

## Performance of a Maize Chopping Machine with an Attached Sharpener Unit El Shal, A. M.<sup>1</sup> and M. I. El Didamony<sup>2</sup>

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### ABSTRACT

The sharpener unit attached to the chopping machine used for maize crops has a substantial effect on knife sharpness and chopping speed, which in turn affects machine productivity, chopping length, chopping efficiency and specific energy requirements. The machine was tested at four chopping speeds, which were 1650, 1900, 2150 and 2400 rpm (47.52, 54.72, 61.92 and 69.12 m s<sup>-1</sup>), and at three crop moisture content levels, which were 60, 70 and 77 %. The results showed that the performance of a sharpener unit attached to a maize chopping machine is better than a maize chopping machine without an attached sharpener unit in terms of productivity, chopping length, chopping efficiency, and energy efficiency. At a constant clearance of 10 mm, an optimum moisture content of 70 %, and an optimum knife speed of 2150 rpm (61.92 m s<sup>-1</sup>), the results showed that the maize chopping machine with a sharpener unit yielded a productivity of 5.74 t h<sup>-1</sup>, a chopping length of 15 mm, a chopping efficiency of 79.37 %, a specific energy requirement of 3.42 kW h t<sup>-1</sup> and operating cost of 35.82 LE t<sup>-1</sup>.

**Keywords:** Sharpener unit; Maize; chopping; machine; Chopping length; Chopping speed; Chopping efficiency.

### INTRODUCTION

Maize is a very important crop for feeding livestock in the summer season as green feed because its food quality as a forage crop is very high. Maize is planted so that it can be chopped to small pieces to feed livestock and is harvested before the grains reach full maturity. This method results in a high silage yield and starch content. High yields at harvest were observed to have a positive effect on ensilage because it results in more rapid and extensive lactic acid fermentation. In addition, more compression results in higher silage densities and a lower risk for atmospheric degradation in silage (Muck *et al.*, 2003). The chopping energy and force requirements increased with increasing stem diameter (Taieb and Imbabi, 1995). Comparisons of chopper operator surveys with studies of chopping knives indicated that the intervals between knife sharpening should be longer and the intensity of sharpening should be reduced (Wild *et al.*, 2009).

Researchers have developed a chopping machine that was used to cut residues of rice, cotton, and maize. They reported that the maximum required power 11.77 kW and consumed specific energy 12.99 kW h t<sup>-1</sup> were found at rotor speeds of 2200 and 1600 rpm, respectively. Increasing the rotor speed from 1600 to 2000 rpm decreased consumed specific energy by 17.11 %, while increasing the rotor speed from 2000 to 2200 rpm increased consumed specific energy by 12.9 % (Younis *et al.*, 2002).

The power consumption for cutting different residues increased with increasing cutting and feeding speeds. The minimum values of power consumption were 13.86, 15.24, and 15.66 kW for cutting corn stalks, rice straw, and cotton stalks, respectively, at a cutting speed of 24.08 m s<sup>-1</sup>. The maximum values for power consumption were 22.97, 23.92 and 25.82 kW for cutting corn stalks, rice straw, and cotton stalks, respectively, at a cutting speed of 43.35 m s<sup>-1</sup> (Lotfy, 2003).

The cutting efficiency increased with increasing cutting drum speed for cotton stalks, which is due to an increase in the number of cuts per time unit and an increase in suitable cutting length. Increasing the cutting drum speed from 1200 to 2000 rpm increased the cutting efficiency from 85.72, 83.5 and 81.85 % to 97.77, 95.43 and 93.87 % at 8, 10 and 12 % moisture content, respectively (El Sisi, 2012).

When harvesting grass and corn silage, significant differences in the wear characteristics of cutting knives exist, which would require a change in grinding methods from the current practices used by most chopper operators (Wild *et al.*, 2011).

The main objective of this study is to analyse the important effect of an attached sharpener unit with chopping machine on knife sharpness as well as how knife speed affects the machine's productivity, chopping length, chopping efficiency and specific energy requirement.

### MATERIALS AND METHODS

#### Materials

The experiments were conducted at EL Ibrahimia district, AL Sharkia Governorate, Egypt during the summer season of 2017 and for the maize variety (T.C-Giza 324). A maize chopping machine with and without an attached sharpener unit were constructed at special workshop in EL Menofia Governorate, Egypt. Physical and mechanical properties of the maize plant are provided in Table 1. A universal 650M tractor with diesel engine operating at a power of 48.5 kW.

