# TEST AND ANALYSIS OF MECHANICAL PROPERTIES OF BUCKWHEAT STEM DURING HARVEST
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# *荞麦茎秆机械收获力学性质测试与分析*

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## ABSTRACT
*Buckwheat crops are subjected to complex stress during harvest. And there are problems such as large deformation, severe brokenness, and high energy consumption of stems during the mechanical harvesting, such as cutting, transporting, threshing, separating and cleaning. In this study, the mechanical properties of buckwheat stem during mechanical harvesting were tested, including tensile, bending, shearing and dynamic cutting, and the effects of moisture content, stem position and working parameter on their mechanical properties were analyzed. The test results showed that the tensile strength, elastic modulus, cutting stress and unit area cutting energy of stem with higher moisture content were significantly greater than those of stem with lower moisture content (P<0.05). The flexural modulus and bending strength of stem with higher moisture content were significantly lower than those of stem with lower moisture content (P < 0.05). The flexural modulus, bending strength, shear strength, cutting stress and unit area cutting energy decreased gradually with the stem height increasing. The cutting parameters had significant effects on the mechanical properties of stem (P<0.05), and the cutting mechanical properties first decreased and then changed steadily with the average cutting speed increasing. The cutting stress gradually decreased with the blade oblique angle increasing, but the unit area cutting energy decreased first and then increased. The average cutting speed and blade oblique angle of buckwheat stem are recommended to be 0.75-1.0 m/s and 30º, respectively. This research can provide basic data for the design of the buckwheat harvesting machinery.*

## 摘要
*荞麦作物在机械收获切割、输运、脱粒分离和清选等作业环节，其茎秆会受到复杂应力作用，存在茎秆受力变形大、破碎严重、耗能大等问题。本文测试了荞麦茎秆在机械收获过程中的力学性质，包括拉伸、弯曲、剪切和动态切割力学性质，并分析了含水率、茎秆部位和相关工作参数对其力学性质的影响。试验结果表明：较高含水率的荞麦茎秆拉伸强度、弹性模量、切割应力和单位面积切割功耗均显著大于较低含水率的荞麦茎秆（P＜0.05）；但较高含水率的荞麦茎秆弯曲模量和抗弯强度显著小于较低含水率的荞麦茎秆（P＜0.05）。随着茎秆离地高度的增大，其弯曲模量、抗弯强度、剪切强度、切割应力和单位面积切割功耗均逐渐减小。切割工作参数（平均切割速度和刀片斜角）对荞麦茎秆的切割应力、单位面积切割功耗影响显著（P＜0.05），随着平均切割速度的增大，切割力学性质参数呈现先减小后平稳变化的规律，而随着刀片斜角的增大，切割应力逐渐减小，而单位面积切割功耗先减小后增大，荞麦茎秆的平均切割速度和刀片斜角建议分别选取 0.75-1.0 m/s 和 30°。本研究为荞麦低损高质收获机械关键部件设计提供了基础数据。*

## INTRODUCTION
Buckwheat, an annual or perennial herb, belongs to a dicotyledonous plant in the *Polygonaceae* family. It originated in China and has a long cultivation history and a large planting area. Buckwheat grains are rich in a variety of biologically active ingredients, which have anti-tumor and anti-oxidant effects after consumption *(Xiang et al., 2013; Wang et al., 2010)*. In recent years, lots of scholars have conducted preliminary explorations on buckwheat harvesting technology and machinery *(Zhang et al., 2019; Wang et al., 2020)*.

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Buckwheat mechanical harvesting methods mainly include combined harvesting and segmented harvesting, and the corresponding machines include combine harvesting machinery, swather and pickup machinery. The problems such as high impurity content in grains and high energy consumption of these machines are mainly caused by severely damaged stems *(Lu et al., 2020)*. The research on the mechanical properties of crops is the basis for the innovative design of mechanical harvesting equipment. Therefore, it is urgent to study the mechanical properties of buckwheat stems to optimize the design parameters of harvesting equipment and improve its performance.

