Developing Stubble Chopper Device Adequate for Small Livestock Barns

Ahmed Shawky El-Sayed[1*], Mohamed Ali Ibrahim Al-Rajhi[2]
and Ayman Mousa Abdel-AZeem El-Beba[3]

[1]Department of Biological Engineering, Agriculture Engineering Research Institute (AENRI), Agriculture Research Center (ARC), Dokki, Giza, Egypt
[2]Department of Animal Production Mechanization, Agriculture Engineering Research Institute (AENRI), Agriculture Research Center (ARC), Dokki, Giza, Egypt
[3]Department of Field and Horticultural Crops Mechanization, Agriculture Engineering Research Institute (AENRI), Agriculture Research Center (ARC), Dokki, Giza, Egypt

Received: 20 November 2018, Revised: 25 May 2019, Accepted: 6 June 2019

Abstract

The main objectives of this research are to develop a sustainable feeding unit in the small barns for daily fresh feed production by minimizing the operation cost of feed manufacturing and mixing the good soften cutter feed with nutrient supplements mechanically using an easy operating system. The storage of mixed fodder for a long period can expose its validity into rancidity and oxidation and reduces the nutritional value. Thus, an adequate feeding unit suitable for small barns is developed. Three experiments are conducted to test the developed unit on the variable levels of the cutting speeds (7.540, 9.426 and 11.304m/s), three feeding rates of (0.3, 0.6 and 0.9 ton/h) and three knife interferences of (5, 10 and 15 mm) to measure the performance rates, efficiency and economic evaluation. The results indicated that the maximum percentage in the soften cutting length > 5 cm was 92.82 % at the helical distribution with the maximum speed of 11.304 m/s, feeding rate of 0.9 ton/h and the largest knife interference of 15 mm. Besides, the maximum feed mixing efficiency (95.45 %) was recorded at the highest adaptable settings. Meanwhile, the maximum machine productivity was recorded at 0.85 ton/h at the same variables. Moreover, the maximum power consumption value (6.85 kWh/ton) was obtained at the lowest cutting speed of 7.540 m/s, feeding rate of 0.85 ton/h and knife interference of 5 mm. The maximum operation cost was 121.20 Egyptian pound/ton with the same factors.

Keywords: rancidity, oxidation, validity, cutting, mixing, feeding
DOI 10.14456/cast.2019.18

*Corresponding author: E-mail: a.shawky71@ yahoo.com

1. Introduction

Feed manufacturers usually choose ingredients that are the least cost but still meet the desired nutritive properties for a given species [1] The primary force driving changes in feeding practices has been economic on how to bring food animals up to weight as quickly and cheaply as possible [1]. Feed availability, new feed ingredients and new feeding practices have played important roles in the concentration of animal food production operations [2].

The reviewed researches are branched into five main topics. First topic is focused on the use of agricultural residues in feed ingredients. Rice straw represents an important agricultural residual in Egypt and approximately 3.5 million tons of rice straw is produced every year.

In general, the maximum intake of rice straw by ruminants is about 1.0 to 1.2 kg per 100 kg live weight [3]. Also crops residues (CRs) are roughages that become available as livestock feeds after crops have been harvested [4]. Livestock farmers, especially in the sector of goats, sheep and cattle, are constantly faced with problem of feed shortage during the dry season [5]. However**,** crop residue such as rice straw could be treated with urea or calcium hydroxide or by supplementing rice straw with protein for the enhancement of intake, degradability and milk yield [6-7]. Second topic concerns improving the feed nutrient value. Generally, supplementation of a ration of rice straw with protein, energy and/or minerals may optimize rumen function and also increase intake [1]. Molasses can be a source of quick energy and an excellent source of minerals for farm animals and it is an effective way to increase the palatability of feeds through the use of diluted molasses (with water) by sprinkle its solution over the fodder from 0.1 % and 0.4 % (when a forage-based diet was fed) to 1 % and 3 %, respectively [8]. Third topic emphasizes on the effect of storage on feed validity. Clearly, oxidation is one of the major reasons that feeds deteriorate and is caused by the reaction of fats and oils with molecular oxygen leading to off-flavors that are generally called rancidity [9]. However, oxidative rancidity is of special interest as it leads to the development of unfavorable off-flavors that can be detected early on in the development of rancidity [10]. Also, keeping quality of alimentary animal fats is governed by factors such as storage temperature, permeability of the packaging material to air and moisture [11]. However, nutritional losses and other deteriorative changes in animal fats are concerned with the changes that result from their reaction with atmospheric oxygen [9]. Fourth, the benefits of feed cutting are examined. More clearly, quality of crop residues and roughages are improved by both chemical and physical methods [12]. Physical treatment of residues prior to chemical treatment improves materials acceptance of chemical treatment. Physical treatment includes chopping, shredding, grinding and pelleting [12]. Also, knife mills or choppers work successfully for shredding forages under various crops and machine conditions. Disc mills produce very small particles if input feed is provided by knife mills or hammer mills [13]. The range of cutting crop residues (1-3 cm) is suitable for sheep and goats while the range of 3-5 cm is suitable for large animals [2]. However, using different chopped roughage can solve serious problems of animal feeding shortage in Egypt [14]. Chopping farm residues in pieces less than 3 cm improves its efficiency when used in feeding livestock [14]. Fifth topic concerns the development of feed cutting devices. The results for an improved designed cutting machine for rice straw and maize stalks indicated that the maximum percentages (87.80 and 92%) in cutting length of less than 5 cm were obtained for rice straw and corn stalks residues, respectively, at cutting speed of 10.09 m/s, feeding rate of 0.771 ton/h and knife clearance of 1.5 mm while the energy consumed was 6.36 and 6.17 kWh/ton [15]. However, a developed combined cutting-unit with the harvesting combine machine was designed and about 27% from straw length < 5 cm was recorded at cutting speed 12.65 m/s while rice-straw length between 5-15 cm was about 54% and rice-straw length > 15 cm was about 19% [16]. In addition, the cutting unit in the Japanese combine was modified and tested and it was found that the power consumption increased with increasing forward speed and cutting speeds, while the energy requirement (kWh/ton) increased with decreasing forward speed and increasing cutting speed with highest percentage value 83% of short pieces < 6 cm was obtained at 0.75m/s [17]. Besides, a suitable developed cutting rice-straw machine was developed for appropriate lengths for the manufacture of animal feed and compost [18]. The productivity of 892 kg/h, power requirement about 5.05 kW, the operation cost of 13.63 Egyptian pound/h at 2015 and specific energy 5.67 kWh/t were obtained [18].