The maize chopping machine without an attached sharpener unit consists of six main parts: the mainframe, cutter disc, machine case, gearbox, feeding drum and power transmission system. The maize chopping machine with an attached sharpener unit was used to produce maize silage. As shown in Fig. 1, it consists of seven main parts: the mainframe, cutter disc, machine case, gearbox, feeding drum, sharpener unit and power transmission system.

**Table 1. Physical and mechanical properties of maize plants.**

Plant characteristic	Average value	Plant characteristic	Average value
Plant height , mm	2650	Ear length , mm	276
Stalk diameter , mm	36	Ear diameter , mm	55
Mass of plant without ears, g	1210	Mass of one ear , g	360
Mass of one maize plant (stalk + ears) , g	2290	Number of ears per plant	3

The mainframe of the chopping machine was constructed from iron bars in L-shape section and with dimensions of 40×40×3 mm. The dimensions of the main base were 1130 mm in length, 450 mm in width and 600 mm in height. The gearbox is set on a stand constructed from iron steel formed in L-shape section and with dimensions of 80×120×630 mm and a thickness of 5 mm. The cutter disc is a rotating plate with a diameter of 550 mm and with sharpened knives attached that are made of iron steel. The plate is attached securely to a thermally hardened shaft that is an iron bar with a diameter of 40 mm

and a length of 440 mm. The shaft rotates around two high-speed bearings that are fixed on the machine stand, and one end of the shaft is coupled to the drive pulley. The chopping knives are fixed at regular angles on the disc circumference with bolts. Every knife was made from hard steel 52 carbon, with a length of 200 mm, a width of 60 mm and a thickness of 10 mm. The case of the machine is constructed from sheet iron with a thickness of 3 mm to protect labourers that use the machine. The gearbox is used to reduce PTO speed and has a reduction ratio of 4:1.

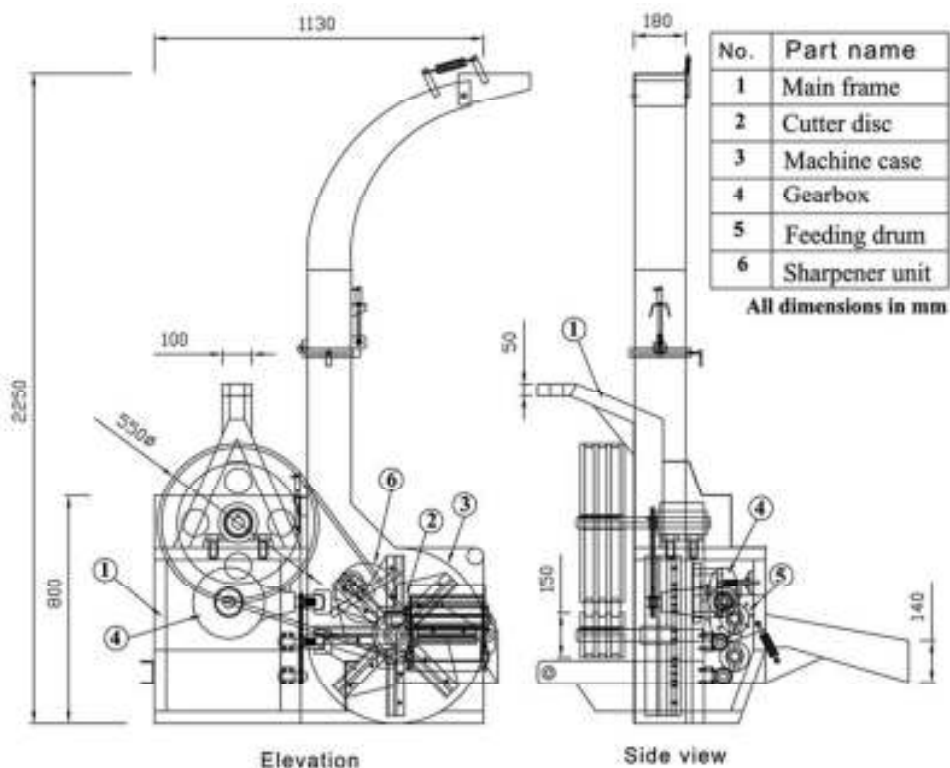


Fig. 1. Maize chopping machine with an attached sharpener unit.

