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# Energy Consumption during Cutting Tree Branches of Fig (*Ficus carica*)

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## ABSTRACT

This study evaluated energy consumption for cutting tree branches of the fig in different moisture contents (MC) levels at 10, 16, 20 and 25 % w.b., branch diameter levels at 0.5, 1, 1.5 and 2 cm, two types of cutting knives, smooth & serrated and three bevel angle of the knives at 15, 20 and 25 degrees. The analysis of results showed that cutting energy-reduced as the MC reduced. The knife bevel angle of 20 degrees at 10 % MC showed the lowest cutting energy. The lowest cutting energy was about 3.68 Joule (J) at a branch diameter of a fig about 0.5 cm at a bevel angle of 20 degrees and MC of 10 % for cutting by a serrated knife.

**Keywords:** Cutting energy; Branches; Smooth knife; Serrated knife; Fig tree.

## INTRODUCTION

Information about the mechanical and physical properties of cutting tree branches of fig (*Ficus carica*) are too important in the machines design like electrical mowers and a pair of scissors. Most studies on the properties of mechanical for plants done during development using standards (force, energy and stress). Most of the studies are conducted for appropriate knife design and operating parameters of the pruning machine.

These properties rely on species, variety, the diameter of the stalk, maturity, MC and structure of cellular (Bright and Kleis,1964; Persson, 1987). Properties of physical are completely different at various diameters of the plant stalk. Hence, it's necessary to determine the mechanical and physical properties like cutting off energy and stress needs for appropriate knife style and operational parameters (Ince *et al.*, 2005). Power of cutting is only slightly affected by the speed of cutting between 1.72-5.2 m $s^{-1}$ (Persson, 1987).

Majumdar and Dutta (1982), studied the required energy of cutting for two rice varieties and one wheat variety in speeds of cutting were 2.53 and 4.5 m $s^{-1}$ and bevel angle of twenty and forty degrees, by employing a pendulum-type impact cutting device. Analysis of the data indicated that the influenced of crop type and bevel angles on the energy of cutting were significant. Increasing shear speed makes decreasing the force of cutting and consequently, the energy of cutting and also the bevel angle of twenty degrees required less energy than the forty-degree angle. Hoseinzadeh *et al.* (2009), declared that required energy for cutting wheat stem is affected by the MC of the wheat stem, variety kind, knife angle and cutting speed. With reducing MC, knife angle and increasing cutting speed, the energy of cutting will reduce. Yiljep and Mohammed (2005), in terms of product kind, mechanical and physical properties of the stem in crops, the estimation of harvesting energy in the agricultural product will be completely different. Prasad and Gupta (1975), declared that the cross-sectional space and MC of the crop had an essential impact on the energy of cutting and maximum force of cutting. Similar outcomes were also stated by (Choi and Erbach ,1986).

Persson (1987), reviewed many studies on the speed of cutting and accomplished that power of cutting is just slightly influenced with cutting speed, though a rise in the speed of cutting can typically increase the power losses caused by material acceleration. Chen *et al.* (2004), stated that the average worth of the extreme force and also the maximum energy of cutting for hemp were 243 N and 2.1 J, respectively. The average worth of the energy of cutting needed to chop a hemp stalk was 2.1 J that was at the lower range of that for maize stalk (2–5 J) (Prasad and Gupta, 1975).

There are no studies on mechanical properties of tree branches of fig and lack of information about the energy of cutting off branches. This study aims to survey energy of cutting required for cutting tree branches of fig for a different-diameters, moisture contents and define of the relationship between the properties of moisture content (MC), the diameter of branches, knife type and bevel angle.

## MATERIALS AND METHODS

All experiments accomplished at a private workshop in Abu Kebir, Al Sharkia Governorate, Egypt during the season of 2019 to measure the energy of cutting for tree branches of fig (fig tree pruning residues) by using a locally manufactured pendulum impact tester.

### Materials.

#### Apparatus

A manufactured pendulum impact tester was consisting of a base, mainframe, pendulum arm, horizontal shaft, wooden angle indicator, branch holder, knife holder, smooth knife and serrated knife Figs. (1& 2).