The main objectives of the research are to investigate on the production of fresh daily feed for the small barns and how to minimize the operating cost of manufacturing feed. The good soften cutter feed mixed with nutrient supplements mechanically with easy operating system was also examined.

2. Materials and Methods

2.1 Design of developed unit

The developed unit depended on the cutting disks knives in the rear part for the Japanese rice combine harvesters is designed. Usually, operating combines in Egypt are conducted without using these parts due to its problems from increasing the mechanical loads so it was removed from rice combine harvesters. The utilization of reusing these units to make separate equipment is examined. The modification of the developed unit is to make a propelled equipment suits small barns using small tractors as the power source from tractor power take off (PTO) or using a separate gasoline motor. The general description of the developed equipment is shown in the schematic drawing (Figure 1).

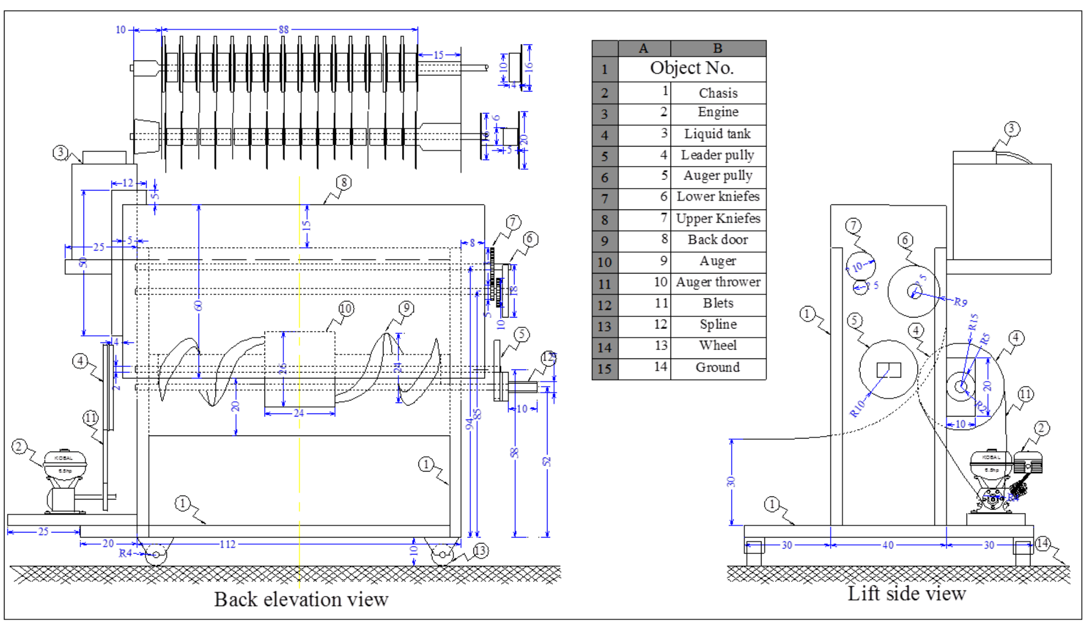

Figure 1. Schematic drawing for the developed feeding equipment (dimensions: cm)

The new developed cutting and mixing unit consists of the following parts as follows:

1) Power source: The power source has duel outlets portions. The first one, as shown in Figures 2-5 built from the hexagonal attached shaft which connected to the PTO in the low power tractors (less than 30 hp) which fits the required power consumption that ranges about 6.85 kWh/ton. On the other hand, a separate gasoline motor 6.5 hp is attached to operate the feeding equipment as shown in Figure 3 and its specifications are listed in Table1.

Table 1. The used gasoline motor specifications

Model	**Kobal, made in China**
Certification	EPA
Engine displacement (cc)	212
Horsepower (hp)	6.5
Speed (max) RPM	3800

Figure 2. The developed unit (rear side view)

Figure 3. The developed unit (front side view)

Figure 4. The developed unit (right plane view)

Figure 5. The developed unit (left plane view)

2) Chassis: The chassis is made from iron heavy square pipes (4 cm) which welded and manufactured locally to stand tracking on its own four wheels (12 cm dia.) and trailed by the tractor with two front bearer bars that turns the feeding equipment on pivotal axial coupling. The developed unit has dimensions of 2.5×0.75×1.65 m (length× width× height) as shown in the schematic drawing Figure 1.

3) The cutting unit: As shown in Figures 6-9, two inside different cutter drums have the cutting action for the picked feed to the unit which do the work by organized steps. The mirrored straw was first caught by the top drum. The straw was then pressed between the cutting edges of the top and the lower cutter drums which rotates in reverse to each other. The top drum consists of two kinds of vertical disc knives. One of these knives has tags to catch the straw and prevent it from sliding as shown in Figure 10(a). Fifteen knives which have tags or the caught disks were arranged side by side sixteen cutter knives disks on the hexagonal section shaft.