Many scholars have conducted a large number of biomechanical tests on the stems of wheat, rice and other crops, and have achieved excellent results. *Zhao et al.* conducted tensile tests for forage stems and measured the maximum tensile load, stress, strain, elastic modulus and other mechanical characteristics, which provided basic data for the design of its harvesting machines *(Zhao et al., 2009)*. *Esehaghbeygi A. et al.* found that the correlation between the elastic modulus, bending strength and moisture content of the wheat stems, and these results can not only evaluate the lodging resistance of wheat stem but also provide a reference for the design of wheat harvester headers *(Esehaghbeygi et al., 2013)*. A study on *energycane* stem showed that selecting appropriate cutting parameters can reduce power consumption *(Mathanker et al., 2015)*. Research about millet stem presented that different cutting speeds and blade oblique angles have a great influence on cutting mechanical properties (*Zhang et al., 2018; Zhang et al., 2020*). Buckwheat stems are different from rice, wheat and other stems. The high moisture content of buckwheat stems makes them break easily during the harvest period, and the lignin content of the bottom stem is high and makes it difficult to cut. However, there was an extreme shortage of machines suitable for buckwheat harvesting. Testing the mechanical properties of buckwheat stem is the premise of designing machinery and equipment, which can obtain the design parameters for improving the performance of the buckwheat harvester.

In this research, the tensile, bending, shearing and dynamic cutting mechanical properties of buckwheat stem were studied, and the effects of different stem positions, moisture content and cutting technical parameters on its mechanical properties were analyzed. These results can provide a reference for the design and optimization of key components of buckwheat mechanical harvesting.

## MATERIALS AND METHODS

### Materials and Test equipment

Heifeng No.1 buckwheat was randomly collected in the test field of buckwheat planting in Taigu County, Shanxi Province, China (112º55′ E, 37º43′ N). The bending test was carried out in the buckwheat field, and the other mechanical properties tests were conducted in the laboratory. After harvesting, the stems were made samples in time and put into sealed bags. Simultaneously, the moisture content (w.b.%) of the stem was measured by the standard method (*ASABE, 2008*).

The test equipment used for tensile and shearing tests was a 5544 universal material testing machine (Instron, United States) with a maximum load of 2 kN. The test tools used for bending tests were spring dynamometers and rulers. The self-made cutting test bench was used for stem dynamic cutting tests (*Zhang et al., 2020*).

### Tensile test

Buckwheat stems are hollow tubes. The stress concentration phenomenon is easy to occur at the clamping parts of the stem when it was fastened by the tensile fixture, which leads to inaccurate test results. So the test methods for physical and mechanical properties of wood were used to make tensile test samples *(China National standardizing committee, 2009).* The shape of the sample was similar to a cuboid, and its length, width, and thickness are *p*, *q*, and *r*, respectively, which were measured by the vernier caliper before the tensile test. And the sandpapers were put into the clamping part of the tensile fixture to increase friction and prevent the stem from slipping. The tensile loading rate was set at 2 mm/min. The tensile force and displacement were recorded by the testing machine, and the tensile strength and elastic modulus were calculated as follows:

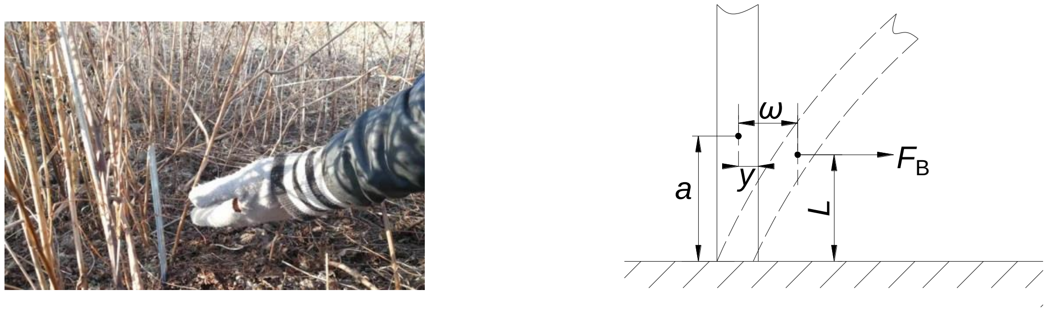
$$\sigma = \frac{F_t}{q\mathrm{r}} \tag{1}$$

$$E = \frac{\sigma}{\varepsilon} \tag{2}$$

$\sigma$ is the tensile strength, [MPa]; $F_t$ is the Maximum tensile force [N]; $E$ is the elastic modulus [MPa];
$q$ is the width of the stem sample, [mm]; $r$ is the thickness of the stem sample, [mm]; $\varepsilon$ is the strain, %.

