

## Measuring the Static and Dynamic Cutting Force of Stems for Iranian Rice Varieties

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### ABSTRACT

In order to help in the engineering design of rice harvesting machines, there is a need to have exact information concerning the physical and mechanical properties of rice stems. The cutting force for rice stems, therefore, was measured by designing and fabricating a static and dynamic shear test apparatus. The effects of moisture levels and the cross-sectional area of stem as well as the variety, blade bevel angle, blade type and cutting speed on shearing strength have been evaluated. The results indicated that the cutting force increased with an increase in the cross-sectional area and decreased with an increase in moisture content. The static and dynamic shearing strength was different among the varieties. The maximum and minimum shearing strengths were related to the varieties Khazar and Hashemi, with an average of 1629 and 1429 kPa for static test and values of 187.4 and 144 kPa for the dynamic test, respectively. The shearing strength decreased from 234.4 kPa to 137.4 kPa with an increase in blade cutting speed from 0.6 to 1.5 m/s. Blade bevel angle and blade type had no significant effect on the shearing strength of rice stem.

**Keywords:** Dynamic cutting force, Rice stem, Static cutting force, Stem shearing strength.

### INTRODUCTION

Rice is the most important cereal crop in developing countries and is the staple food of more than 60 percent of the world's population. About 95 percent of the world's rice is produced in developing countries and 92 percent in Asia. This is in contrast to wheat, which is only 40 percent (Juliano, 1993).

Iran produced about 2.1 (Mt) per year from 550 (ha×1000) with an average of 3845.5 kg/ha in 2002 (FAO, 2002). Cutting the paddy for harvesting is a major labor-consuming operation in gathering this crop (Chancellor, 1965). In Iran, harvesting of paddy is commonly done using a hand sickle. Manual harvesting, besides incurring significant grain losses, creates a high

demand for labor at the time of harvest causing further delay in harvesting operation which has its own disadvantages (Ranganna *et al.*, 1995). Under these circumstances, timely harvesting of the crop is of extreme importance.

In the recent years, Iranian rice producers have been using imported rice harvesters or experimentally designed reapers that are not suitable for Iranian paddy varieties and field conditions. As a result, most farmers do not use these implements. Thus, there is a need for designing and constructing better harvesting implements. In order to aid in the engineering design of the harvesting machines, it may be essential to determine the cutting characteristics of rice stems and to investigate the blade parameters such as blade cutting speed, bevel angle and blade type.

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Considerable experimental work has been carried out by many researchers to determine the physical and mechanical properties and to evaluate the force and energy used in cutting forage crops (Chancellor, 1965; Halyk and Hurlbut, 1968; Mohsenin, 1986 and O'Dogherty *et al.*, 1995).

Halyk and Hurlbut (1968) studied the ultimate shear strength of alfalfa stem internodes using the direct shear method. They found that the shear strength of alfalfa internodes varied from 4.08 to 183.5 kg/cm<sup>2</sup>.

O'Dogherty *et al.* (1995) found that the mean ultimate shear strength was in the range of 5.39 to 6.98 MPa for five varieties of winter wheat and was equal to 8.53 MPa for spring wheat at moisture levels ranging from 10 to 15 % wet basis.

Summers *et al.* (2002) investigated the cutting properties of rice straw to aid development of novel header system for combines. Results showed that the cutting location (nodes / internodes) and number of stems were significant factors in the cutting force, while rice variety was not.

The objectives of this study were, (1) to develop an apparatus to simulate actual conditions and capable of measuring the dynamic cutting force using a reciprocating cutting mechanism; (2) to measure the static cutting force with a quasi-static shear test apparatus; and (3) to investigate the effects of moisture content and cross-sectional area of stem as well as variety, blade bevel angle, blade cutting speed and blade type on the shearing strength of rice stems.