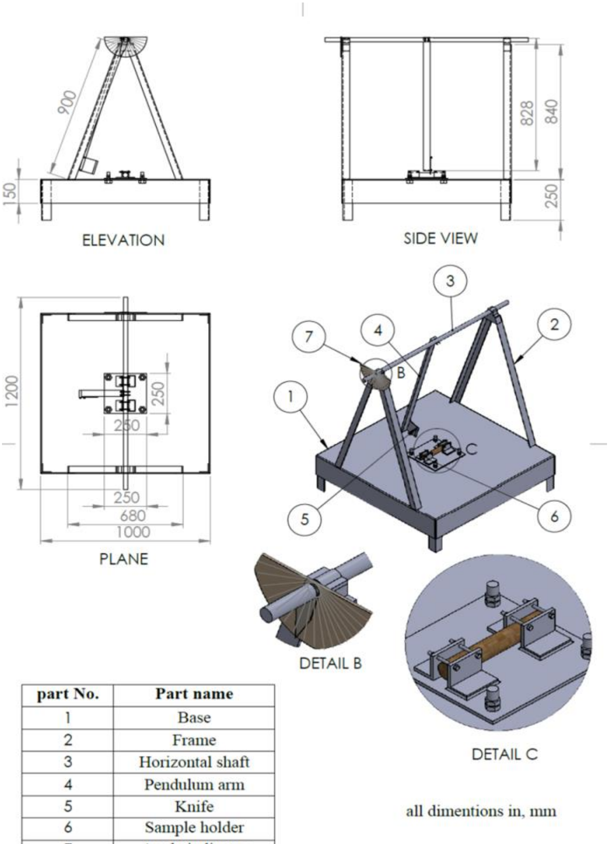
A base was manufactured using mild steel sheet of 6 mm thickness with dimensions of 1000 × 1000 mm to support the pendulum impact tester. The surface of the base was completely horizontal and was 250 mm above the ground level using stand made from 40 × 40 × 4 mm angle iron. A mainframe was manufactured using 40 × 40 × 4 mm angle iron to provide structural stability to pendulum impact tester components. It was designed in a triangular shape on both sides on top of the base with dimensions of 840 mm in height, incline length of 900 mm, on horizontal base length of 680 mm.

A pendulum arm was hanged at its top end, a knife was fixed at the lower end and was made to swing freely in the vertical plane by a horizontal shaft passing through two bearings at either end fixing on top of the mainframe. Pendulum arm was fabricated of a rectangular mild steel bar of 800 × 50 × 40 mm dimensions. The mass of the pendulum arm plus knife were 13.04 kg and the dimension from the pendulum arm gravity centre to the horizontal shaft was 600 mm.

Wooden angle indicator in pendulum impact tester measure the deflection angle of pendulum arm, consists of the pointer and graduated angular scale. Wooden angle indicator scale was marked on a wooden sheet of 300 mm diameter and mounted on the horizontal shaft. Pointers of 100 mm length were fabricated and mounted on a horizontal shaft. Wooden angle indicator measures the angle of the pendulum arm before and after cutting off the branch.

A cast iron bench vice was manufactured to use as branch holder. The bench vice was bolted to holder base. The branch holder frame was 250 mm length, 250 mm width and was fitted to the base.

**Fig. 1. Apparatus.**




| part No. | Part name |
|---|---|
| 1 | Base |
| 2 | Frame |
| 3 | Horizontal shaft |
| 4 | Pendulum arm |
| 5 | Knife |
| 6 | Sample holder |
| 7 | Angle indicator |

**Fig. 2. Apparatus views and parts.**

**Methods:**

**Experimental conditions:**

A pendulum impact tester was studied under the following parameters to estimate the energy of cutting for tree branches of fig as follows:

- Four moisture content levels:10, 16, 20 and 25 % w.b.,
- Four branch diameter: 0.5, 1, 1.5 and 2 cm,
- Three bevel angle of the knives:15, 20 and 25 degrees,
- Two types of cutting knives: smooth and serrated.

**Instruments**

A manufactured pendulum impact tester unit was evaluated using the following:

**Digital Vernier calliper:**

It was used for measuring the diameter of fig branches. The range of reading is 0.01 to 15 cm with 0.05 mm accuracy.

**Moisture content:**

The moisture content of tree branches of fig was measured according to ASAE Standard S358.2 (*ASAE Standards*, 2000). The samples were weighed then the sample kept in the electric oven for 24 hours at 103$^{o}$ C and then reweighed.