## Bending test

The stem bending test was carried out in the field. The straight stems without disease and insect pests were randomly selected, a ruler was set vertically near the stem, and the measured stem position (distance from the ground was *a,* Fig.1b) was marked. The stem was hooked by the spring dynamometer. The field test picture is shown in Fig. 1a.




a. The field test b. The test schematic diagram

**Fig. 1 - Bending test of buckwheat stem in field**

According to the method in literature (*A. Ince S. et al.,2005; Esehaghbeygi A. et al., 2013*), pull the stem at a slow and uniform speed in the horizontal direction to the point of deflection $\omega$ ($\omega$=50 mm), and the pulling force $F_B$ (N), the distance from stress point to the ground $L$(mm), the distance between the stem axis and the surface of stem $y$ (mm) in the pulling direction, the inner diameter of stem stress point $d$ (mm) and the outer diameter of stem stress point $D$ (mm) were measured. The test schematic diagram is shown in Fig. 1b. The flexural modulus $E_b$ [GPa], moment of inertia $I$ (mm$^4$), bending strength $\sigma_b$ [MPa] and the flexural stiffness $E_b I$ (Nm$^2$) were calculated as follows:

$$E_b = \frac{F_B L^3}{3\omega I} \tag{3}$$

$$I = \frac{\pi D^4 (1-\alpha^4)}{64} \tag{4}$$

$$\alpha = \frac{d}{D} \tag{5}$$

$$\sigma_b = \frac{F_B L y}{I} \tag{6}$$

## Shearing test

The collected buckwheat stems were made into 70 mm length samples, the midpoint of stem internode and node were used as the shearing point, and the outer diameter of stem midpoint was measured before the test. The shearing fixture was installed on the mechanical testing machine and the shearing speed was set to 5 mm/s. After the shearing tests, the stem wall thickness was measured. The maximum shear force $F_s$ and shear energy $W_s$ can be recorded by the mechanical testing machine and the shear strength was calculated as follows:

$$\tau = \frac{F_s}{A} \tag{7}$$

$$A = \frac{\pi}{4}\left[D^2 - (D-2t)^2\right] \tag{8}$$

where: $\tau$ is the shear strength, [MPa]; $F_s$ is the maximum shear force [N]; $A$ is the cross-sectional area of stem [mm$^2$]; $D$ is the outer diameter of stem [mm]; $t$ is the wall thickness of stem [mm].

## Dynamic cutting test

The self-made cutting test bench was used to the dynamic cutting test of buckwheat stem (Fig.2). The function of the cutting test bench, the introduction of the testing method and the calculation of data are consistent with *Zhang's* research (*Zhang et al., 2020*). During the dynamic cutting test, the standard type Ⅱ cutter (including the type Ⅱ moving blade and the type Ⅳ guard) commonly used in harvester were selected *(China National standardizing committee, 2009)*, and the blade oblique angle and average cutting speed were set to 0-48° and 0-1.5 m/s, respectively.

The ratio of average cutting speed to feeding speed has a great influence on the re-cutting, missed cutting and one-time cutting performance of stem, and it was set at 1.6 after the initial tests. The adjustment of blade oblique angle is shown in Fig. 3.

**Fig. 2 - The dynamic cutting test of buckwheat stem**

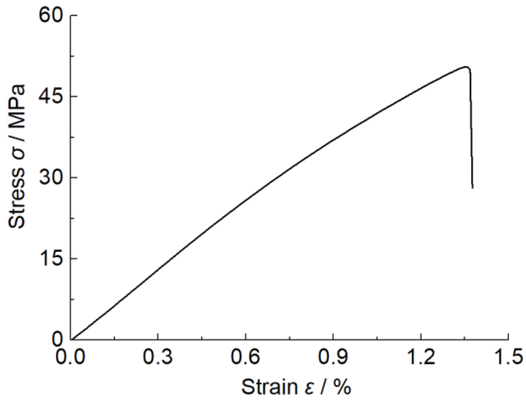
**Fig. 3 - The adjustment of blade oblique angle**

