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Research Article

STUDY ON EFFECT OF STEM DIAMETER, MOISTURE CONTENT AND AGE OF HENNA PLANT ON CUTTING FORCE

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Abstract: Henna (*Lawsonia inermis*), is cultivated in Western Rajasthan (Arid Zone). The cultivation of henna is very intensive in and around Sojat and Marwar Junction Tehsils of Pali district (average annual rainfall > 400 mm /yr.). The cultivation of henna is spread over about 32000 ha area, which fetches more than 400 million Indian Rupees of revenue every year. On maturity, the stem of henna is very woody and harvesting is performed with a sharp edge curved heavy sickle. This operation involves a lot of human drudgery with a poor efficiency. To design and develop a harvesting machine/device for henna, it is imperative to study the effect of different parameters, *viz.* stem diameter, age of henna plant and moisture content of the stem's woody material on cutting force. The paper deals with interactive as well as component relationships between the cutting force, stem diameter, moisture content and age of the henna plant. The data could be fitted in a multi linear relationship between age, moisture content, stem diameter and cutting force. The model is validated well as the slope of the plot between the observed and predicted values of the cutting force is close to unity (*i.e.* 0.97).

Keywords: *Henna crop, Henna harvesting machine/device, Cutting force of henna stem, Age of henna plant, Cutting force relationship for henna*

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Introduction

Henna (*Lawsonia inermis*), popularly known as "mehandi" is a perennial shrub indigenous to North Africa. The plant has been introduced widely throughout the tropics and sub-tropics as an ornamental (frequently as a fragrant hedge), and as a commercial crop. Since ancient times henna leaf powder has been employed as a cosmetic dye for hair, skin and nails and it has acquired a particular significance in Islamic Culture. Prior to the wide spread availability of the synthetic dye stuffs, henna was also employed as a dye for textile and leather. More recently, there has been an increase in its usage as a natural hair dye in Western Europe and North America. In India it is used as cosmetic for application on hands during festivals and religious occasions. The essential oils extracted from henna flowers are used in perfume industry and it has various medicinal values. Henna is an important dye plant under cultivation in India, Pakistan, Sudan, Iran, Yemen, Moracco, Niger, Egypt, etc. In India Henna is mainly cultivated in Sojat and Marwar Tehsils of Pali districts and adjoining regions in Western Rajasthan, shown in [Fig-1] as shaded area, which contribute over 90% of henna production in India of the total produce about 30% is exported and India is largest exporter of henna. The stem of henna is very woody and harvesting is performed with a sharp edge curved heavy sickle [1]. This operation involves a lot of human drudgery with a poor efficiency. It is, therefore, required to develop/ improve the existing system in order to provide ease of operation. The cultivation of henna in Pali district of Arid Zone is spread over about 32000 ha area, which fetches more than 400 million Indian Rupees of revenue every year. Out of this, 30419 ha area is concentrated in Pali district only (rainfall > 400mm/yr). Sojat, which is worldwide known for quality henna, accounts for about 66 % of area occupied by Pali. Henna is harvested once or twice a year. Harvesting period is very important from the production point of view. It is harvested in October and November. Harvesting is done before leaves turn completely yellow. There is no reliable estimate of the global production of henna perhaps because henna is a minor commodity of international trade. However, the average volume of world trade in henna leaves either powered or whole, was at least 9,000 tonnes per annum. Leaf studded branches are cut from as close to the ground as possible and kept for 3-4 days for drying. Harvesting of henna involves two simultaneous operations *i.e.* holding the stem with one hand and cutting the same with a sickle. The whole operation is full of drudgery despite being inefficient and time consuming. Mechanization of harvesting operation fully and/or partially will go a long way in saving labour and providing ease of operation thereby increasing area under henna cultivation.

Review of literature

There is not much information available on the design and development of henna harvester. A sharp edge curved heavy sickle and gloves are used for cutting the henna stems with impact action. Some big farmers in the Pali district used harvester in order to save labour cost but could not succeed as falling of leaves took place due to vibration of cutter bar of the harvester [1]. Therefore, due to non-availability of information on henna harvesting machine, the available information on machines / devices for harvesting of other crops have been reviewed and presented for cutting force and energy. The cutting energy with a specific knife configuration was studied for prototype header and the crushing resistance of corn stalk. Two knife designs were compared for required cutting energy and found not to be significantly different with values of 0.054 J/mm2 of stalk cross-section area and 0.063 J/mm2. An average crushing resistance of 6.5 N per percent of relative deformation was measured to validate the developed mathematical models [2]. Jekendra [3] reported for the cutting process of forage crops and indicated that it was greatly influenced by its physical and rheological properties. Beyond the physiological maturity stage, moisture content of forage crops such as sorghum and maize decreased sharply as the age of the plant increased, whereas, the stem diameter decreased with the ageing of the plant.

