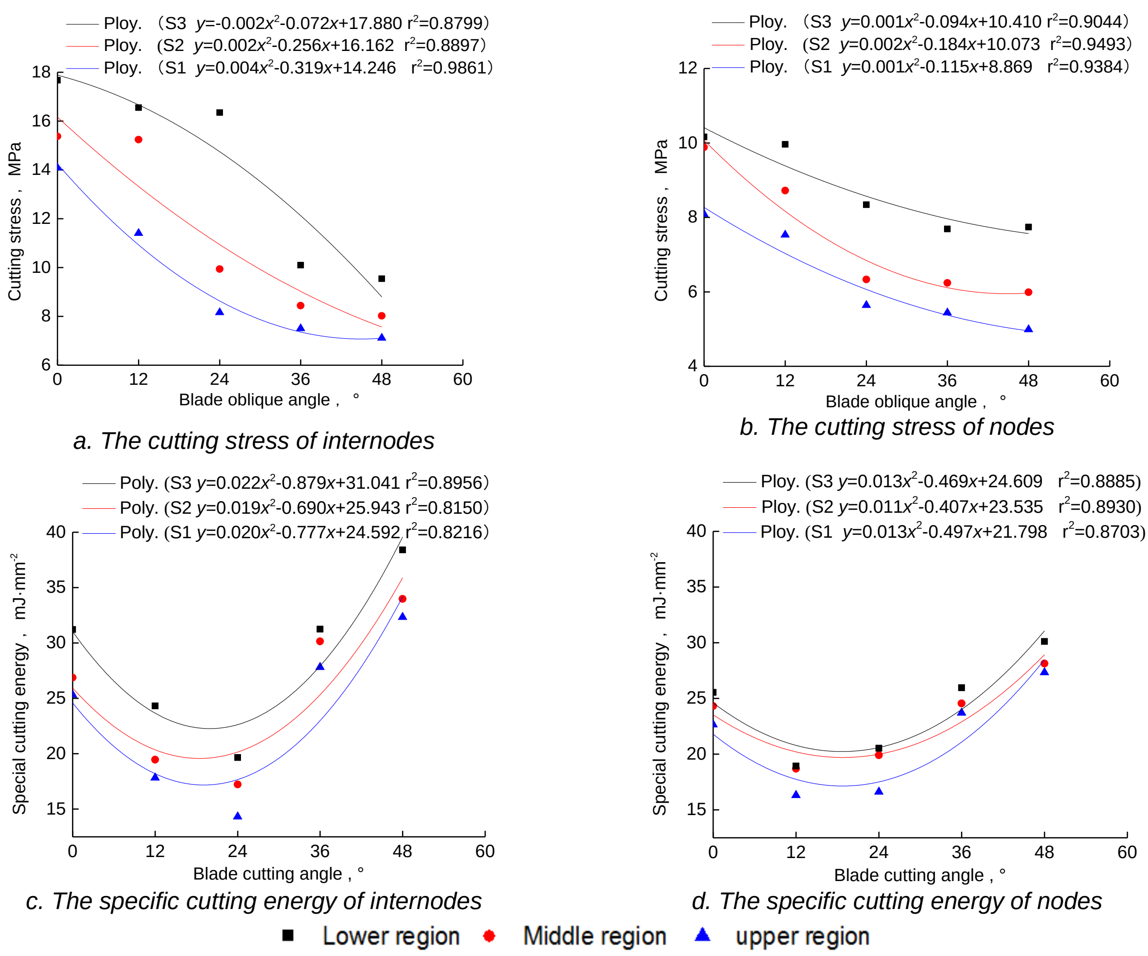


Fig. 6 - The relationship between mechanical cutting properties and blade oblique angle

The specific cutting energy of the millet stem initially decreased and then gradually increased as blade oblique angle was increased (Fig.6c–6d). These findings agreed with those for *Atriplex* and corn stems and indicated that the minimum specific cutting energy was at a blade oblique angle of 24º. The reason was that cutting energy is used not only to cut stems but also for friction between stem and blade when the blade oblique angle is excessively large. Although the cutting force decreased, the frictional force increased rapidly *(Pang, 1982)*. However, these results differed from those for energycane and Miscanthus x giganteus stems *(Johnson et al., 2012; Mathanker et al., 2015)*.