## RESULTS

### Tensile test results of buckwheat stem

The tensile test picture and stress-strain curve of buckwheat stem are shown in Fig. 4a and Fig. 4b, respectively. From Fig.4b, the stem had no obvious yield point, and the stress changed uniformly with the strain increasing until the stem sample broke during the entire tensile test.

a. The tensile test picture




b. Stress-strain curve of stem

**Fig. 4 - The tensile test**

The effect of moisture content on tensile mechanical properties is shown in Table 1. It can be seen from Table 1 that the range of the maximum tensile force of buckwheat stems was unstable. Since buckwheat stems are biological materials, which may be determined by the number of fibers and their connection mode, the tensile strength and elastic modulus are selected for further analysis in this study. Through multiple comparisons of mean values, the tensile strength and elastic modulus of the stem with higher moisture content were significantly greater than those with lower moisture content ($P$<0.05). This result indicates that buckwheat stems with lower moisture content are prone to breakage, and it was agreed with the tensile tests of corn stems previously mentioned (*Yu et al.,* 2012).

**Table 1**

**Tensile test results of buckwheat stem**

| Moisture content [%] | Sample | $F_t$ [N] | $\sigma$ [MPa] | $E$ [MPa] |
|---|---|---|---|---|
| 57.33 | 1 | 135.60 | 64.64 | 5858.30 |
| | 2 | 84.62 | 42.05 | 4410.15 |
| | 3 | 89.97 | 50.10 | 4895.58 |
| | 4 | 77.95 | 50.06 | 4647.80 |
| | 5 | 64.93 | 41.74 | 4,410.15 |
| | Mean | 90.61 | 49.72A | 5017.00A |
| 40.56 | 1 | 82.71 | 37.26 | 4179.28 |
| | 2 | 87.53 | 49.81 | 4069.31 |
| | 3 | 89.01 | 38.76 | 4030.39 |
| | 4 | 74.27 | 43.17 | 4321.88 |
| | 5 | 86.58 | 44.54 | 4123.71 |
| | Mean | 84.02 | 42.71B | 4114.91B |

*Note: Different letters (A, B) represent significant differences in tensile mechanical properties among moisture content (p<0.05).*

Therefore, the moisture content of the stem should not be too low when the buckwheat is harvested, otherwise, it will cause serious deformation of the stem and increase the impurity content of the grains.

## Bending test results of buckwheat stem

The effects of moisture content and stem position (test site) on the bending mechanical properties are presented in Table 2. Different moisture content and stem position have effects on the moment of inertia, flexural modulus and bending strength of buckwheat stem. For the same stem position, the moment of inertia of stem with higher moisture content was significantly greater than those with lower moisture content (*P*<0.05), but the flexural modulus and bending strength of stem with higher moisture content were significantly lower than those with lower moisture content (*P*<0.05). The flexural stiffness of the stem with the moisture content of 75.34% and 63.68% was not significant (*P* >0.05). For stems with the same moisture content, the moment of inertia, flexural modulus, bending strength, and flexural stiffness of the stem test site at a height of 120 mm from the ground are significantly lower than those of the test site at 60 mm (*P*<0.05). As a result,, the higher collision point of the stem divider, the easier it is to cause the stem to bend and break off in the working process of the harvester. The height of the collision point between the stem and the stem divider should be reduced as much as possible to avoid stem lodging and grain loss.

**Table 2**

**Bending test results of buckwheat stem**

| Test site (height from the ground) [mm] | Moisture content [%] | $I$ [mm$^4$] | $E_b$ [GPa] | $\sigma_b$ [MPa] | $E_b$ [Nm$^2$] |
|---|---|---|---|---|---|
| 60 | 75.34 | 46.42 Aa | 2.43 Ba | 20.64 Ba | 0.11 Aa |
| 60 | 63.68 | 34.18 B | 3.31 A | 25.51 A | 0.11 A |
| 90 | 75.34 | 43.21 a | 2.15 a | 20.42 a | 0.09 ab |
| 120 | 75.34 | 32.54 b | 1.54b | 15.58 b | 0.05b |