Figure 6. The cutting and mixing unit initial parts

Figure 7. The electrical sprayer distributor

Figure 8. The cutting unit feeding trays

Figure 9. The outlet cutting rough feed

4) The cutting unit modification: There are three main modifications as follows:

a) The lower cutting rotor as shown in Figures 10-11, the bottom cutting rotor has been modified by adding and distributing an additional cutting blades between collars of the cutting rotor with two distributions arranged as the vertical one and the helical one, along the cutting rotor drum to duplicate the cutting force on the feeding forages to decreases its lengths as required (Figure 9).

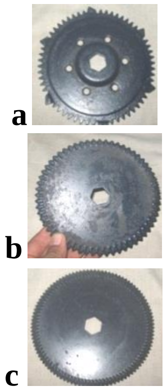

Figure 10. The different disc knives (a and b 16 cm dia.) for the upper rotor and (c) for the lower rotor (16 cm dia.).

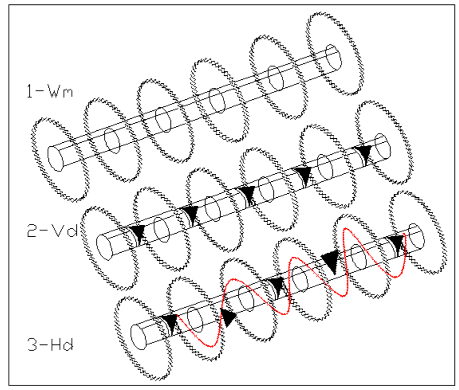

Figure 11. The different attached knives distributions (1-Wm: without modification, 2-Vd: vertical distribution and 3- Hd: helical distribution).

b) The inlet feeding trays: Two main trays on the both sides of the cutting unit are merged to set the feed rate equally between the used straw residual and the dried forage and to balance the feed ingredients (Figure 8). The tray dimension is 120×30 cm.

c) The outlet tray: This part was designed as shown in Figures 5 and 7 to provide the feeding directly to the animals, which falcate the feed process.

5) The mixing unit: As shown in Figures 6 and 12, the right hand of the auger has double sides which conveys each other inversely in the direction to the convey zone that mixes the fallen mixed cutter feed.

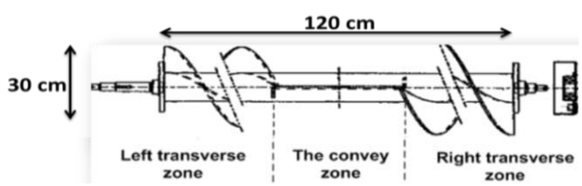

Figure 12. The mixing feed auger

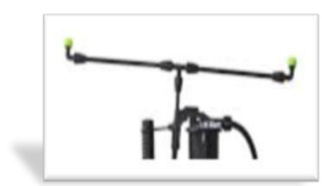

Figure 13. The duel sprayer nozzles

6) The electrical sprayer distributor (for useful supplements liquid): As shown in Figure 7, an adequate garden sprayer is used for spraying liquid through the outlet cutter feed with reviewed ranges of its discharge rate (1 l/10 kg dry rough-feed) from doubled hanged sprayers on the cutting door (as shown in Figure 13). The sprayer has 12 litre tank with rechargeable 12 volt battery and operates with inlet strong pump that provides flow rate up to 1 l/min. In addition, the mass of the discharged supplement was controlled by adapting the nozzles collar to set its cone diameter by rolling it.

7) The transmission unit: The power transmitted (as shown in Figures 2 and 3) from the driving pulley of 7 cm dia. on the gasoline motor shaft to the main idler shaft front pulley (22 cm dia.) to the other left pulley (12 cm dia.) on the same shaft. The power was then branched to the cutting and the mixing unit pulleys, respectively (17 and 20 cm dia.), as shown in Table 2. The different changeable linear speeds are due to controlling the gasoline lever at three different loads as listed.

Table 2. The cutting and mixing unit linear speed

Motor pulley (rpm)	Cutting pulley (rpm)	Cutting pulley (m/s)	Auger pulley (rpm)	Auger pulley (m/s)
2400	847	7.540	720	7.540
3000	1059	9.426	900	9.425
3600	1270	11.304	1080	11.310

2.2 Study of performance parameters

The performance parameters of the designed machine are described as follows:

1) Three cutting speeds (V) of 7.540, 9.426 and 11.304 m/s which changed according to the transmission system.
2) Three feeding rates (F) of 0.3, 0.6 and 0.9 ton/h which settled experimentally by adapting the feeding quantity with the time using the merged cutting unit trays as listed in Table 3.
3) Three knife interferences (I) of 5, 10 and 15 mm which according to lateral controlling lever that gauge the interference distance between the two cutting rotors (Figure 2).

Table 3. The used feed ingredients at the changed feeding rates

Feeding rate (ton/h)	Feed ingredients		
	Straw (kg)	Dried clover (kg)	Supplement liquid (litre)
0.3 (5 kg/min)	3.0	1.5	0.5
0.6 (10 kg/min)	6.0	3.0	1.0
0.9 (15 kg/min)	9.0	4.5	1.5

2.3 Measurements

Three experiments were conducted and replicated three times. The developed feed equipment was studied to evaluate the developed unit without modification (Wm) and after distributing the additional blades in the vertical (Vd) and helical (Hd) distributions to measure the following:

1) The cutting lengths percentages (CL, %): After each cutting treatment, a sample of 1 kg weight from cutting crop material was taken and separated into three categories, i.e. less than 5, more than or equal 5-10 and more than 10 cm. Each cutting length in the sample was weighed and calculated as a percentage from the total sample weight. The mean length cutting straw was calculated using the following equation according to Wanapat *et al.* [7]:

$$M.L.S = \frac{\Sigma_i^n .X_i .W_i}{W_{i-n}} \quad (1)$$

Where: M.L.S is the mean length cutting straw,
Xi is the mean length of each division (Wm, Vd, Hd) and
Wi is the sample weight of each division, g.