The feeding drum unit consists of two cylinders. The upper cylinder is made from hard steel 52 carbon and has a diameter of 250 mm. Eight plates of sheet iron with a thickness of 10 mm and a length of 200 mm are fixed to the upper cylinder and revolve with it. The bottom cylinder has a diameter of 100 mm and a length of 200 mm. The feeding unit gate has dimensions of 210×350 mm and controls the feeding rate of maize plants to the cutter disc.

The sharpener unit consists of a stone disc with a diameter of 210 mm and a thickness of 20 mm and is fixed on the machine case with a special frame. The distance between the stone disc and chopping knives can be controlled by a controller bolt with a hand wheel as shown in Fig. 2.

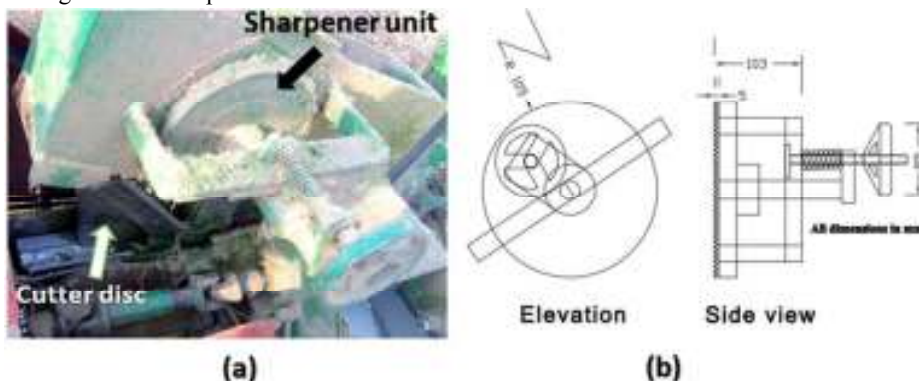
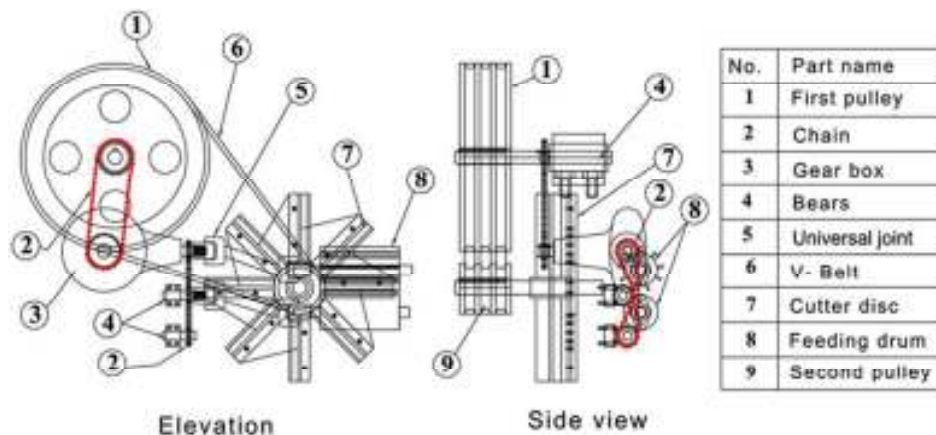


Fig. 2. (a) Photo of sharpener unit; (b) Engineering drawing of sharpener unit.

Power is transmitted from the tractor PTO shaft operating at a speed of 540 rpm to the power shaft of the machine through a universal joint and then transmitted from the machine power shaft to the gearbox shaft through a chain. The first pulley is fixed on the main power shaft of the machine and has a diameter of 550 mm. The second pulley is fixed on the shaft of the cutter disc, has a diameter

of 150 mm, and uses three V-belts. The gearbox has two shafts with the first shaft gaining its rotating speed from the main power shaft of the machine through a chain. The second shaft in the gearbox transmits the rotating speed to the feeding drums by two universal joints and reduces the speed in a 4:1 ratio, as shown in Fig. 3.