**Measurements:**

**Principle of operation**

The principle of conservation of energy, a pendulum impact tester works on the equilibrium position of the pendulum arm the potential energy equal zero but when the swinging arm released from the initial angle of $\theta^{\circ}_1$ it is expected to swing to the other side of equilibrium position through an angle $\theta^{\circ}_o$ . However, $\theta^{\circ}_o$ is normally less than $\theta^{\circ}_1$ due to frictional losses in the component parts and air resistance, so the energy changed from maximum potential energy and zero kinetic energy when the pendulum arm is at its extreme position (upswing) to zero potential energy and maximum kinetic energy at the equilibrium line. The sample placed at the point of maximum kinetic energy and zero potential energy of the pendulum arm and fixed by the branch holder. When the arm is released, it gains velocity until it cuts the sample placed in the path of the knife.

The apparatus is designed as the branch is cut via passing knife through finger lips, as in Fig.3. The pendulous arm is released at beginning of initial angle $\theta^{\circ}_1$ and it continues its path till it reaches the utmost speed, passes between lips of the finger and hence, after cutting the branch, it comes up in the other side at an angle $\theta^{\circ}_c$. The tests were repeated many times for any level of moisture, diameter and they were analysed.

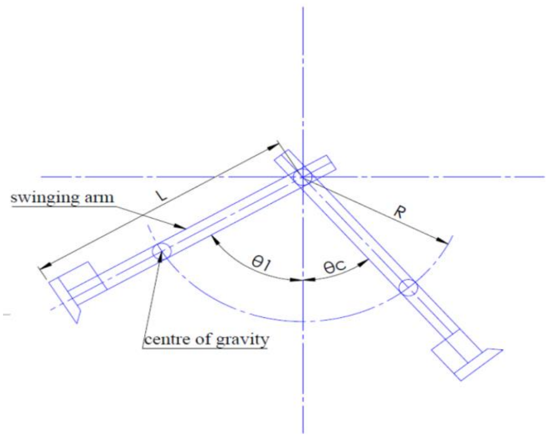



**Fig. 3. Displacement of the impact swinging arm during cutting.**

**Cutting energy**

The energy required for cutting fig pruning residues was determined by using the following equation as stated by Prasad and Gupta (1975) & Alizadeh *et al.* (2011).

$$E_c = W_t\, R\,(\cos\theta_c - \cos\theta_{\circ})$$

**Where:**

**$E_C$ = Cutting energy, J. $\theta_c$ = Maximum angle of pendulum arm from vertical after cutting, Degree. $\theta_o$ = Maximum angle of pendulum arm from vertical in an absence of sample, Degree. $W_t$ = The pendulum arm plus knife weight, N.**

**R = Dimension from the pendulum arm gravity centre to the horizontal shaft, m.**

## RESULTS AND DISCUSSION

**Apparatus calibration**

Using the least-squares method, the regression equation to define maximum upswing angle without cutting (final angle) ($\theta^{\circ}_o$) from a known initial angle ($\theta^{\circ}_1$) was acquired, in Fig. 4.

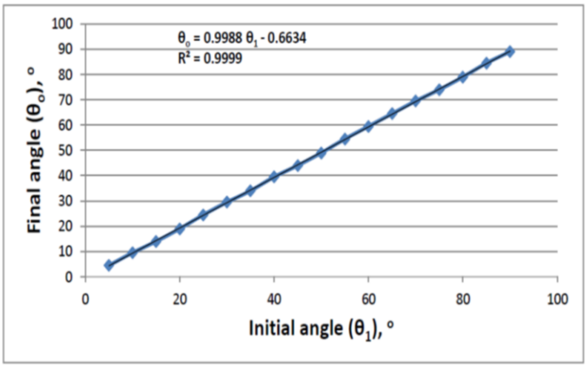



**Fig. 4. The relation between the final angle and the initial angle of a pendulum.**

**The obtained results will be discussed under the following heads:**

**Effect of the diameter of fig branches, moisture contents, knife type and bevel angle on cutting energy.**

The diameter of tree branches of fig, moisture contents, knife type and bevel angle are essential parameters governing the cutting energy. The obtained results in Fig. (5) declared that, at bevel angle of 20˚ and at the MC of 10 %, the lowest cutting energy for all diameters of fig branches for smooth knife and serrated knife.