2) The mixing efficiency (M, %): After every treatment the outlet of mixed feed random sample was analyzed. Each ingredient weight (straw, dried forage and supplement liquid) was dived into the total weight to measure the mixing efficiency percentages by the following equation:

$$\mathrm{M} = \frac{S_{W\times}D_{W\times}L_W}{T_W} \times 100\ \% \quad (2)$$

Where: M% is the mixing efficiency,
S_w is the straw weight (g),
D_w is the dried clover weight (g),
L_w is the supplement liquid weight (g) and
T_w is the total sample weight (1000 g).

3) The machine productivity (P, ton/h): The machine productivity was calculated by using the following equation:

$$P = \frac{M \times 60 \times 1}{1000} ton/h \quad (3)$$

Where: P is the machine productivity (ton/h), M is straw feed mass (kg), 60 is minutes, 1 is one ton and 1000 is constant.

4) The fuel consumption (F), L/min: Fuel consumption was determined by measuring the volume of fuel consumed during the operation time for each run and calculated in liter per hour. It was measured by completely filling the fuel tank before each end run and refilling the fuel tank was used as a scaled container. The fuel consumption rate was calculated by the following equation:

$$F = \frac{V}{T} \quad L/h \quad (4)$$

Where: F: rate of fuel consumption, L/h, V: rate of consumed fuel, L and T: time, h.

5) The consumed power requirements (Pr, kW.h/ton): The consumed power requirements were calculated by using the following equation [19]:

$$Pr = \left(\frac{Fs \times \rho_f \times C.V}{3600} \right) \times \left(\frac{427 \times \eta_{th} \times \eta_m}{75 \times 1.36 \times P} \right) kW.h/ton \quad (5)$$

Where: Pr is energy requirements (kW.h/ton),
Fs is fuel consumption rate (L/h),
ρf is density of fuel (kg/L) (for diesel = 0.85 kg/L),
C.V is calorific value of fuel (Kcal/kg,),
427 is thermal-mechanical equivalent (kg.m/Kcal),
ηth is thermal efficiency of the engine, assumed 40 % for diesel engine,
ηm is mechanical efficiency to engine, assumed 80 % for diesel engine and
P is machine productivity (ton/h).

6) The operating cost (C, Pound/ton): The operating cost was determined using the following formula:

$$\text{Operating cost (C)} = \frac{\text{Machine hourly cost (Pound/h)}}{\text{Actual machine capacity (ton/h)}} \text{ Pound/ton} \quad (6)$$

3. Results and Discussion

3.1 Factors affecting mean cutting length percentages

In general, the obtained first percentage category of cutting length < 5 cm at the effect of the cutting speed (V) within the tested variables; the different feeding rates (F) and also the knife interferences (I). Figure 14 shows From these figures, it could be cleared that, there are high effect for V at the new development for the new knife distribution on the beneath cutting rotor from the vertical to the helical arrangements which improves significantly the desired cutting length category < 5 cmmore than the other categories > 5-10 and >10 cm.

The results indicated that increasing the cutting speeds from 7.540 to 11.304 m/s would directly increase the percentage of cutting length < 5 cm at the both variable levels for F and I. As shown in Figure 14, the maximum values of the cutting length percentages for the 1st category distribution of soften length (< 5 cm) were 83.83, 89.41 and 92.82 % for the (Wm, Vd and Hd), respectively and the highest value (F) 0.9 ton/h at the highest (V) of 11.304 m/s while the minimum values for the 1st category were 71.39, 76.97 and 80.38 % for the (Wm, Vd and Hd) distributions, respectively at the lowest value of (F) 0.3 ton/h and (V) of 7.540 m/s. Also, as shown in Figure 14(b), the maximum values of the cutting length percentages for 1st category were 82.85, 88.43 and 91.84 % for the (Wm, Vd and Hd) distributions, respectively, at the highest value (V) of 11.304 m/s and the highest value (I) of 15 mm while the minimum values for the 1st category were 72.50, 78.08 and 81.49 % for Wm, Vd and Hd distributions, respectively at the lowest value (V) of 7.540 m/s and (I) of 5 mm. It could be stated that the distribution percentage of cutting length less than 5 cm were increased by increasing both knife interference and feeding rate levels. There are high significance differences between the tested treatments and the total interaction between it to CL %. The analysis of variance for the data of 1st category for CL % at different tested factors indicated highly significant differences between the treatments. A simple power regression analysis is applied to relate the change in the 1st category < 5 cm with the change in the tested factors in the form of:

(Wm) Without modification	[<5 cm] = (50.178, 55.758 and 59.168)+ 2.498 V + 4.854 F + 0.0983 I	
	R^2= 0.9977	C.V. = (0.306, 0.286 and 0.0274)

Mean cutting length percentages for length catogry < 5 cm at three diffient experiments (Wm, Vd and Hd). Wm: Knives without modification, Vd and Hd: Knives vertical and helical distributions.