Fig.6 presents the relationship between the mechanical cutting parameters and blade oblique angle for the internodes and the nodes, where the fitting equation accuracy was larger than 0.81. Fitting of the test data revealed that the minimum specific cutting energy of the upper, middle and lower regions of the internodes were 17.05, 19.68 and 22.26 mJ·mm^{-2}, respectively, at blade oblique angles of 19.68º, 18.16º and 19.43º, respectively. Meanwhile, the minimum specific cutting energy for nodes in the upper, middle and lower regions were 17.05, 19.77 and 20.38 mJ·mm^{-2}, respectively, at blade oblique angles of 18.04º, 18.50º and 19.12º, respectively. Overall, the average and optimised blade oblique angle was 18.8º for all regions of the millet stems. Through the verification test, the specific cutting energy was reduced by 28.99% and 25.97% for internodes and nodes, respectively when 18.8º and 0º blade oblique angles were compared (Table 2).

Table 2

Comparison of specific cutting energy for millet stem internodes and nodes

Blade oblique angle [°]	Moisture content [%]	Specific cutting energy [mJ·mm^{-2}]					
		Internodes			Nodes		
		S1	S2	S3	S1	S2	S3
0	10.07	19.63±5.48	22.65±4.96	25.35±5.24	22.80±2.55	23.55±3.36	21.54±6.22
	71.32	25.34±3.08	26.87±4.55	29.21±4.64	22.63±4.55	24.31±2.49	27.55±5.42
18.8	10.07	14.56±1.90	17.11±2.29	17.24±1.76	15.94±3.43	17.24±1.76	17.72±2.04
	71.32	17.90±3.77	18.46±3.75	20.15±3.82	16.11±2.96	17.91±3.95	20.37±2.40
Saving energy ratio [%]		27.59	27.88	31.50	29.45	26.56	21.90
Average [%]		28.99			25.97		

Note: values presented are mean ± standard deviation from the original data.

CONCLUSIONS

Cutting tests were conducted to investigate the mechanical cutting properties of the internodes and nodes of millet stems. This research revealed the effects of stem region, moisture content and blade oblique angle on mechanical cutting parameters. The main conclusions of this study are as follows.

(1) The force–displacement curves in the cutting experiments indicated that the cutting process must be divided into the extrusion and cutting processes due to the hollow core structure of millet stems.

(2) The cutting force and energy of the internodes were 248.41–451.30 N and 0.45–0.79 J at 0° blade oblique angle（72.59% [w.b.]), respectively, and those of the nodes were 395.86–679.94 N and 1.35–2.27 J at 0° blade oblique angle（72.59% [w.b.]), respectively. The cutting force and energy of the nodes were significantly larger than those of the internodes (p<0.05), but the cutting stress of the nodes was greatly smaller than that of the internodes (p<0.05).

(3) The cutting stress was decreased from lower region to upper region of millet stems, and the parameters of cross section, cutting force and cutting energy of the lower stem region were significantly larger than those of the upper region (p<0.05).

(4) The cutting stress and specific cutting energy initially increased and then reduced with increasing moisture content. Cutting millet stems with moisture content of approximately 41.33% should be avoided during mechanical harvesting and deep stem processing to save energy.

(5) The blade oblique angle has a strong influence on the mechanical cutting properties of millet stems. Cutting stress was reduced with the increase in blade oblique angle. However, the specific cutting energy was initially reduced and then increased with the increase in blade oblique angle. Specific cutting energy was reduced by 28.99% and 25.97% for internodes and nodes, respectively when 18.8º and 0º blade oblique angles were compared.

ACKNOWLEDGEMENTS

This research, titled ‘Effects of stem region, moisture content and blade oblique angle on mechanical cutting of millet stems’, was funded by the National Key Research and Development Plan of China (2016YFD0701801). The authors are grateful and honoured to have obtained support from the Key Laboratory of Biomechanics.

