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Modelling the Technical Efficiency of gum Arabic Harvester in the Gum belt of Sudan

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Abstract: **The research was conducted in North and West Kordofan States to model and assess efficiency of gum arabic harvester. Field measurement at *Nawa* site was conducted where gum from 120 *hashab* trees were harvested by the harvester and 40 *hashab* trees were harvested by hand. Tree growth attributes were measured. Stop watch was used to control picking time. Gum fall-in and gum fall-out of the harvester was counted and weighted. Microsoft Excel. Mathematical models were experienced where variables of performance and efficiency were tested. The results showed that harvester theoretical material capacity was higher than hand theoretical capacity by107 gum nodule/h, harvester effective material capacity was also higher than hand effective material capacity by 96 nodules/h, collection efficiency of harvester was higher than that of hand by 1.6 % and time efficiency of harvester was higher than that of hand by 3.3 %. The results showed highly significant correlation (P≤0.01) between nodules fall in harvester and picking time and also between number of branches and picking time. The research concluded that gum arabic harvester is efficient in terms of time, speed, safety and gum quality according to 72.7% of users. The study recommended use of the harvester instead of harmful hand collection method. It also recommended further research focusing on invention and intermediate technology for harvesting and postharvest of gum Arabic production.**

Keywords: **gum production, nodules, harvesting, tapping, Kordofan, Sudan.**

1. INTRODUCTION

In Sudan, forests dominated by Hashab tree class with a considerable share (21%) and increasing trend during the last two decades (Adam et al., 2017). Gum arabic (GA) is edible, dried, gummy exudates from the stems and branches of *Acacia senegal* and *Acacia seyal* (Duqan and Abdullah, 2013). *Acacia senegal* grows and reaches 4–5 m in height, to obtain the gum, a part of bark is partially removed once a year, whereupon resin is exuded in droplets from the wound. These droplets grow to nodules 2–5 cm in diameter and are picked. A couple of additional pickings commonly follow after 1 or 2 weeks. The procedure does not damage the growth of the tree if correctly done (Elmqvist *et al*., 2005). The international specifications used to assess the quality of gum arabic in the world market are based on the Sudan gum obtained from *A. senegal variety senegal*. The quality of gum arabic must conform to international specifications, which state the specific optical rotation and nitrogen content (-26° to - 34° and 0.26 - 0.39%) respectively. The quality parameters must be adhered to, by both the producers and the processing enterprises (Lelon *et al*., 2013/2010). Quality is generally defined as a measure of excellence, whoever, in production aspects, quality is a state of being free from defects and significant variations. Quality aspects are often associated with a cost and a price. The cost of quality means the cost undertaken in the process of improvement including efforts that would not have been expended if quality were perfect (Campanella, 1999). Determinants of quality include factors associated with tapping aspects, post-harvest, handling and environmental controls (Chikamai and Odera, 2002). Within the *Acacia senegal* species, the main factors affecting grades of gum arabic quality are different botanical sources (varieties), tapping methods, harvesting period and environmental factors (Chikamai and Odera, 2002). In Sudan only the var. *Senegal* occurs (Cossalter, 1991), tapping is the commonly used method of harvesting gum in Sudan, it is carried out during the early part of the dry season during October/November (Phillips, 2012). The modern tapping tool used in Sudan is a sharp spear (Sunki), besides the sunki, an axe is also commonly used. It is suggested that gum should be left to mature form nodules at least for 14 days after which it can be harvested off. Depending on the area, this period can even be extended to 4 or 6 weeks (Idris and Haddad, 2012). The long maturity period poses the risk of appropriation of gum by competing collectors particularly in communal forest where access to the common plots is unrestricted and the rules of management are unclear. Gum arabic exudes from the cracks on bark of wild trees in the dry season, with little or none in the rainy season when flowers are out. A tree, on an average, may yield 250 g of gum arabic per annum (two seasons), Yields from cultivated trees are said to increase up to the age of 15 years, when they level off and then begin to decline after 20 years (ITC, 1983; Abdel Rahman, 2001). Gum arabic from the Sudan is a product of *Acacia Senegal* and A. seyal species. The first harvest of the gum takes place 30 to 40 days after the tapping or slashing of the bark. The gum balls for med are picked many times warm periods. Collection continues every one or two weeks, depending on the hardening state of the gum- until the on- set of the rain in June. Gum picking should be done in the morning as the gum tends to melt with the rise in temperature. During picking ensure that every gum partial is collected from the tree. The gum Arabic tree is capable of producing 400-600gm of gum per tapping season. In a plantation of 5m*5m spacing an average yield of 200 kg per hectare is expected (Odo, 1994).