**Fig. 3. Power transmission system.**

**Methods**

The performance of the chopping machine with sharpener unit and chopping machine without a sharpener unit attached were studied under the following parameters:

- Four chopping speeds: 1650, 1900, 2150 and 2400 rpm (47.52, 54.72, 61.92 and 69.12 m s<sup>-1</sup>), and
- Three moisture contents: 60, 70 and 77 %.

**Instruments**

A balance scale (OHAUS U.S.A) was used to find the mass of the plant samples. The maximum mass of the balance was 2610 g. Its accuracy was 0.1 g.

A laser tachometer was used for measuring the rotating speed of the pulleys and shafts. This tachometer is suitable to measure rotating speeds from 0.05 to 19999 rpm with an accuracy of ± 0.05 %.

For measuring the fuel consumption of the tractor, the fuel tank was filled to the top before and after the chopping operation. The amount of diesel fuel used to refill the tank was measured after the test and was defined as the fuel consumption for the chopping operation in litres per hour.

Plant moisture contents were determined by the standard oven method. The plant moisture content percentage was calculated in relation to the dry sample according to the following equation:

$$MC = ((M_w - M_d) / (M_d)) \times 100 \quad (1)$$

Where *MC* is the maize plant moisture content, %; *M<sub>w</sub>* is the sample's mass before drying, g; and *M<sub>d</sub>* is the mass of the dried sample, g.

A digital Vernier calliper with an accuracy of 0.01 mm was used to measure the diameter of maize stems and ear diameters.

**Measurements**

Machine productivity is calculated by dividing the mass of the cut maize (corn) plant by the run-time of the chopping machine.

The suitable chopping length (*L<sub>c</sub>*) should be in the range of 0 < *L<sub>c</sub>* < 50 mm (Habib *et al.*, 2002), and the chopping efficiency is calculated as:

$$\eta_c = (S_a/S_b) \times 100 \quad (2)$$

Where  $\eta_c$  is the chopping efficiency, %; *S<sub>b</sub>* is the mass of the chopped material before sieving, g; and *S<sub>a</sub>* is the mass of the chopped material after sieving by chopping length.

A sample was taken from the chopped material and weighed to find the mass of *S<sub>b</sub>*, sieved using a standard sieve (50-mm mesh), and weighed again to determine the mass of *S<sub>a</sub>*.

Volumetric fuel consumption per unit time was determined by measuring the volume of the consumed fuel during the experiment time. It was calculated as the following:

$$VFC = V/t \quad (3)$$

Where *VFC* is the volumetric fuel consumption rate, l h<sup>-1</sup>; *V* is the volume of consumed fuel, l; and *t* is the duration of the experiment, h.

The following formula was used to estimate Power (*P*) as provided by Hunt (1983):

$$P = (FC/c) \times (\eta_{th}/100) \times HV \quad (4)$$

Where *P* is required power, kW; *FC* is fuel consumption, kg h<sup>-1</sup>;  $\eta_{th}$  is the thermal efficiency, %; *HV* is the fuel heating value, kJ kg<sup>-1</sup>; and *c* is a constant, 3600.

The following formula was used to calculate the specific energy requirements for the chopping machines:

$$\text{Specific energy requirement (kW h t}^{-1}\text{)} = (\text{Power, kW}) / (\text{Machine productivity, t h}^{-1}) \quad (5)$$

The chopping cost determined using the following equation:

$$C = p/h(1/a + i/2 + t + r) + (1.2 \text{ W.F. S}) + m/144, \text{ (EL Awady, 1978)} \quad (6)$$

Where *C* is hourly cost, LE h<sup>-1</sup>; *P* is Price of the machine, LE; *h* is yearly working hours, h y<sup>-1</sup>; *a* is life expectancy of the machine, y; *i* is interest rate / year, %; *t* is taxes over heads ratio, %; *r* is repairs and maintenance ratio, %; *W* consumed Power, kW; *F* is fuel price, LE l<sup>-1</sup>; *S* is specific fuel consumption, l kW<sup>-1</sup> h<sup>-1</sup>; *m* is operator monthly salary, LE; 1.2 is factor a counting for ratio of rated power and lubrications; 144 is the monthly average working hours; h.