At a bevel angle of 20˚ and at MC 10 %, by increasing diameter of the branch from 0.5 to 2 cm, cutting energy increased from 3.68 to 23.42 and from 3.68 to 20.85 J for smooth knife and serrated knife, respectively.

For all moisture contents, bevel angles, and the diameter of fig branches, the results declared that cutting energy for the serrated knife was lower than a smooth knife. This may attribute to a lot of cellulose and fibres in branches that need a serrated knife to cut as saw cutting in wood to have less cutting energy than the smooth knife.

Cutting energy-reduced with reducing MC and reducing branch diameter. These findings are just like the analysis results of Alizadeh *et al.* (2011). They declared a reduce in the energy of cutting rice stalk by reducing the diameter of the stalk.

The lowest energy of cutting was about 3.68 J at branch diameter of a fig about 0.5 cm, at a bevel angle of 20 degrees and MC of 10 % for cutting by a serrated knife.

The energy of cutting increased by increases in the MC. This effect of MC was also declared by Annoussamy *et al.* (2000) for the straw of wheat and by Chen *et al.* (2004) for the stalk of hemp.

The reason for this distinction could also is expressed because of the viscous damping impact of MC as informed by Persson (1987). The energy of cutting was greater in the higher branch diameter because of the aggregation of more mature fibres in the thickness of the branch.

The influence of branch diameter on the maximum force of cutting and energy of cutting is consistent with Prasad and Gupta (1975) who according that each the energy of cutting and utmost force of cutting are directly proportional to the cross-sectional space of maize stalk.

**Effect of bevel angle and diameter of fig branches on cutting energy**

Bevel angle and diameter are principal parameters governing the cutting energy. The results declared that at bevel angle of 20˚ the lowest cutting energy for all diameters and all MC of fig branches for smooth knife and serrated knife were obtained Figs. (5 and 6).

At MC of 10 % by increasing, the bevel angle from 15 to 20˚, cutting energy decreased from 6.36 to 3.68, from 14.32 to 10.35, from 23.42 to 16.95, and from 33.37 to 23.42 J for the smooth knife at the diameter of fig branches 0.5, 1, 1.5 and 2 cm, respectively.

At MC of 10 % by increasing, the bevel angle from 20 to 25˚, the cutting energy increased from 3.68 to 5.02, from 10.35 to 13.00, from 16.95 to 20.85, and from 23.42 to 29.70 J for the smooth knife at the diameter of fig branches 0.5, 1, 1.5 and 2 cm, respectively.

At MC of 10 % by increasing, the bevel angle from 15 to 20˚, cutting energy decreased from 5.02 to 3.68, from 11.68 to 9.02, from 19.55 to 15.64, and from 28.46 to 20.85 J for the serrated knife at the diameter of fig branches 0.5, 1, 1.5 and 2 cm, respectively.

At MC of 10 % by increasing, the bevel angle from 20 to 25˚, the cutting energy increased from 3.68 to 5.02, from 9.02 to 11.68, from 15.64 to 18.25, and from 20.85 to 25.96 J for the serrated knife at the diameter of fig branches 0.5, 1, 1.5 and 2 cm, respectively.

The needed energy is a result of interaction among shear, frictional, and compression forces. At less bevel angle, the slippery surface of the bevel edge is augmented so the frictional forces are additional. The energy which lost in friction is less when the slope of the knife bevel edge come near the static frictional angle. The static friction angle of the fig branches and knife material is expected to differ from 18 to 24$^{o}$ and hence the needed energy is minimum at about 20$^{o}$. At more bevel angle the knife needs more force to penetrate the hard outer layer of the sample and thereby increasing needed energy.

**Effect of moisture contents and the diameter of fig branches on cutting energy**

MC and diameter are principal parameters governing the cutting energy. The obtained results in Figs (5 and 7) declared that at the MC of 10 %, the lowest cutting energy for all diameters of fig branches and all bevel angle for smooth knife and serrated knife were obtained.