Table-1 *Different physical parameters affecting cutting force requirement of henna stem*

Age of plant, (years)	Moisture content of woody material of stem, (%, wb)	Size of stem (mm)	Cutting force required, (kg_f)	X-sectional area of henna stem (mm^2)	Cutting strength of stem (kg_f/mm^2)
1	48.5	5	15	19.6	0.76
		6.4	20	32.2	0.62
		8.6	35	58.1	0.6
		10	50	78.5	0.64
2	44.3	10	65	78.5	0.83
		11	70	95	0.74
		12.4	80	120.7	0.66
10	42.2	10	60	78.5	0.76
		12.3	80	118.8	0.67
		14.5	95	165	0.58
25	26.2	12.5	60	122.7	0.49
		18.5	120	268.7	0.45
		22	175	379.9	0.46

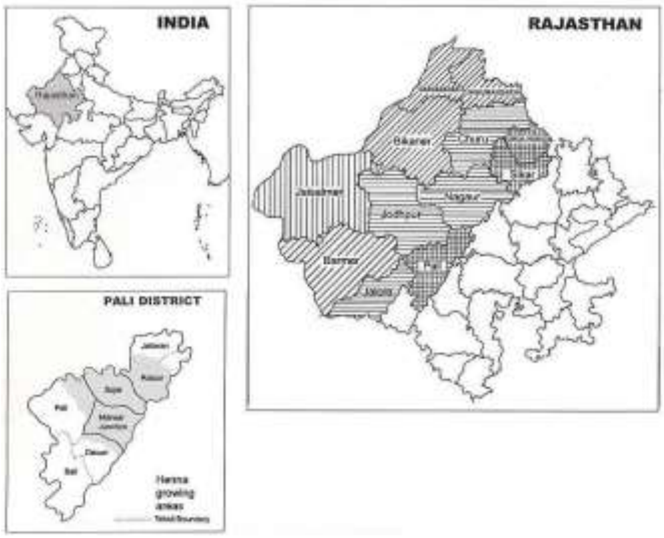

Fig-1 Map sowing location of henna growing area in India (district Pali)

The shear strength of maize and sorghum stems increased with the decrease in moisture content. Yiljep and Mohammed [4] conducted trials for measuring energy requirement and efficiency of cutting for sorghum stalk with the help of pendulum-like oscillating arm. Cutting energy required had negative linear relationship and cutting efficiency relation with cutter weight and moisture content of stem. The minimum cutting energy requirements for 20 and 120 mm diameter stalks were 7.89 and 12.65 Nm, respectively, at corresponding knife velocities of 2.9 and 3.5 m/s. The cutting efficiencies were observed maximum 98 and 97% for knife velocities 2.9 and 3.5 m/s, respectively. Some studies suggested that the cutting energy of a single stalk was a function of the square of the diameter with a typical value of 15 J for 38 mm diameter sorghum, without specifying the type of knife used [5-6]. Johnson and Lamp [5] also suggested static cutting forces ranging from 215 N to 570 N for 30 mm diameter corn stalks. However, the value of cutting force (Fc) varies greatly with the condition of the crop. Speed, sharpen type of crop, diameter of stock, moisture of stem, cutting height and forward speed of the harvester were factors which affected the cutting force Fc. A manually engine operated pigeon pea harvester was developed drawn [7] which would be helpful as pigeon pea stem is also hardy in nature. The complex and highly variable effects of those parameters, as observed in literature [6], make an analytical estimation of Fc very difficult to obtain. Most of the data available in literature for cutting energy as reported by Jekendra and Singh [8] are relevant to the cutting process in a forage harvester cutter head (cylinder, flywheel and flail type). From the review it may be inferred that none of the researchers studied harvesting of henna crop. The development of henna harvesting machine/tool depends on the properties of the stem, such as, the cutting force and energy required to cut the henna plant. Appropriate and efficient cutting of the plant stem is critical for the good operation of a harvesting machine. There are many factors which affect the required cutting force and energy of a plant stem, some relating to the plant itself, others to the cutting device and the interactions between both. Therefore, it is imperative to study the effect of different parameters on harvesting of henna crop.