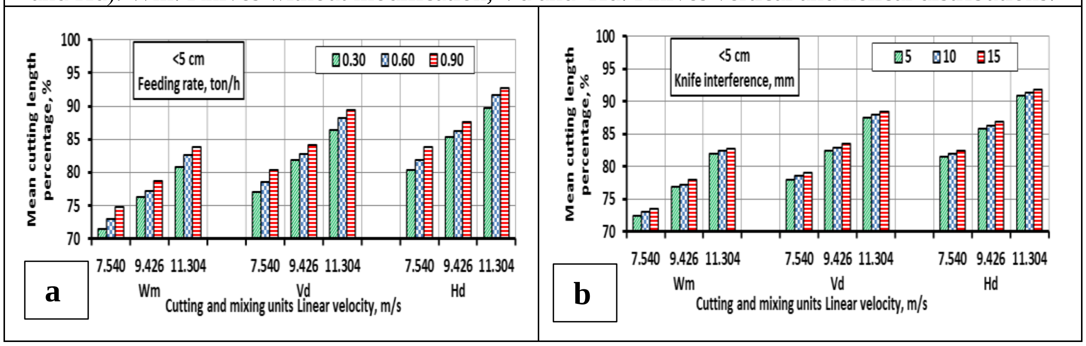

Figure 14. The effect of cutting and mixing unit linear velocity on the mean cutting length percentages of category < 5 cm at the different feeding rates and knife interference

Mean cutting length percentages for length catogry > 5-10 and > 10 cm at three diffient experiments (Wm, Vd and Hd).

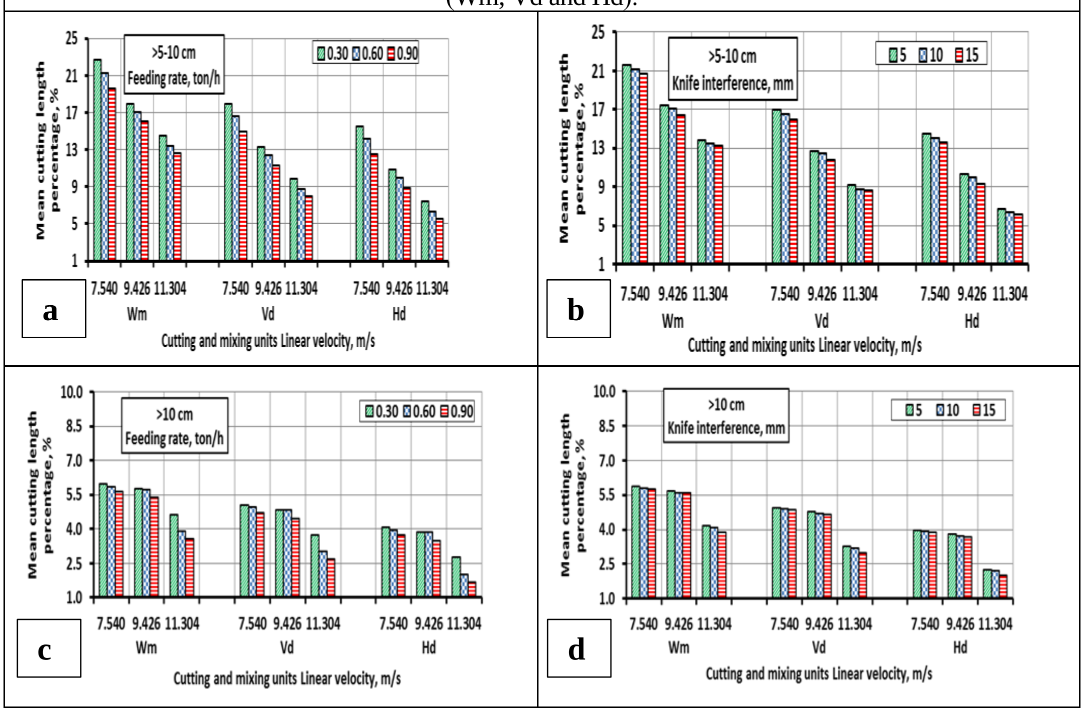

Figure 15. The effect of cutting and mixing unit linear velocity on the mean cutting length percentages of category > 5-10 and > 10 cm at the different feeding rates and knife clearances

Figure 15 showed that there are an oppositely relationship by increasing the cutting speed the (CL) percentages decreased with increasing both of the F and the I. The results showed that increasing the cutting speeds from 7.540 to 11.304 m/s adversely decreased the percentage of cutting length (> 5-10 and > 10 cm) at both variable levels for F and I. The maximum values of the

CL% for 2nd and 3th categories (> 5-10 and > 10 cm) as shown in Figure 15 (a and b), were (22.63, 17.95 and 15.53 %) and (5.98, 5.08 and 4.09 %), respectively, for the lowest feeding rate (F) 0.3 ton/h and the lowest cutting speed (V) of 7.540 m/s while the minimum values were (12.58, 7.90 and 5.48 %) and (3.59, 2.69 and 1.70 %) for the (Wm, Vd and Hd), respectively, at the highest value of (F) 0.9 ton/h and (V) of 11.304 m/s.

In that manner, as shown in Figure 15 (c and d), the maximum values of the CL% for 2nd and 3th categories were (21.63, 16.95 and 14.53 %) and (5.87, 4.97 and 3.98 %), respectively, for the lowest (V) of 7.540 m/s and the minimum (I) of 5 mm. The minimum values were (13.26, 8.58 and 6.16 %) and (3.89, 2.99 and 2.00 %) for the (Wm, Vd and Hd), respectively, at the maximum value (V) of 11.304 m/s and (I) of 15 mm. From the results, the new CL% with ($P < 0.05$) could be clarified. The analysis of variance for the data of 2nd and 3th categories showed highly significant differences. The power regression equations for 2nd and 3th categories are as follows:

(Vd) Knives distribution

[>5-10 cm] = (39.479, 34.799 and 32.379) –2.029 V –3.864 F- 0.0826 I

R^2= 0.9967 C.V. = (1.347, 1.850 and 2.293)