## MATERIALS AND METHODS

Four Iranian rice varieties including Binam, Hashemi, Khazar, and Fajr, were cultivated in the standard fertilized fields of the Rice Research Institute located at Rasht in Iran. The stems were cut 5 cm from ground level and placed in sealed containers and carried to the laboratory. The original shape of the rice stems at the point of the cut was stamped without disturbing the

calculation of the cross-sectional area, which was assumed to be circular. The moisture content of the stems was determined by oven drying at 80°C for 24 hours.

### Static Shear Test

A static shear test apparatus, Figure 1, was designed to carry out the tests for determining the cutting force for rice stems. It consists of a cutter bar, blade section, frictionless pulley, loading tanks, regulator, stem holder and stand.

The rice stem was tightly and rigidly held in the proper position by a wooden grip. The cutter bar was connected to the water supply

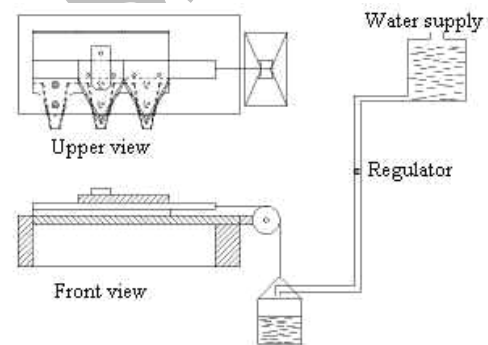


Figure 1. Static shear test apparatus.

through a pulley and string. The loading rate was adjusted by a regulator to maintain a constantly increasing quasi-static load of 10 cm<sup>3</sup>/s of water supplied from a constant level tank to ascertain the stem shear force. The rice stem, using a special wooden grip, was held between the two cutting edges and was cut into two pieces by the increasing load. The shearing strength was then calculated by dividing the force to the cross-sectional area and expressed in kPa.

### Dynamic Shear Test

A reciprocating shear test apparatus (Figure

2) was designed and fabricated to simulate actual conditions and to determine the dynamic force required to cut the rice stem. The motion from the electromotor was transmitted using a belt and pulley through a crank and pitman arm to the cutter bar. Different speeds of cutter bar were obtained by changing the frequency in a controller connected to the electromotor. A beam strain gage transducer was used to sense the bending stresses. The transducer was placed between the cutter bar and the pitman and the motion was transmitted to the beam from the cutter bar. A computer recorded the output from the transducer through a *PROTEK506* digital multimeter.

The rice stem, fixed in a special holder, was fed between the reciprocating cutter bar blades and stationary ledger plates of the



Figure 2. Dynamic shear test apparatus.

shear apparatus and, with the dynamic actuation of the blades, the stem was cut into to pieces. The readings obtained from the experiment were given in millivolts. These values were further converted into Newtons using the calibration constant of the strain gage-load cell.

## RESULTS AND DISCUSSION

Figure 3 illustrates the static cutting characteristics of all the four rice varieties. The variety Khazar is found to exhibit most resistance to cutting, followed by the variety Fajr. The variety Hashemi is observed to offer less resistance to shearing compared to the rest of the varieties. The mean cross-sectional area of the variety Khazar was

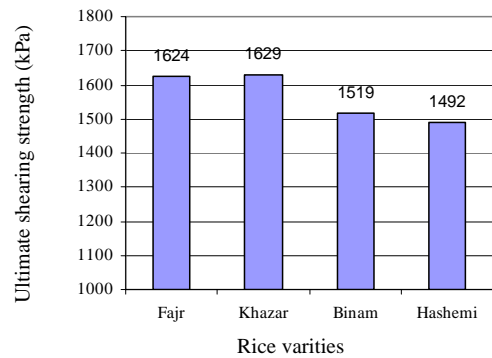


Figure 3. Static ultimate cutting force for four varieties.

about two times greater than cross-sectional area of the variety Hashemi (Figure 4).