The main functional component in harvesting device/machine is cutting mechanism, which is performed on the principle of impact, shear and/or a combination of the two forces. The cutting properties of henna stem have been studied for designing suitable cutting mechanism. This particular paper deals with interactive as well as component relationships between cutting force, stem diameter, moisture content and age of the henna plant.

Materials and methods

The stalk materials from henna plantations of different age groups *i.e.* ranging from 2 to 25 years were cut into pieces of required length and kept in sealed polyethylene bags for further use in the experimental set-up to determine force and energy requirement. In addition, other physical parameters such as, stem diameter, weight and moisture content of woody material of the stem were also determined.

Measurements of physical properties

Diameter: A vernier calliper with 0.1 mm least count and 250 mm maximum reading was used for measuring major and minor stalk diameters.

Weight: The weight of the stalk was recorded using a digital balance with a least count of 1 mg.

Moisture Content: The moisture content of the henna stalk was measured using gravimetric method. The stalks were kept in an oven for 24 h at 105ºC. The loss in weight was recorded and moisture content was determined as per ASAE Standards by using the following equation:

$MC_{wb} = 100*(w_i - w_d)/w_i$

Where,

MC_{wb}= moisture content, % (wb); wi = initial weight; wd = dried weight

Fig-2 Setup for measuring cutting force and energy requirement for henna stem

Experimental set-up

A test rig was fabricated for recording the force applied in cutting the henna stalk. A double-edged pruner with an edge angle of was used for this purpose [Fig-2]. During the experiment a stalk was fitted firmly in the stalk holder. The force was measured by using a spring balance and by increasing the weight till the stalk was just cut. The spring balance was calibrated every time the experiment was carried out by determining the weight with the help of a balance. Energy required in cutting of henna stem was determined by dropping different weight from a certain known height till the stalk was just cut.

Results and discussion

The interactive effect of physical parameters viz. stem diameter, moisture content and age of plant on cutting force data for henna stem are given in Table 1. These parameters have direct bearing on cutting force required for harvesting the henna crop.

Relation between moisture content and age of henna plant

The moisture content changes with the age of henna plant. Therefore, following mathematical relationship (quadratic) was developed between moisture content of henna stem and age of plant:

$B = -0.065 A^2 + 1.053 A + 34.561$ (1)

$R^2 = 0.98$

Where,

B= moisture content, % (wb)

A= age of plant stem, years

A plot of moisture content versus age of henna plant is presented in [Fig-3]. It is clear from the figure that as the age of the plant increased the moisture content of its stem gradually decreased up to first few years and then it decreased abruptly, which is in line with the findings of Jekendra (1999) for maize and sorghum stalks.

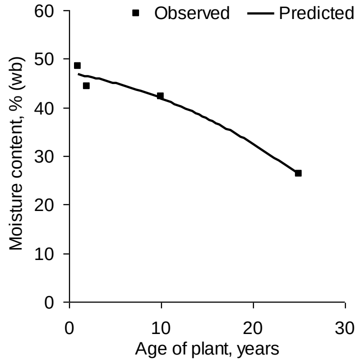

Fig-3 Relationship between moisture content of henna stem and age of plant

From the table it may be further inferred that the cutting strength of the henna stem changes with the age of the plant. Thus, a mathematical relationship was developed between cutting strength and age of plant. Figure 4 established the following relationship between cutting strength of henna stem and plant age:

$S = 0.0022 A^2 - 0.083 A + 1.136$ (2)

$R^2 = 0.72$

Where,

S= cutting strength of henna stem, (kgf / mm^2)

From the figure it is clear that initially during the first few years (2-4) of the plant age cutting strength of the henna stem is fairly high. Then it starts decreasing gradually as the age of henna plant increases. As the age of plant has increased the moisture content decreased, which resulted in reduced cutting strength.

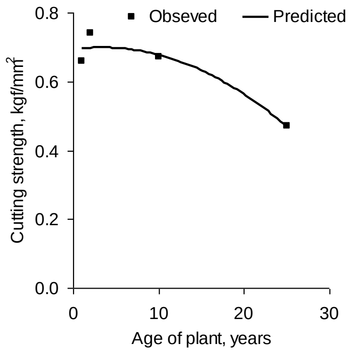

Fig-4 Relationship between cutting strength of henna stem and age of plant.