REFERENCES

[1] Annor G. A., (2017), Why do millets have slower starch and protein digestibility than other cereals?. *Trends in Food Science & Technology*, Vol. 2017, Issue 66, pp. 73-83, Ed. Elsevier, London/England;

[2] Aydın İ., (2018), Mechanical properties of cotton shoots for topping. *Industrial Crops & Products,* Vol. 2018, Issue 112, pp. 396-401, Ed. Elsevier, Amsterdam/Netherlands;

[3] Chen Y., (2007), Effect of harvest date on shearing force of maize straws. *Livestock Science*, Vol.2007, Issue 111, pp. 33-44, Ed. Elsevier, Amsterdam/Netherlands;

[4] Dauda S. M., (2014), Physical and mechanical properties of kenaf stems at varying moisture contents. *Agriculture & Agricultural Science Procedia*, Vol. 2, Issue 2, pp. 370-374;

[5] Devi P. B., (2014), Health benefits of finger millet (eleusine coracanal) polyphenols and dietary fibre: a review. *Journal of Food Science & Technology*, Vol. 51, Issue 6, pp. 1021-1040, New Delhi/India;

[6] Igathinathane C., (2010), Corn stalk orientation effect on mechanical cutting. *Biosystems Engineering*, Vol. 107, Issue 2, pp. 97-106, Ed. Elsevier, San Diego/USA;

[7] Ince A., (2005), Bending and shearing characteristics of sunflower stalk residue. *Biosystems Engineering*, Vol. 92, Issue 2, pp. 175-181, Ed. Elsevier, San Diego/USA;

[8] Johnson P. C., (2012), Cutting energy characteristics of miscanthus x giganteus stems with varying oblique angle and cutting speed. *Biosystems Engineering*, Vol. 112; Issue 1; pp. 42-48, Ed. Elsevier, San Diego/USA;

[9] Kocabıyık H., (2004), Determination of cutting properties of sunflower stalk. *Journal of Agriculture. Mach. Science*，Vol. 10, Issue 3, pp. 263–267;

[10] Liang K., (2018), Metabolic variation and cooking qualities of millet cultivars grown both organically and conventionally. *Food Research International*, Vol. 2018, Issue 106, pp. 825, Ed. Elsevier, Amsterdam/Netherlands;

[11] Mathanker S.K., (2015), Effect of blade oblique angle and cutting speed on cutting energy for energycane stems. *Biosystems Engineering*, Vol. 2015, Issue 133, pp. 64-70, Ed. Elsevier, San Diego/USA;

[12] Özbek O., (2009), Some mechanical properties of safflower stalk. *Applied Engineering in Agriculture*, Vol. 25, Issue 4, pp. 619-625, Spokane/U.S.A.;

[13] Pang S.H., (1982), Theory of sliding cutting and the choice of its angle. *Journal of Huazhong Agricultural College*, Vol. 1982, pp. 64-69, Wuhan/P.R.C.;

[14] Tavakoli H., (2009), Some engineering properties of barley straw. *Applied Engineering in Agriculture*, Vol. 25, Issue 4, pp. 627-633, Spokane/U.S.A.;

[15] Zhao C.H., (2009), Experiment on stalk mechanical properties of legume forage and grasses. *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 25, Issue 9, pp. 122－126, Beijing/P.R.C;

[16] Zhao C.H., (2011), Mechanical properties and microstructure of new species forage stems in harvesting period. *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 27, Issue 7, pp. 179－183, Beijing/P.R.C.;

[17] Zhang X.W., (2012), Current situation and problems of millet harvesting machinery. *Agricultural Technology & Equipment*, Vol. 2012, Issue 20, pp. 32-34, Beijing/P.R.C.;

[18] Zhou D., (2012), Temporal dynamics of shearing force of rice stem. *Biomass & Bioenergy*, Vol. 47, Issue 4, pp. 109-114, Ed. Elsevier, London/ England;

[19] ZuoLi Fu., (2011), Experiment for alfalfa stem-cutting and study for mechanical properties, *2011 ASABE Annual International Meeting*, pp.1-8, Spokane/U.S.A.

[20] ***ASABE Standards, 2008. S358.2. Moisture Measurement – Forages. *American Society of Agricultural and Biological Engineers*, St. Joseph, MI, Spokane/U.S.A.;