$$\text{Operating cost (LE t}^{-1}\text{)} = \text{Machine cost, LE h}^{-1} / \text{Machine productivity, t h}^{-1} \quad (7)$$

## RESULTS AND DISCUSSION

### Productivity

Chopping speed is the principal parameter governing the productivity of the chopping machine. Results for the chopping machine without an attached sharpener unit indicated that, by increasing the chopping speed from 1650 to 2400 rpm, productivity increased from 2.65 to 4.21, from 3.64 to 5.38, and from 4.32 to 6.48 t h<sup>-1</sup> at moisture contents of 60, 70 and 77 %, respectively. Results for the chopping machine with an attached sharpener unit show that by increasing the chopping speed from 1650 to 2400 rpm, productivity increased from 3.78 to 5.66, from 4.11 to 6.41, and from 4.51 to 7.21 t h<sup>-1</sup> at moisture contents of 60, 70 and 77 %, respectively, as shown in Fig. 4.

These results agree with Okasha (2016), machine productivity was 0.63, 0.68 and 0.72 t h<sup>-1</sup> with increasing cutting speeds of 1200, 1600 and 2000 rpm, respectively, at 8 % moisture content. These results agree with Ibrahim (2006), machine productivity for cutting maize stalks increased to 0.82, 1.08, 1.13, 1.35 and 1.8 t h<sup>-1</sup> with increasing cutting speeds of 1200, 1400, 1600, 1800 and 2000 rpm at 10.10 % moisture content.

The chopping speed markedly influences the productivity of the chopping machine without a sharpener unit as well feed rate and the productivity of the chopping machine with a sharpener unit. In addition, the productivity of the chopping machine with a sharpener unit is higher than the productivity of the chopping machine without a sharpener because the sharpener unit facilitates the chopping operation.

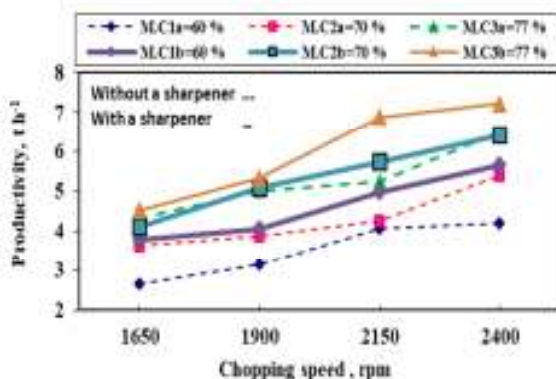


Fig. 4. Productivity for two machines under different moisture contents.

### Chopping length

Results for the chopping machine without a sharpener unit indicated that by increasing the chopping speed from 1650 to 2400 rpm, the average chopping length decreased from 30 to 15 mm at a constant clearance of 10 mm and moisture contents of 60, 70 and 77 %, respectively. Meanwhile, the results for the chopping machine with a sharpener unit showed that by increasing the chopping speed from 1650 to 2400 rpm, the average chopping length decreased from 25 to 10 mm at a constant clearance of 10 mm and moisture contents of 60, 70 and 77 %, respectively.

We noticed that when the chopping speed was 2150 rpm and moisture content of 70 %, the average chopping length was 15 mm for the chopping machine with a sharpener unit.

These results agree with Shinnars (2003), who stated that for forage utilisation, a medium chopping length of approximately 8 to 12 mm and up to approximately 20 mm when including kernel processing is recommended for maize silage.

These results indicate that decreased chopping length can be attributed to an increase in chopping speed. The average chopping length of the chopping machine with a sharpener unit was observed to be smaller than the average chopping length of the chopping machine without a sharpener unit. This result is attributed to the sharpener unit, which has a lower chopping force and therefore yields a lower length.

### Chopping efficiency

Results for the chopping machine without a sharpener unit indicated that by increasing the chopping speed from 1650 to 2400 rpm, chopping efficiency increased from 63.32 to 82.26, from 62.54 to 78.78, and from 57.34 to 76.21 % at moisture contents of 60, 70 and 77 %, respectively. Meanwhile, results for the chopping machine with a sharpener unit showed that by increasing chopping speed from 1650 to 2400 rpm, chopping efficiency increased from 68.22 to 89.12, from 64.7 to 86.69, and from 62.9 to 85.55 % at moisture contents of 60, 70 and 77 %, respectively, as shown in Fig. 5.