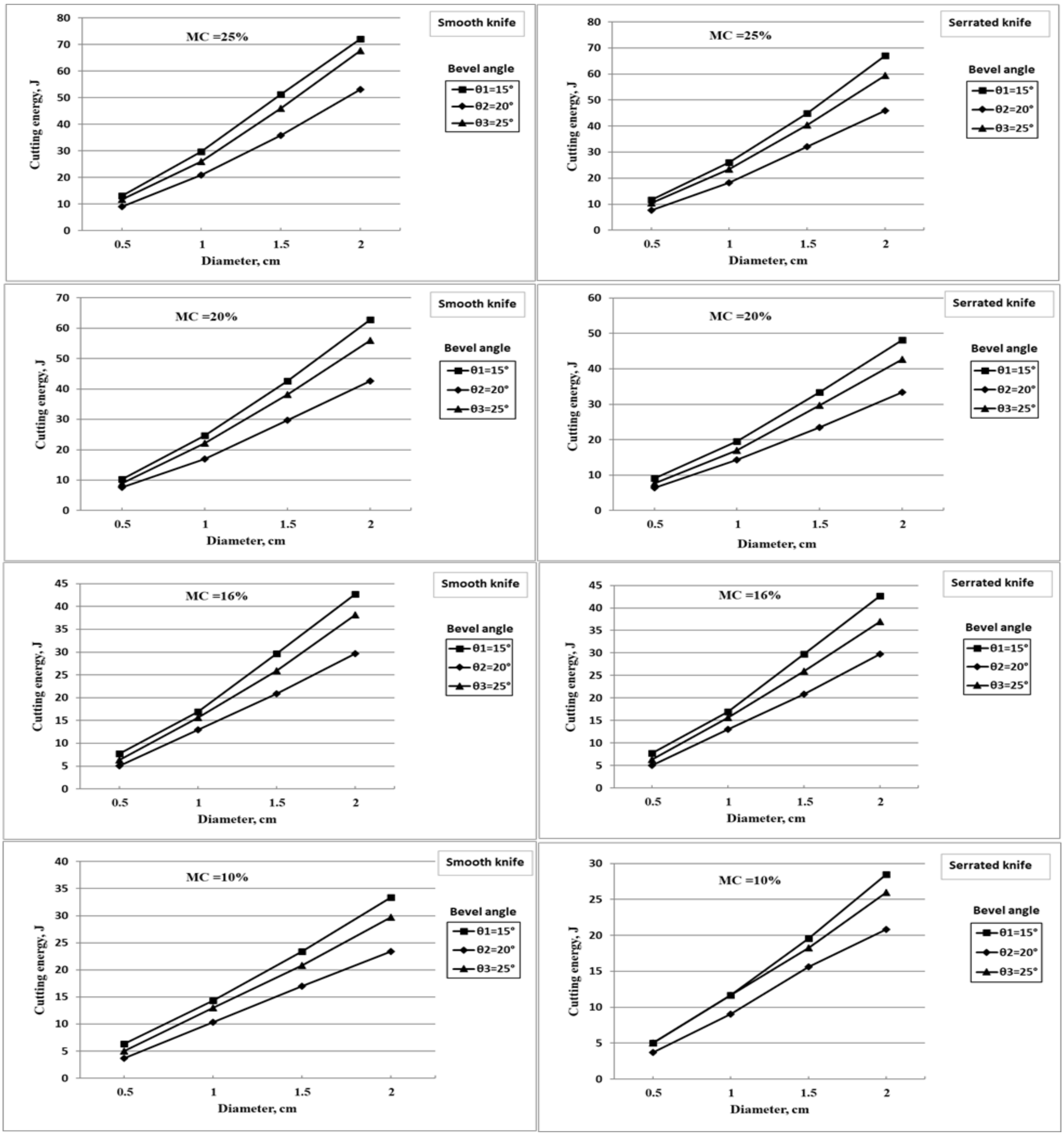



**Fig. 5. Effect of the diameter of fig branches, moisture contents, knife type and bevel angle on the energy of cutting.**