*Note: Different letters (A, B) and (a, b) represent significant differences of bending mechanical properties in moisture content and test site, respectively (p<0.05).*

## Shearing test results of buckwheat stem

The shear mechanical properties of buckwheat stem (with the moisture content 76.62%, w.b.) were obtained in Table 3. As shown in Table 3, the cross-sectional area, maximum shear force, shear energy and shear strength of buckwheat stem decreased with the increase of stem height. Through mean multiple comparisons, it was found that there were significant differences in the cross-sectional area and maximum shear force of stem in different positions (*P*<0.05). For internodes, the shear energy and shear strength of different positions were significantly different (*P*<0.05). In terms of nodes, the shear energy and shear strength of the 1st stem node were significantly greater than those of the 5th stem node (*P*<0.05), while the difference between the 2nd and 4th stem nodes was not significant (*P*>0.05). Meanwhile, the average shear strength of stem internode and node was 11.10 MPa and 15.70 MPa, respectively, and the stem node shear strength was greater than that of stem internode. Buckwheat crops will be impacted and sheared by rod teeth during the threshing process, and this research clarifies the positions of the stem with lower shear strength, which provides help for targeted flexible threshing components.

**Table 3**

**Shearing test results of buckwheat stem**

| Order from the ground | Internode | | | | Node | | | |
|---|---|---|---|---|---|---|---|---|
| | $A$ [mm$^2$] | $F_s$ [N] | $\tau$ [MPa] | $W_s$ [J] | $A$ [mm$^2$] | $F_s$ [N] | $\tau$ [MPa] | $W_s$ [J] |
| 1 | / | / | / | / | 26.53a | 595.92a | 22.46a | 1.65a |
| 2 | 20.55a | 383.46a | 18.66a | 0.84a | 25.65a | 438.13ab | 17.08ab | 1.39ab |
| 3 | 19.92ab | 212.09b | 10.65b | 0.78ab | 21.12b | 334.00b | 15.82b | 1.35b |
| 4 | 19.91ab | 160.05bc | 8.04bc | 0.61b | 21.07b | 318.87b | 15.14b | 1.32b |
| 5 | 17.60b | 120.29c | 6.83c | 0.45c | 20.63b | 165.31c | 8.01c | 0.63c |

*Note: The 1st internode stem is very close to the ground, far less than the stubble height, its mechanical properties do not need to be measured. Different letters (a, b, c) represent significant differences of shearing mechanical properties in stem position, respectively (p<0.05).*

**Dynamic cutting results of buckwheat stem**

The average cutting speed and blade oblique angle were set to 1 m/s and 30°, respectively, and the stem dynamic cutting test was carried out to analyze the differences between the moisture content and stem position on its cutting mechanical properties. The test results are shown in Fig.5. In the case of the moisture content, the cutting stress and unit area cutting energy of stem had the same trend, and both increased with the increase of moisture content. The reason is that the increase of stem moisture content leads to increased stem toughness *(Wang et al., 2020).* In Fig.5, it was found that the regression fitting equation of stem moisture content and cutting mechanical properties showed a quadratic function relationship, and the fitting accuracy was greater than 0.92. It can predict its cutting mechanical properties according to the stem moisture content. These results provide a reference for selecting the appropriate moisture content of buckwheat stem to reduce its cutting force and cutting energy during harvest. For the stem position, the change rule of cutting mechanical properties of buckwheat stem is basically the same as that of shear mechanical properties, and the cutting stress and unit area cutting energy decreased with the increase of stem height. Similarly, the unit area cutting energy of the 2nd internode from the ground was significantly greater than that of the 4th internode ($P$<0.05), and there was a significant difference in cutting stress between the 2nd internode and the other internodes of the stem ($P$<0.05), which is due to the higher lignin content and mechanical strength of the bottom stems *(Li et al., 2011).*