In developing the productivity accounts for agriculture, USDA has adopted the gross output model rather than the value-added approach. One of the advantages of this choice is that it explicitly measures the contribution of intermediate inputs, while an inherent disadvantage is that it is not consistent with productivity measures that are based on and consistent with other industries in the national accounting framework. The rationale for adopting the gross output measure is not trivial, as it has been shown that a significant proportion of output growth can be attributed to additional use of improved intermediate inputs for pesticides, fertilizer and herbicides (FAO, 2017). Agricultural productivity and efficiency is at the centre of many of the debates, policies and measures concerning the farming sector. The emphasis placed by the Sustainable Development Goals on agricultural productivity underlines the many reasons for which additional research on statistical frameworks for productivity and efficiency targeted to developing countries is necessary (FAO, 2017). The aim of this paper is to assess the technical efficiency of the gum Arabic harvester in term of time.

2. MATERIALS AND METHODS

2.1 Study Area

North Kordofan State extends between latitudes 12° 14̅ N and 16° 38̅ N and longitudes 26° 56̅ E and 32° 22̅ E with total area of 190,840 km^2. It lies in low rainfall savannah zone within the semi- arid climate where the annual rainfall ranged from 200-400mm (Kevie, 1973, Abdulla, 2006 and Khiry, 2007). The State is sparsely vegetated, vegetation is exposed to extreme conditions and must survive drought, which can stretch over several years with little or no rain at all. In the semi-arid ecosystems with a single rainy season there is usually a short growth period followed by a long dry season with great reduction in the amount of green plant material (Schmidt and Karnieli, 2000 and Dafalla, 2006). The extremes of air temperature are 10° C and 40° C, the mean relative humidity ranges from 21% in the dry season to about 75% during the rainy season; the wind speed is usually less than 8 Km/hr (Eldukheiri, 1997). In the northern part, the soils are classified as Cambric Arenosols and are locally named Goz. They are coarse textured sandy soils of Aeolian origin. They have high infiltration rates and inherent low fertility. In the southern part, the soils are alluvial in origin with a silt clay texture. They are non-cracking clay soils mixed with Aeolian sand and locally named Gardud (FAO, 1997).

2.2 Experiment site

Acacia Project, 37 km south east of El-Obeid, Kordofan State. The geographic location is between longitudes 30.25¹10.09 E and 30.30 17.8 E and latitudes 12.59. 20.41 N and 12.53 13.28 N the total area of the project is 28000 Feddans which was

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planted with gum arabic trees in 1997. The inter-row spacing is 3m and the intra-row spacing is 5m. *Hashab* trees were evenly grown, approximately about 280 *hashab* tree/ feddan (Acacia Project Reports, 2007). The soil is hard crust; generally flat, non-cracking clay mixed with Aeolian sand and with low infiltration rates locally named Gardud (FAO, 1997). Pure Hashab trees grown in rows (5 x 4 meter spaced therefore, Hashab plantations were more or less stunted possibly due to soil compaction (Taha, 2006). The climate is semi-arid with annual rainfall ranging from less than 200 mm in the north to about 350 mm in the south, the temperature is highest during July ranging 30 - 40° C (Abdulla, 2006).

2.3 Data collection

2.3.1 Design and Fabrication of Gum Arabic Harvester

The gum arabic harvesting tool (Figure 3.1) composes toothed harvesting ring made of hard steel of 4 cm diameter and the teeth are cut with 450 inclination, the ring is connected to 150 cm long sliding arm which can be moved up down by the operator. Bellow the harvesting ring there is cylindrical container made of aluminium of 25 cm length and 15 cm diameter with two light holed plates through which the sliding arm can moved up and down and also can be rotated, the container has an adjusting arm by which the cylinder position can adjusted closer to the ring to receive the harvested gum. In harvesting, the sliding rod is pushed upward to put the teeth of ring on the gum then the arm is drawn downward, therefore, the gum is pulled out of the tree and fall down in the container.