The relationship between cutting strength and moisture content is presented in Fig 5. Mathematically the cutting strength and moisture content (%,wb) of the henna stem may be correlated in the following form:

$S = -0.009 B^2 + 0.548 B - 7.023$ (3)

$R^2 = 0.88$

It is evident from the figure that up to 30% moisture content cutting strength increases at an enormously high rate and beyond that there is an abrupt decline. It is this moisture content (30%, wb) at which maximum force will be required for cutting the henna stem.

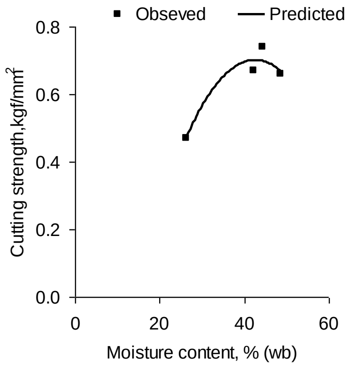

Fig-5 Relationship between cutting strength of henna stem and its moisture content

To study the interactive effect of stem diameter, moisture content and age of plant on cutting force data for henna stem are given in Table1. These parameters have direct bearing on cutting force required for harvesting the henna crop. A multi variable linear relationship was developed between age of henna plant, moisture content, stem diameter and cutting force. The following mathematical relationship was worked out:

$F = -20.93 - 2.06 A - 0.29 B + 10.77 C$ (4)

$R^2 = 0.91$ and

standard errors 14.91, 0.596, 0.359 and 0.803 respectively for intercept, and variables A, B and C

Where,

A = age of henna plant, years

B = moisture content (%)

F= predicted cutting force, kgf

C= diameter of henna stem, mm

Using the above equation, the values of cutting force were predicted. The relationship between the observed and predicted values of cutting force is presented in [Fig-6] The model is validated well as the slope of the line in the figure is close to unity.

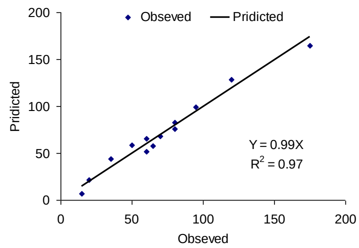

Fig-6 Relationship between observed and predicted values of cutting force for henna stem

Conclusion

A definite relationship (quadratic) existed between moisture content of woody material of stem and age of henna plant. As the age of the henna plant increased the moisture content its stem gradually decreased upto fist few years and then it decreased abruptly. Initially during the first few years (2-4) of the plant age the cutting strength of the henna stem is fairly high. It starts decreasing gradually as the age of the henna plant increases. The moisture content of the stem decreased with ageing of the henna plant, which resulted in reduced cutting strength. The cutting strength of the henna stem increases at an enormously high rate upto 30% wb moisture content and beyond that there was an abrupt decline. It is this moisture content (30%) at which maximum cutting force will be required. A multi variable linear relationship existed between age, moisture content stem diameter and cutting force. The model is validated well as the slope of the line between the observed and predicted values of the cutting force is close to unity (*i.e.* 0.97).

Application of research: The cutting strength of henna stem can be estimated which will help designing and developing henna cutter.

Research Category: Agriculture Engineering

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Institute: ICAR-Central Arid Zone and Research Institute, Jodhpur, 342 003, Rajasthan, India
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Study area / Sample Collection: CAZRI, Jodhpur, 342 003

Cultivar / Variety / Breed name: Alba variety of henna

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

References

[1] Singh M., Singh Y.V., Jindal S.K. and Narain P. (2005) *Central Arid Zone Research Institute, Jodhpur, India*, 1-55.
[2] Nieuwenhof P. (2003) *Unpublished M.Sc. Thesis, Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.*
[3] Jekendra Y. (1999) *Archivos de Zootecnia*, 48, 75-78.
[4] Yiljep Y. and Mohammed U. (2005) *Agricultural Engineering International: The CIGR E Journal. Manuscript PM 05 004, VII.*
[5] Johnson W.H. and Lamp B.J. (1966) *Principles, equipment and systems for corn harvesting. Wooster, OH: Agricultural consulting associates Inc.*
[6] Persson S. (1987) *Mechanics of cutting plant material. St-Joseph, MI, ASAE.*
[7] Tiwari V.K. (2017) *Unpublished M.Tech. Thesis, Junagadh Agriculture University, Junagadh, Gujarat.*
[8] Jekendra Y. and Singh P. (1991) *Africa and Latin America*, 22(1), 59-63.