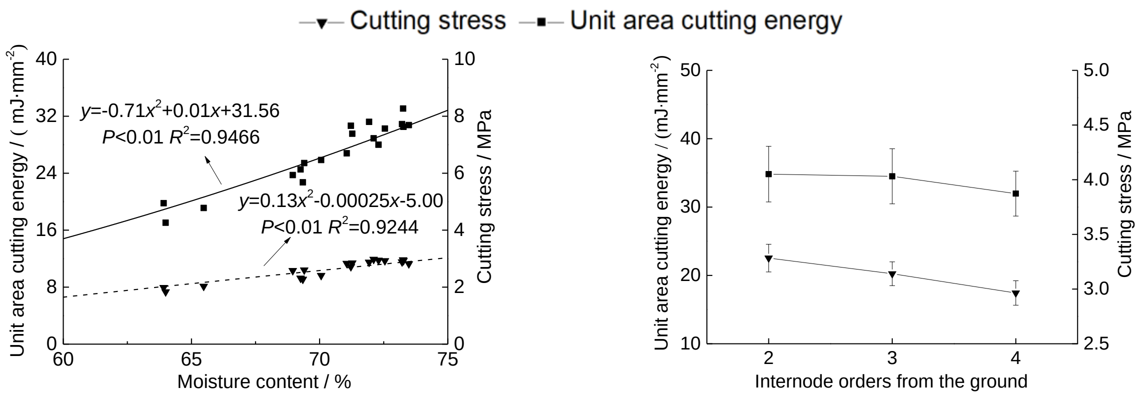



**Fig. 5 - Variation of cutting mechanical properties under different stem position and moisture content**

Similarly, the maximum cutting force and cutting energy decreased with the stem height increasing, and the differences were significant ($P$<0.01). The maximum cutting force, cutting energy and cross-sectional area of the stem were regressed, and the fitting equation is shown in Fig. 6. The accuracy of the fitting model is greater than 0.92, and these results provide a basis for choosing a suitable cutting height to reduce the cutting force and power consumption of the buckwheat stem.

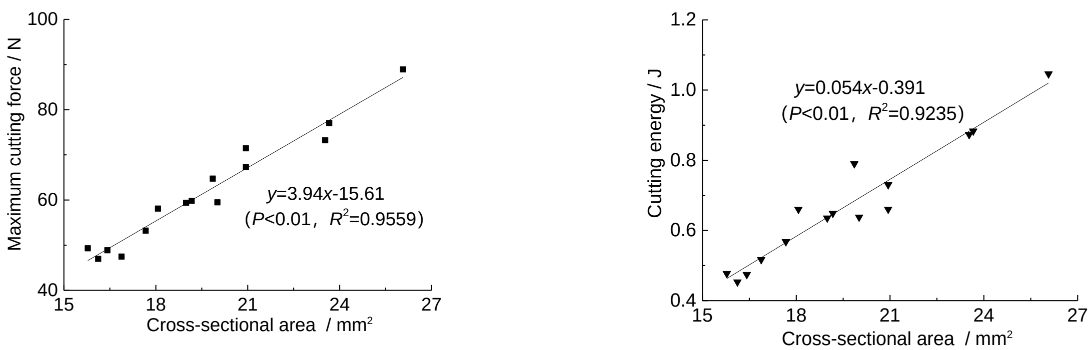



**Fig. 6 - Correlation between cross-sectional area, cutting force and cutting energy**

Cutting is the primary working process of buckwheat harvesting machinery *(Igathinathane, 2010)*, and the cutting parameters have a great influence on its cutting mechanical properties, especially cutting speed and blade oblique angle *(Johnson et al., 2012; Mathanker, et al., 2015).* In this paper, dynamic cutting experiments with different average cutting speeds and blade oblique angles were carried out, and the results are shown in Fig. 7.

As can be seen in the first picture of Fig.7, the cutting stress and unit area cutting energy of stem first decreased and then remained unchanged with the increase of average cutting speed when the blade oblique angle was 30°, and the cutting mechanical properties at a cutting speed of 0.5 m/s were significantly greater than those at a cutting speed of 0.75-1.5 m/s.

The conclusion of the study is consistent with that of *Zhang's* research about the millet stalk *(Zhang. et al., 2020),* and the average cutting speed should be greater than 0.75m/s to reduce the cutting force and cutting energy. However, relevant studies had shown that too fast cutting speed will cause increased vibration of the cutting header and additional energy consumption, and the average cutting speed should not be too large *(Ji. et al., 2017)*. So, this paper suggests that the average cutting speed should be kept at 0.75-1.0 m/s when the buckwheat is to be harvested.