These results are consistent with the findings of El Ashry *et al.* (2004), who stated that chopping efficiency for maize crop residues increased as the knife rotation speed increased, while the chopping efficiency decreased with increased average moisture content of straw. The cutting efficiency increased with decreased moisture content and increased cutting drum speed. In addition, the cutting efficiency increased from 91 to 95.8 % with increasing cutting speed from 1200 to 2000 rpm at 8 % moisture content (Okasha, 2016). This result can be attributed to the large influence of chopping speed on increasing chopping efficiency. The chopping efficiency of the chopping machine with a sharpener unit is higher than the chopping efficiency of the chopping machine without a sharpener unit because the sharpener unit facilitates the chopping operation.

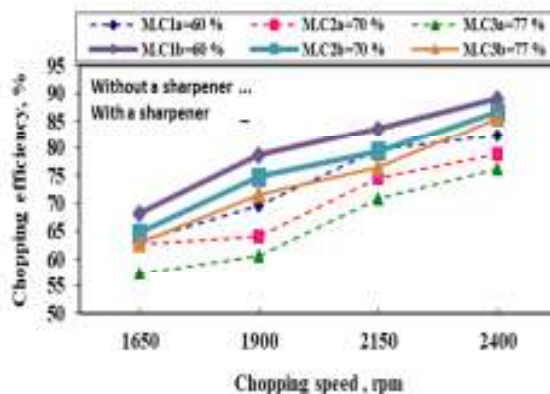


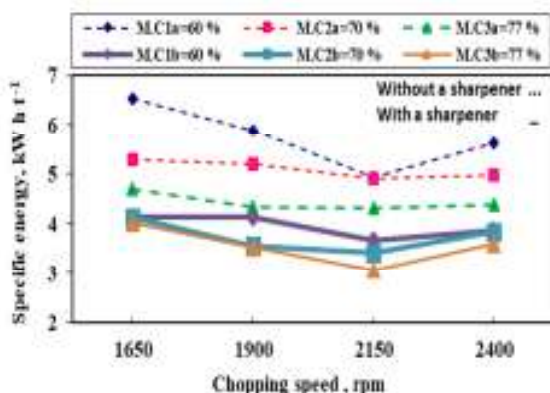
Fig. 5. Chopping efficiency for two machines under different moisture contents.

**Specific energy requirement**

Results for the chopping machine without a sharpener unit indicated that, by increasing the chopping speed from 1650 to 2150 rpm, the specific energy requirement decreased from 6.53 to 4.93, from 5.28 to 4.91, and from 4.71 to 4.32 kW h t<sup>-1</sup> at moisture contents of 60, 70 and 77 %, respectively. Increasing chopping speed from 2150 to 2400 rpm caused an increase in the specific energy requirement from 4.93 to 5.61, from 4.91 to 4.97, and from 4.32 to 4.38 kW h t<sup>-1</sup> at moisture contents of 60, 70 and 77 %, respectively.

Meanwhile, results for the chopping machine with a sharpener unit showed that by increasing chopping speed from 1650 to 2150 rpm, the specific energy requirement decreased from 4.15 to 3.68, from 4.14 to 3.42, and from 4.03 to 3.07 kW h t<sup>-1</sup> at moisture contents of 60, 70 and 77 %, respectively. Increasing the chopping speed from 2150 to 2400 rpm caused an increase in the specific energy requirement from 3.68 to 3.88, from 3.42 to 3.86, and from 3.07 to 3.60 kW h t<sup>-1</sup> at moisture contents of 60, 70 and 77 %, respectively, as shown in Fig. 6.

The data are consistent with the findings of Zhang *et al.* (2003), who stated that the average specific energy required for chopping whole-plant corn ranged from 2.5 to 5.9 kW h t<sup>-1</sup> DM. Average specific energy for an added flail cutter/blower ranged from 2.0 to 4.7 kW h t<sup>-1</sup> DM, and the specific energy requirement for a total harvester ranged from 4.5 to 10.6 kW h t<sup>-1</sup> DM. When a forage harvester was used to cut forage, energy savings of up to 31 % was noticed in drier crops at 62 % moisture compared with 83 % moisture (Savoie *et al.*, 1989).