(Hd) Knives distribution

[>10 cm] = (10.343, 9.443 and 8.453) - 0.469V- 0.990 F- 0.0157 I

R^2= 0.9908 C.V. = (1.939, 2.347 and 3.056)

3.2 Factors affecting feed mixing efficiency (M %)

As shown in Figure 16(a), the maximum values of M were 88.38, 94.63 and 95.45 %, respectively, at the highest (F) 0.9 ton/h and the highest (V) of 11.304 m/s. The minimum values of M were 75.94, 82.19 and 83.01 % for the (Wm, Vd and Hd), respectively, at the lowest value of (F) 0.3 ton/h and (V) of 7.540 m/s. Also, as shown in Figure 16(b), the maximum values of M were (87.40, 93.65 and 94.47 %), respectively, at (V) of 11.304 m/s and (I) of 15 mm. The minimum values of M were (77.05, 83.30 and 84.12 %) for the (Wm, Vd and Hd), respectively, at the lowest value (V) of 7.540 m/s and (I) of 5 mm. The use of two- part auger with high rotational speed and screw pitch led to the efficiency of feed mixing at the highest speeds with the maximum levels of (F and I). There are significance differences between the tested factors and the total interaction between it to M with ($P < 0.05$). The power regression equations for M% are as follows:

Wm, Vd and Hd Knives distributions

[M%] = (54.728, 60.978 and 61.798) + 2.498 V + 4.854 F + 0.098 I

R^2 = 0.9977 C.V. = (0.289, 0.269 and 0.266)

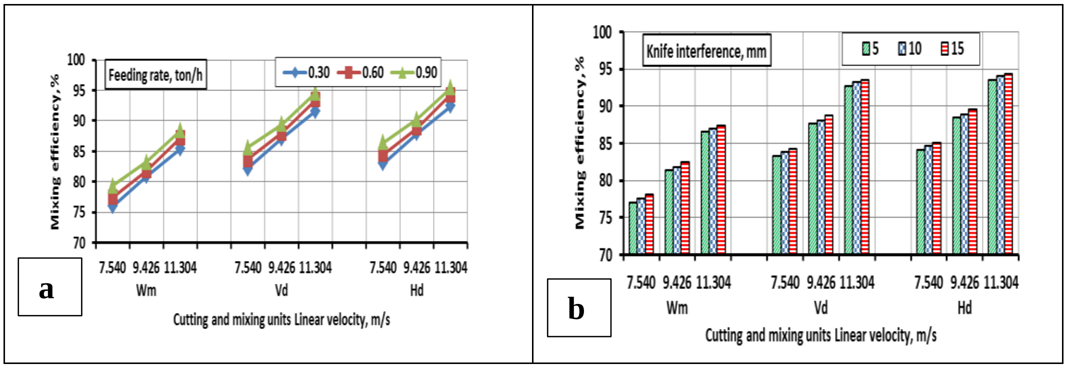

Figure 16. The effect of cutting and mixing unit linear velocity on the feed mixing efficiency at the different feeding rates and knife interference

3.3 Factors affecting the machine productivity (P, ton/h)

As shown in Figure 17(a), there are direct relations between the highest values of P (0.79, 0.84 and 0.85 ton/h), respectively, at (F) 0.9 ton/h and (V) of 11.304 m/s while the minimum values of P were (0.23, 0.24 and 0.25 ton/h) for the (Wm, Vd and Hd), respectively, at the lowest value of (F) 0.3 ton/h and (V) of 7.540 m/s. Moreover, the maximum values of P were (0.52, 0.56 and 0.57 ton/h), respectively, at (V) of 11.304 m/s and (I) of 15 mm as shown in Figure 17(b). The minimum values of P were (0.46, 0.49 and 0.50 ton/h) for the (Wm, Vd and Hd), respectively, at the lowest value (V) of 7.540 m/s and (I) of 5 mm. The application of the maximum cutting speed, feeding rates and knife interferences allowed relatively mass production and improved the cutting unit to contain large capacity of the feed to produce these values of huge capacities.

The statistical analysis showed high significance differences between the tested treatments and the total interaction between it to P with ($P < 0.05$) and highly significant differences between the treatments. The obtained regression equations for P were in the form of:

Wm, Vd and Hd

Knives distributions

$$[P(ton/h)] = (-0.161, -0.161 \text{ and} -0.161) + 0.0149\,V + 0.841\,F + 6.037e\text{-}4\,I$$

$R^2 = 0.9999$ C.V. = (0.328, 0.321 and 0.311)

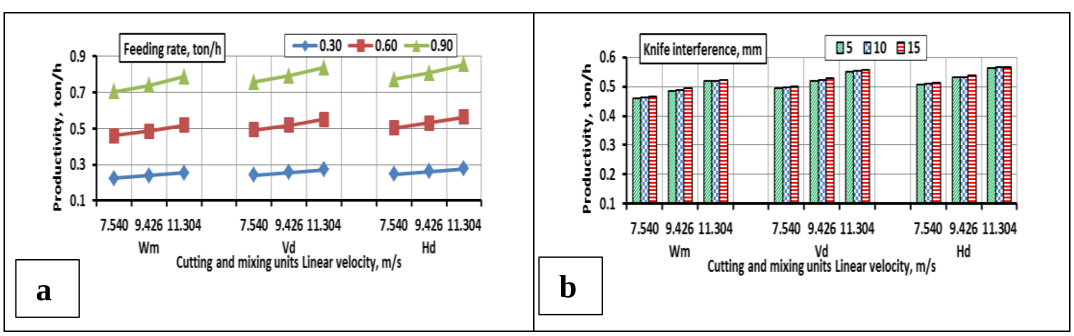

Figure 17. The effect of cutting and mixing unit linear velocity on the total machine productivity at the different feeding rates and knife interference

3.4 Factors affecting power requirements (Pr, kWh/fed)

As shown in Table 4, the fuel consumption rates range from 0.49 to 0.62 l/h which is more economical for the operating of the designed feed equipment.