The effect of blade oblique angle on cutting mechanical properties was tested at an average cutting speed of 1.0 m/s. From the second picture in Fig.7, the cutting stress decreased with the increase of the blade oblique angle, which is because the sliding cutting can reduce the cutting force of the stem. The larger blade oblique angle, the larger sliding cutting angle, and the more significant sliding cutting function on the stems *(Song. et al., 2015)*. Nevertheless, the unit area cutting energy decreased first and then increased with the increase of blade oblique angle, and it was the smallest when the blade oblique angle was 30°. This is due to the fact that the blade cutting displacement increased, and the frictional power consumption between the blade and the stem increased significantly when the blade oblique angle increased to a certain extent *(Pang. et al., 1982)*. In general, the increase of blade oblique angle will reduce the cutting stress and unit area cutting energy to a certain extent, but a too large blade oblique angle may cause the larger energy consumption or the stalk to be unable to be clamped and cut *(Pang. et al., 1982)*. Therefore, this study recommends that the blade oblique angle should be about 30° for buckwheat stem cutting.

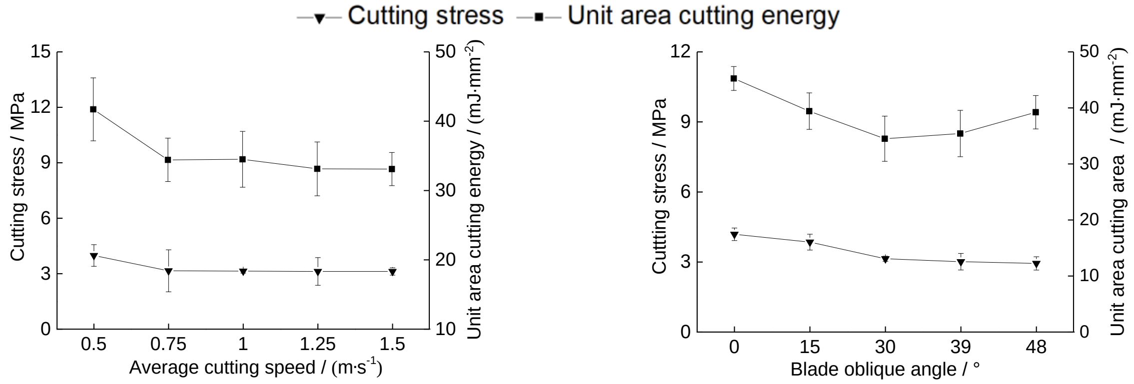



**Fig. 7 - Variation of cutting mechanical properties in different average cutting speeds and blade oblique angles**

## CONCLUSIONS

The tensile, bending, shearing and dynamic mechanical properties of buckwheat stem during mechanical harvesting were tested, and the following conclusions were obtained:

(1) The moisture content had a significant effect on the tensile mechanical properties of the stem. The lower moisture content of the stem had small tensile strength and elastic modulus and was easy to break.

(2) The moisture content and stem position had significant effects on the bending and dynamic cutting mechanical properties of the stem. The bottom stem with lower moisture content had higher bending strength, flexural modulus and cutting stress, and was not easy to bend and cut.

(3) The stem position had a significant effect on the shearing mechanical properties of the stem, and the shear strength and shear energy of the stem in the upper position were significantly smaller than those in the lower position.

(4) The average cutting speed and blade oblique angle have a great influence on the cutting mechanical properties of the stem. This research suggests that the cutting speed and blade oblique angle of buckwheat stems should be 0.75-1 m/s and 30°, respectively.