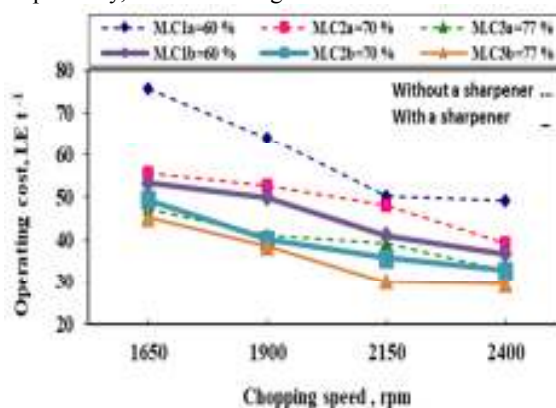


**Fig. 6. The specific energy requirements for two machines under different moisture contents.**

The specific energy requirement of the chopping machine with a sharpener unit was lower than the specific energy requirement of the chopping machine without a sharpener unit because the sharpener unit facilitated the chopping operation. In addition, a higher productivity was observed for the chopping machine with a sharpener unit than the chopping machine without a sharpener unit. The optimum specific energy requirement for the two machines was achieved at a chopping speed of 2150 rpm. An increase in the specific energy requirement from 2150 to 2400 rpm for the two machines is due to an increase in power that was greater in proportion to an increase in machine productivity.

**Operating cost**

Relating the use of chopping machine, results in Fig. 7. Indicated that, by increasing chopping speed from 1650 to 2400 rpm, operating cost decreased from 75.73 to 49.23, from 55.67 to 39.13, and from 47.18 to 32.74 LE t<sup>-1</sup> at moisture contents of 60,70 and 77 % respectively. Meanwhile with the use of chopping machine with sharpener results showed that by increasing chopping speed from 1650 to 2400 rpm, operating cost decreased from 53.31 to 36.75, from 49.36 to 32.90, and from 45.25 to 29.43 LE t<sup>-1</sup> at moisture contents of 60,70 and 77 % respectively, as shown in Fig. 7.



**Fig. 7. Effect of chopping speed on operating cost for two machines under different moisture contents.**

This can be attributed to the high influence of chopping speed on decreased operating cost as well operating cost of chopping machine with sharpener lower than of operating cost of chopping machine is attributed to higher productivity of chopping machine with sharpener than of chopping machine.

**CONCLUSION**

We recommend using a chopping machine with a sharpener unit for chopping maize for forage at a constant clearance of 10 mm, a moisture content of 70 % and an optimum knife speed of 2150 rpm (61.92 m s<sup>-1</sup>). The productivity of the chopping machine with a sharpener unit was 5.74 t h<sup>-1</sup>, the chopping length was 15 mm, the chopping efficiency was 79.37 %, specific energy requirement was 3.42 kW h t<sup>-1</sup>, and operating cost of 35.82 LE t<sup>-1</sup>. It was found that the sharpener unit had a positive effect on the performance of the machine and saved energy, time and money.

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تأثير المسن الملحق مع آلة تقطيع الذرة على الأداء  
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تهدف هذه الدراسة الى دراسة تأثير اضافة مسن ملحق بالآلة تقطيع الذرة على أداء الماكينة وصفات الذرة المقطعة ودراسة تأثير المتغيرات التالية اربع سرعات سكاكين 1650 و 1900 و 2150 و 2400 لفة الدقيقة وثلاث نسب رطوبة للنبات 60 و 70 و 77 % على الانتاجية وطول القطع وكفاءة القطع والطاقة المستهلكة وتكاليف التشغيل . كانت أهم النتائج المتحصل عليها هي أن آلة تقطيع الذرة الملحق بها مسن للسكاكين أدى الى تحسن الأداء في جميع مراحل التشغيل وعند خلوص ثابت 10 مم ومحتوى رطوبة للنبات 70% وسرعة سكاكين مثلى 2150 لفة الدقيقة (61.92 مترًا ثانية) وكانت الإنتاجية 5.74 طن \ ساعة ، طول القطع 15 مم ، كفاءة القطع 79.37 % ، الطاقة المستهلكة 3.42 كيلو وات ساعة \ طن ، وتكلفة التشغيل 35.82 جنيه \ طن .