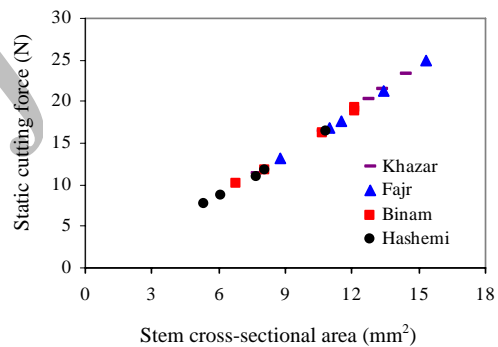


Figure 4. Effect of stem cross-sectional area on the static cutting force at moisture content of 78% (wet basis).

## Effects of Variables on the Dynamic Shearing Strength

Figure 5 shows the relationship between the dynamic shearing strength and the moisture content of the rice stem for the variety Khazar at 0.6 m/s blade speed. The dynamic shearing strength decreases as the stem moisture content increases. The moisture content of the rice stem decreases as they approach the harvesting stage causing drying of the stem.

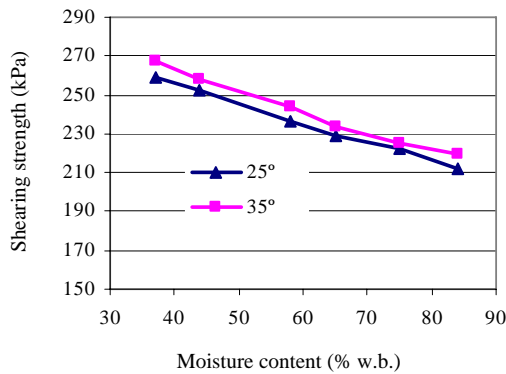


Figure 5. Effect of moisture content on dynamic shearing strength.

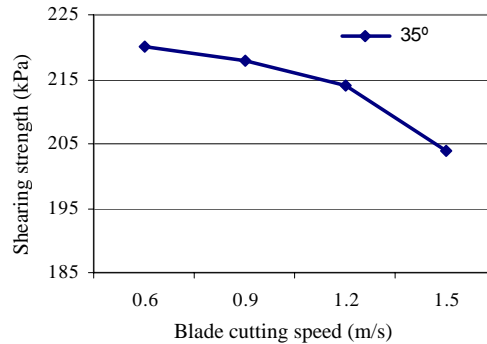


Figure 7. Relationship of cutting speed with stem shearing strength at different bevel angles.

Further more, the dynamic cutting force is observed to increase with an increase in the cross-sectional area in respect of all the varieties tested (Figure 6).

The effect of blade cutting speed on the shearing strength for the variety Khazar at 35° is shown in figure 7. An increase in the cutting speed decreased the shear strength and it reached the minimum at the blade speed of 1.5 m/s. The fact that the cutting force was lower at the higher speeds may reflect a change in the coefficient of kinematics friction above a certain speed.

Figure 8 presents the shearing strength for two types of blades (smoothed-edge and under serrated-edge) at three blade bevel angles in the variety Fajr at a 1.5 m/s cutting

speed. There is little difference between shearing strength of the two types of blade at different blade bevel angles. It may be due to the different ways of the penetration into the stem.

According to Figure 8, the shearing strength is at the minimum at a bevel angle of 25°. The variation in the frictional area between blade and stem, which was a little more with the 35° bevel angle, may have contributed to a higher shearing strength. A similar relationship was found for wheat by Kushwaha *et al.* (1983) and Chancellor (1965) for rice straw.

Figure 9 illustrates the dynamic shearing strength for four varieties at the same cross-sectional area of the stem. The varieties Khazar and Fajr, the two high-yielding

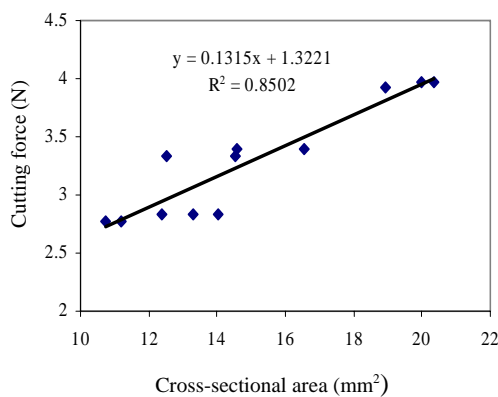


Figure 6. Relationship between cross-sectional area of the stem and cutting force.