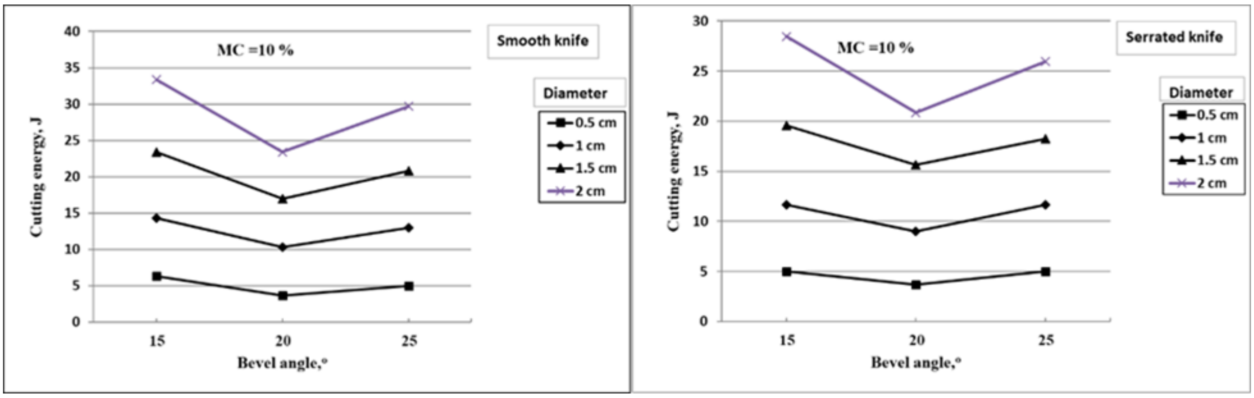



**Fig. 6. Effect of bevel angle and diameter of fig branches on cutting energy.**

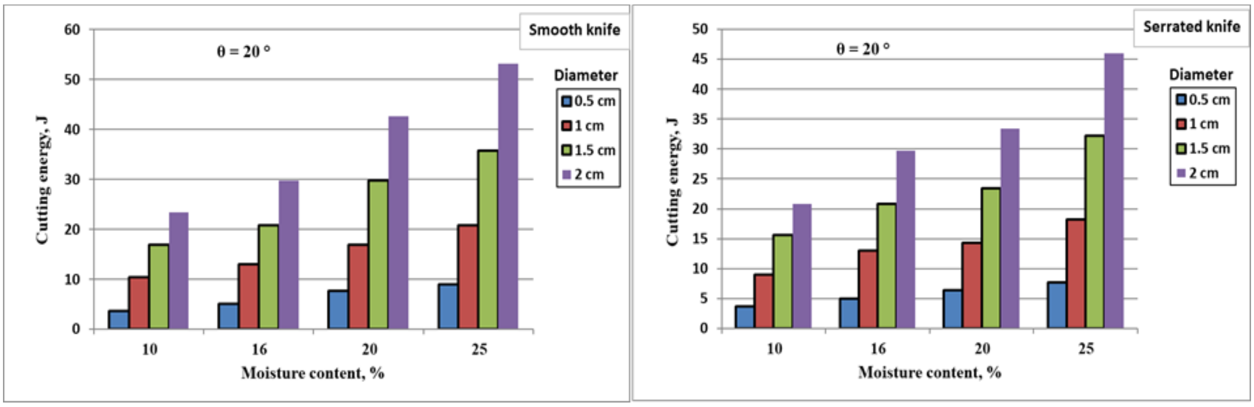



**Fig. 7. Effect of moisture contents and diameter of fig branches on cutting energy.**

At a bevel angle of 20˚ and at a diameter of fig branches 0.5 cm the lowest cutting energy was about 3.68, 5.02, 7.69 and 9.02 J for the smooth knife at the MC of 10, 16, 20 and 25 %, respectively.

At a bevel angle of 20˚ and at a diameter of fig branches 0.5 cm the lowest cutting energy was about 3.68, 5.02, 6.36 and 7.69 J for the serrated knife at the MC of 10, 16, 20 and 25 %, respectively.

As mentioned above, by increasing MC cutting energy is increased. When the MC of the branch is low, the branch is dry and breaking the branch by the knife impact. This action makes cutting easy, while the branch that has high MC is resistant the breaking. This is because the high MC cause coalescence the tissue of the branch and hence needed the energy of cutting will be increased. These feedbacks are comparable to (Chen *et al.*, 2007; Hoseinzadeh *et al.*, 2009).

**Effect of knife type and diameter of fig branches on cutting energy**

Knife type and diameter are principal parameters governing the cutting energy. The obtained results in Figs (5 and 8) declared that at the serrated knife, the lowest cutting energy for all diameters and MC of fig branches were obtained.

At a bevel angle of 20˚ and at the MC of 10 % the cutting energy was about 3.68, 10.35, 16.95 and 23.42 J for the smooth knife at a diameter of fig branches 0.5, 1, 1.5 and 2 cm, respectively.