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**REFERENCES**


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

[2] ASABE Standards, 2008. S358.2. Moisture Measurement-Forages. American Society of Agricultural and Biological Engineers, St. Joseph, MI, Spokane/USA;

[3] Esehaghbeygi A., (2013), Bending and Shearing Properties of Wheat Stem of Alvand Variety, *World Applied Sciences Journal*, Vol. 6, Issue 8, pp.1028-1032, Islamabad/Pakistan;

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

[5] Ji J.T., (2017). Analysis of minimum amplitude points and optimization of connection position for header of micro grain combine (微型谷物联合收割机割台最小振幅点分析及挂接点优化), *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 33, Issue 12, pp. 28-33, Beijing/ P.R.C.;

[6] Li Y.M., (2011), Experiments and analysis on mechanical property of corn stalk reciprocating cutting (玉米茎秆往复切割力学特性试验与分析), *Transactions of the Chinese Society of Agricultural Engineering*, Vol.27, Issue 1, pp.160-174, Beijing/P.R.C.;

[7] Lu Q., (2020), Problems and thoughts on mechanized harvesting technology of buckwheat in China (我国荞麦机械化收获技术问题与思考), *Agricultural Engineering*, Vol. 10, Issue 1, pp.6-9, Beijing/P.R.C.;

[8] 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;

[9] Pang S.H., (1982), Theory of sliding cutting and the choice of its angle (关于滑切理论与滑切角的选用). *Journal of Huazhong Agricultural College*, Vol. 1982, pp. 64-69, Wuhan/P.R.C.;

[10] Song Z.H., (2015), Experiment on cutting characteristics of cotton stalk with double supports (棉花秸秆双支撑切割性能试验), *Transactions of the Chinese Society of Agricultural Engineering*, Vol.31, Issue 8, pp.37-45, Beijing/P.R.C.;

[11] Wang B.A. et al., (2020), Test and analysis of cutting force of highland barley in mature stage (成熟期青稞茎秆切割力的测试与分析), *Journal of Gansu Agricultural University,* Vol. 55, Issue 2, pp.201-207, Lanzhou/ P.R.C.;

[12] Wang J.W., (2020), Cleaning performance and optimization of internal and external roller rotary buckwheat thresher, *International Agricultural Engineering Journal*, Vol. 29, Issue 2, pp.174-181, Bangkok/Thailand;

[13] Wang J.W., (2020), Design and threshing outputs study of internal and external rotary roller buckwheat thresher, *INMATEH Agricultural Engineering*, Vol. 60, Issue 1, pp.173-182, Bucharest / Romania; https://doi.org/10.35633/inmateh-60-20

[14] Wang W., (2010), Advances in chemical constituents of Tartary buckwheat and its bioactivities (苦荞麦化学成分及生物活性研究进展), *Rain Fed Crops*, Vol. 30, Issue 6, pp.419-423, Shenyang/ P.R.C.;

[15] Xiang D.B., (2013), Research progress on buckwheat cultivation (荞麦栽培研究进展), *Crops*, Vol. 2013, Issue 3, pp.1-6, Beijing/ P.R.C.;

[16] Yu Y. et al., (2012), Experimental study on tensile properties of corn straw (玉米秸秆拉伸特性的试验研究), *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 28, Issue 6, pp.70-76, P.R.C.;

[17] Zhang J., (2019), Design and finite element analysis of buckwheat threshing device, *Journal of Chinese Agricultural Mechanization*, Vol. 40, Issue 7, pp.7-12, Nanjing//P.R.C.;

[18] Zhang Y.Q., (2018), Effects of stem region, moisture content and blade oblique angle on mechanical cutting of millet stems, *INMATEH-Agricultural Engineering*, Vol. 55, Issue 2, pp.105-112, Romania;

[19] Zhang Y.Q., (2020), Simulation and Test of Cutting Mechanical Characteristics of Millet Stalk Based on ANSYS/LS-DYNA, *INMATEH-Agricultural Engineering*, Vol. 61, Issue 2, pp.143-150, Bucharest / Romania. https://doi.org/10.35633/inmateh-61-16

[20] Zhao C.H., (2009), Experiment on stalk mechanical properties of legume forage and grasses (豆禾牧草茎秆的力学特性试验), *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 25, Issue 9, pp.122-126, Beijing / P.R.C.;

[21] ***Ministry of Industry and Information Technology, (2009), *Agricultural machinery-cutter bars-part 3: knife sections, ledger plates and knife backs, GB/T 1209.3-2009*, China Machine Press, Beijing/P.R.C.;

[22] ***Ministry of Industry and Information Technology, (2009), *General requirements for physical and mechanical tests of wood, GB/T 1928-2009*, China Machine Press, Beijing / P.R.C.