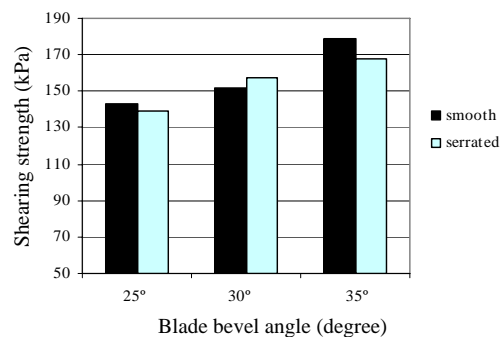
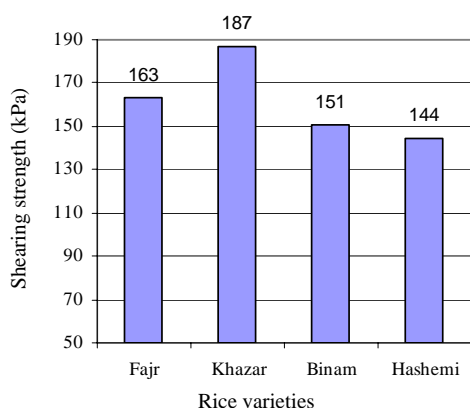


Figure 8. Effect of blade type and bevel angle on the stem shearing strength in the variety Fair.



**Figure 9.** Dynamic shearing strength for different rice varieties.

varieties, have mean cross-sectional areas up to 1.5 to 2 times higher than the varieties Binam and Hashemi as local varieties. The higher the cross-sectional area, the greater the contact area and this resulted in more friction between the blade and the stem.

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اندازه گیری نیروی برشی استاتیکی و دینامیکی ساقه ارقام برنج ایرانی

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#### چکیده

به منظور کمک به طراحی مهندسی ماشینهای برداشت برنج، داشتن اطلاعات صحیح در مورد خصوصیات فیزیکی و مکانیکی ساقه های برنج ضروری می باشد. در این راستا، نیروی برش ساقه برنج با طراحی و ساخت دستگاه اندازه گیری نیروی برش به دو روش استاتیکی و دینامیکی اندازه گیری شد. اثرات درصد رطوبت و سطح مقطع عرضی ساقه و همچنین نوع رقم، زاویه لبه تیغه، نوع تیغه و سرعت



برشی تیغه بر روی نیرو و مقاومت برشی ساقه مورد بررسی و ارزیابی قرار گرفت. نتایج نشان داد که با افزایش سطح مقطع عرضی ساقه، نیروی برش افزایش پیدا کرد و افزایش درصد رطوبت موجب کاهش مقاومت برشی گردید. مقاومت برش استاتیکی و دینامیکی ارقام مختلف برنج متفاوت بود. بیشترین و کمترین آن مربوط به ارقام خزر و هاشمی به ترتیب با میانگین ۱۶۲۹ و ۱۴۹۲ کیلوپاسکال برای حالت استاتیکی و ۱۸۷/۴ و ۱۴۴ کیلوپاسکال برای حالت دینامیکی بدست آمد. مقاومت برش دینامیکی ساقه با افزایش سرعت تیغه از ۰/۶ به ۱/۵ متر بر ثانیه از ۲۳۴/۴ به ۱۳۷/۴ کیلوپاسکال کاهش پیدا کرد در حالیکه زاویه لبه تیغه و نوع تیغه تاثیر قابل ملاحظه‌ای بر روی مقاومت برش ساقه نداشت.

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