At a bevel angle of 20˚ and at the MC of 10 % the cutting energy was about 3.68, 9.02, 15.64 and 20.85 J for the serrated knife at a diameter of fig branches 0.5, 1, 1.5 and 2 cm, respectively.

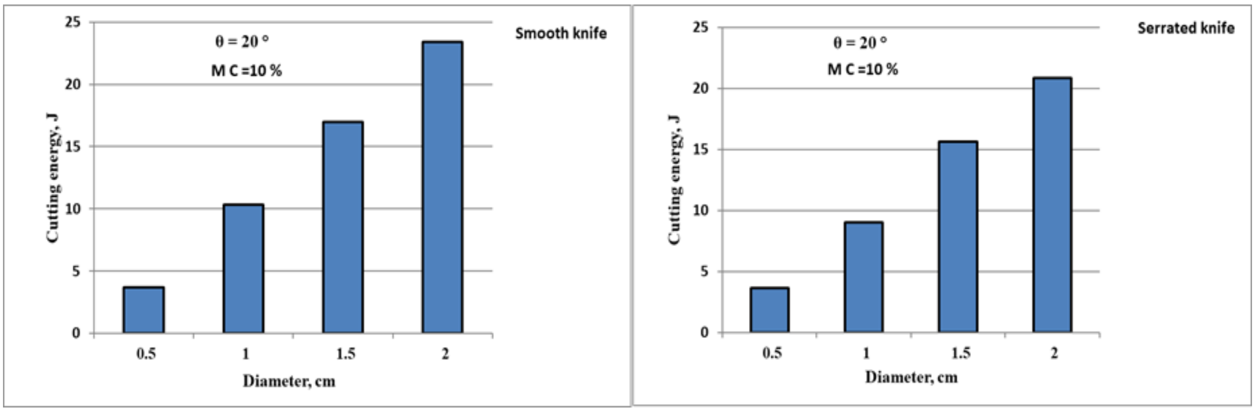



**Fig. 8. Effect of knife type and diameter of fig branches on cutting energy.**

## CONCLUSION

Experimental results revealed that cutting energy decreased with decreasing MC and decreasing branch diameter. At a bevel angle 20˚, the lowest cutting energy for all diameters and all MC of fig branches for the smooth knife and the serrated knife were obtained. For all MC, bevel angles and the diameter of fig branches, the results declared that cutting energy for the serrated knife was lower than the smooth knife. This may attribute to a lot of cellulose and fibres in branches that need a serrated knife to cut as saw cutting in wood to have less cutting energy than the smooth knife.

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## الطاقة المستهلكة أثناء قطع فروع شجرة التين

**أحمد محمد الشال و علاء عونى**
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تناول البحث حساب الطاقة اللازمة لتقليم أشجار الفاكهة والاستفاده من مخلفاتها بدون أى اضرار للبيئة عن طريق تقطيعها الى قطع صغيرة ثم الاستفادة منها بعد ذلك . تم تصنيع جهاز لقياس طاقة القطع لبعض فروع أشجار التين لأربعة مستويات من محتوى الرطوبة (١٠ و ١٦ و ٢٠ و ٢٥ ٪ ) ، أربع متوسطات لأقطار فروع اشجار التين (٠.٥ و ١ و ١.٥ و ٢ سم ) ، نوعان من سكاكين القطع ، الحافة الملساء والمسننة وثلاثة زوايا شطف للسكاكين (١٥ و ٢٠ و ٢٥ درجة). أظهرت نتائج تحليل المعطيات أن طاقة القطع لفروع شجر التين انخفض مع انخفاض محتوى الرطوبة و انخفضت طاقة القطع في الأفرع مع انخفاض فى قطر الفرع و كان طاقة القطع أكبر باستخدام سكين حافة ملساء وذلك بسبب وجود السليوز واحتياجه الى سكين مسنن لتقليل الطاقة . كان أقل طاقة قطع فيها حوالي ٣.٦٨ جول عند قطر فرع التين حوالي ٠.٥ سم في زاوية شطف لسكينة مسننة ٢٠ درجة ، ومحتوى رطوبة ١٠ % . أظهرت زاوية شطف السكينة ٢٠ درجة أقل طاقة قطع وطاقة القطع تزيد مع زيادة الرطوبة وتقل مع نقصها اى علاقة طردية. وجد أن السكينة المسننة تعطى أقل استهلاك فى طاقة القطع عن السكينة الملساء .