Table 4. The fuel consumption rates at the tested factors

Distribution	V and F	Wm	Vd	Hd	V and I	Wm	Vd	Hd
Fuel cons. Max l/h	11.304m/s	0.57	0.61	0.62	11.304m/s	0.56	0.60	0.61
	0.9 ton/h				15 mm			
Fuel cons. Min l/h	7.540m/s	0.49	0.52	0.54	7.540 m/s	0.49	0.53	0.54
	0.3ton/h				5 mm			

Generally, there are a direct relation as shown in Figure 18 (a) that the maximum values of Pr were equaled at 6.85 kWh/ton for the (Wm, Vd and Hd) distributions, respectively, at the lowest feeding rate (F) of 0.3 ton/h and the lowest cutting speed (V) of 7.540 m/s while the minimum values for Pr was equaled at (2.28kWh/ton) for the (Wm, Vd and Hd) distributions, respectively at the maximum value (F) of 0.9 ton/h and (V) of 11.304 m/s. From the results it could be stated that the consumed fuel was not affected by the machine loads unless the changing of machine speed was decreased by the power requirements at the higher values of V than the lowest speeds. Figure 18(b) shows a linear relationship between Pr and V at the different values of F and I which explains that there were no significant differences between the tested factor I and Pr but the significant difference was found between the changing of the cutting speed and the feeding rate. The obtained regression equations for Pr were in the form of:

(Wm), (Vd) and (Hd) distributions [Pr kW.h/ton] = (8.757, 8.757 and 8.757) - 4.929e -17 V -7.615 F +1.266e-19 I $R^2 = 1$

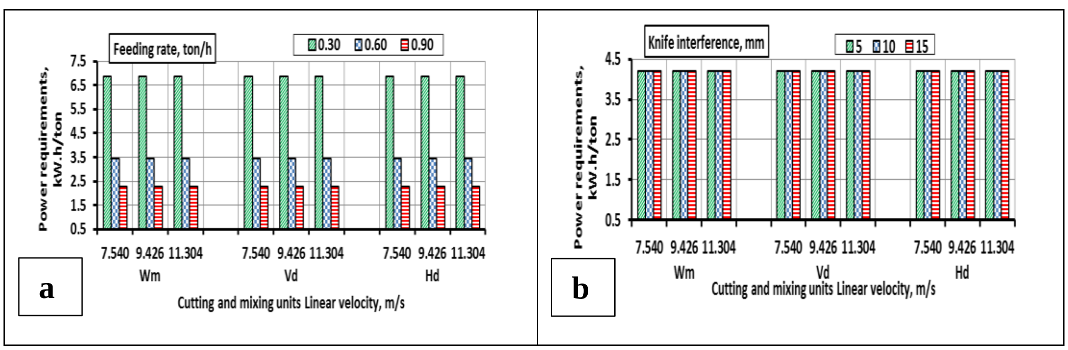

Figure 18. The effect of cutting and mixing unit linear velocity on the power requirements at the different feeding rates and knife interference

3.5 Factors affecting operating cost (C, Pound/ton)

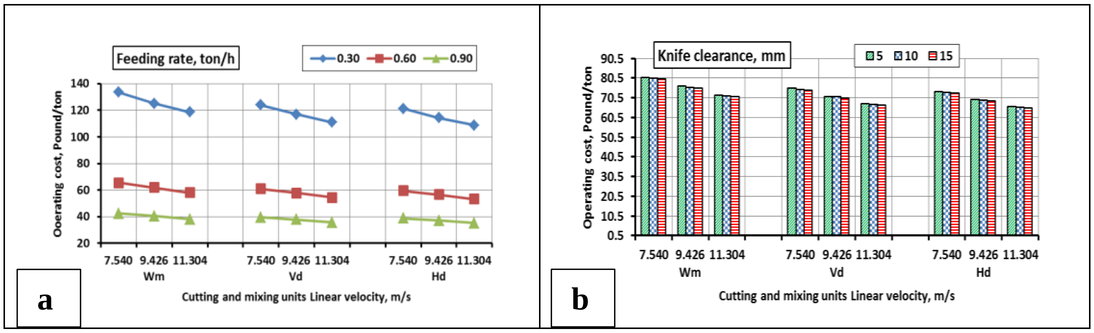

Figure 19. The effect of cutting and mixing unit linear velocity on the machine operating cost at the different feeding rates and knife interference

As shown in Figure 19 (a), there are inverse relations. The maximum values of C were (133.35, 123.93 and 121.20 Pound/ton), respectively, at (F) of 0.3 ton/h and (V) of 7.540 m/s. The minimum values of C were (38.13, 35.79 and 35.11 Pound/ton) for the (Wm, Vd and Hd), respectively, at the maximum value of (F) 0.9 ton/h and (V) of 11.304 m/s. However, the maximum values of C were (80.91, 75.23 and 73.59 Pound/ton), respectively, at (V) of 7.540 m/s and (I) of 5 mm while the minimum values of C were (71.13, 66.70 and 65.40 Pound/ton), respectively at (V) of 11.304 m/s and (I) 15 mm as shown in Figure 19(b). The manufacturing cost was 10 thousand Egyptian pounds in 2018. The results showed that the use of minimum cutting speeds, feeding rates and knife interferences could increase the operating costs more than the levels of economical operation for the developed machine. The power regression equations for (C) were in the form of:

(Wm), (Vd) and (Hd) Knives distributions: [C (Pound/ton)] = (184.334, 170.540 and 166.554) – (2.362, 2.060 and 1.975) V – (142.088, 132.423 and 129.607) F – (0.0898, 0.07821 and 0.0751) I

$R^2 = 0.9999$ C.V. = (0.310, 0.289 and 0.283)

4. Conclusions

It could be concluded that the maximum percentage in the soften cutting (length > 5 cm) was 92.82 % at the helical distribution with the maximum speed of 11.304 m/s, feeding rate of 0.9 ton/h and the largest knife interference of 15 mm. Besides, the maximum feed mixing efficiency of 95.45 % was recorded at the highest adaptable settings. The maximum machine productivity was recorded at 0.85 ton/h at the same variables. The maximum power consumption value at 6.85 kWh/ton was obtained at the lowest cutting speed of 7.540 m/s, feeding rate of 0.85 ton/h and knife interference of 5 mm. In addition, the maximum operation cost was 121.20 Pound/ton with the same factors. It is recommended to establish this modified system in the small barns.

5. Acknowledgements

Many thanks for Prof. Mohamed El Kholy and Prof. Gamal Hasan Elsayed, Agriculture Engineering Research Institute, Egypt.

References

[1] Chenost, M. and Kayouli, C., 1997. Roughage utilisation in warm climates. *FAO Animal Production and Health Paper 135*, Rome

[2] Church, D.C., 1991. *Livestock Feeds and Feeding*. 3rd ed. Englewood Cliffs: Prentice Hall.

[3] Devendra, C., 1997. Crop residues for feeding animals in Asia: technology development and adoption in crop/livestock Systems. In: C. Renard, ed. *Crop Residues in Sustainable Mixed Crop/Livestock Farming System*. Wallingford: CAB International, pp. 241-267.

[4] De Leeuw, P.N., 1997. Crop residues in tropical Africa : trends, in supply, demand and use. In : C. Renard, ed. *Crop Residue in Sustainable Mixed Crop/Livestock Farming Systems*. New York : CAB International.

[5] Philip, D., Nkonya, E., Pender, J. and Oni, O.A., 2009. Constraints to increasing agricultural productivity in Nigeria: a review. *NSSP Working Paper 6*. Abuja: International Food Policy Research Institute (IFPRI).

[6] Walli, T.K, Garg, M.R. and Makka, H.P.S., 2012. Crop Residue Based Densified Total Mixed Ration- A User friendly Approach to Utilise Food Crop By-products for Ruminant Production. *FAO Animal Production and Health Paper No. 172*, Rome.

[7] Wanapat, M., Polyrach, S., Boonnop, K., Mapato, C. and Cherdthong, A., 2009. Effect of treating rice straw with urea and calcium hydroxide upon intake, digestibility, rumen fermentation and milk yield of dairy cows. *Livestock Science*, 125(2), 238-243.

[8] Senthilkumar, S., Suganya, T., Deepa, K., Muralidharan, J. and Sasikala, K., 2016. Supplementation of molasses in livestock feed. *International Journal of Science, Environment and Technology*, 5(3), 1243-1250.

[9] Akamittath, J.G., Brekke, C.J. and Schanus, E.G., 1990. Lipid oxidation and colour stability in restructured meat systems during frozen storage. *Journal of Food Science*, 55(10), 1513-1517.

[10] Przybylski, R., and Eskin, N.A.M., 1995. Methods to measure volatile compounds and flavor significance of volatile compounds. In: K. Warner and N.A.M. Eskin, eds. *Methods to Assess Oil Quality and Stability of Oils and Fat- Containing Foods*. Champaign: AOCS Press, pp. 107-133.

[11] Rawls, H.R. and Van Santen, P.J., 1990. A possible role for singlet oxygen in the initiation of fatty acid autoxidation. *Journal of the American Oil Chemists' Society*, 47(1), 121-125.

[12] Mathers, J.O. and Otchere, E.O., 2012. Research on the nutrition of working animals: needs, experiences and methods. *FAO Document*, p 9.

[13] Hoque, M., Sokhansanj, S., Naimi, L., Bi X and Lim, J., 2007. Review and analysis of performance and productivity of size reduction equipment for fibrous materials. *ASABE Paper Number: 076164*. Paper presented at ASABE Annual International Meeting Minneapolis, Minnesota.

[14] El-Berry, A.M., Baiomy, A., Radwan, H.A. and Arif, E.M., 2001. Evaluation of (Hematol) machine in rice straw chopping. *9th Conference of MISR Society of Agricultural Engineering*, September 9-11, 2001, 65-76.

[15] El-Iraqi, M. and El-Khawaga, S., 2003. Design and test performance of cutting machine for some crop residues. *MISR Journal of Agricultural Engineering*, 20(1), 85-101.
[16] Abo-Habaga, M.M and Khader, M.O., 2005. Developed of a combined cutting unit with rice harvesting combine machine for utilization in field waste. Journal of Agricultural Science, 30(3), 1481-1487.
[17] El-Hanfy, E.H. and Shalby, S.A., 2009. Performance evaluation and modification of the Japanese combine chopping unit. *MISR Journal of Agricultural Engineering*, 26(2), 1021-1035.
[18] Abo-Habaga, M.M., Yehia, I. and Abo-Elasaad, G.A., 2015. Development of a rice straw bales chopper. *Journal of Soil Science and Agricultural Engineering*, 6(10), 1249 -1262.
[19] Hunt, D., 1983. *Farm Power Machinery Management*. 8th ed. Ames: Iowa State University Press.