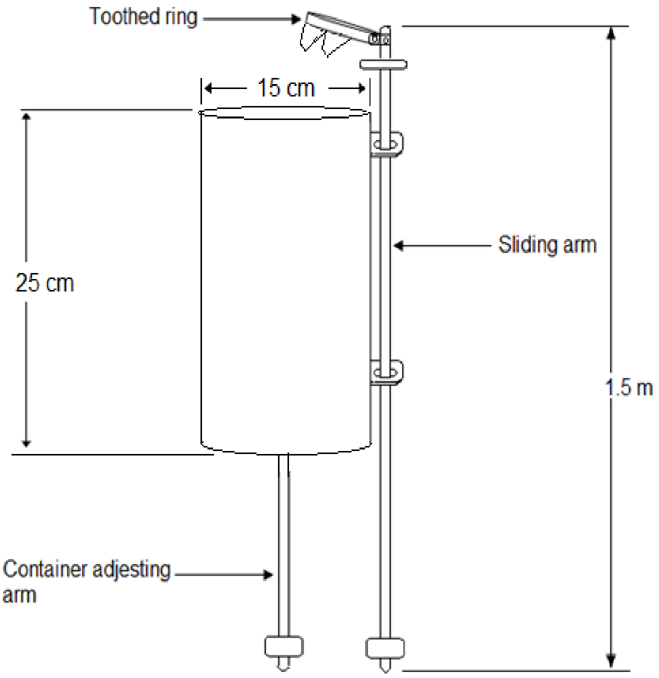

Figure 1: Schematic design of Gum Arabic harvesting tool

2.3.2 Field experiment and measurements

Field measurement at *Nawa* site, Acacia Company was conducted during gum collection period 08/12/2018 and 24/12/2018 (by harvester) and 25/03/2019 (by hand). About 120 *hashab* trees (by harvester) and 40 *hashab* trees (by hand) which have more than five gum nodules were randomly selected. With the aid of calliper, height devices and distance tape, the trees attributes constituting diameters, height, number of branches, crown diameter, crown area, were measured and recorded in special data sheet which was prepared for this purpose. Two labours were prior trained and they were asked to carry the responsibility of gum collection using the harvester. Stop watch was employed to control the time of collection. Observation about the accessibility and suffering during the collection time was also recorded. Time of collection (picking time), the harvested nodules fall inside the harvester container as well as those fall out the harvester container were also counted and recorded. Gum weight for each individual tree using sensitive balance was carried out.

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2.3.3 Data analysis

A mathematical modelling was used to construct equations to express relationship between harvester picking time and number of branches with nodules and relationship between tree height and falling nodules by solving differential equation system. Performance variables of the harvester such as theoretical material capacity, effective material capacity, material efficiency, collection efficiency and time efficiency were determined using implement parameters equations.

Figure 2 Gum collection using harvester (A), measuring tree diameter (B), interview (C) and Gum weighing (D) (Photos authenticated by Muneer and Suhad).

3. RESULTS AND DISCUSSION

3.1 Characteristics of *Hashab* Trees in *Nawa* site, Acacia Company, North Kordofan

The parameters of Hashab trees in *Nawa* site Acacia Company were measured. These included tree heights, stem diameter, crown diameter, the numbers of main branches and crown cover. The average height, diameter, crown diameter, numbers of main branches and the crown cover were 3.4± 1.4m, 8.2± 3cm, 2.9± 1.2m, 4.6± 2.3 branches and 7.8± 6.9m^2, respectively (Table, 4.1). The statistical analysis of the results showed that the maximum tree height was 6.50m and the minimum tree height was 1.30m, while the maximum stem diameter was 18.50cm and the minimum stem diameter was 2.90cm. In the same line the results showed that the maximum crown diameter was 7.00m and the minimum was 1.00m, the maximum number of branches of trees was 13 branch and the minimum number was 1.00 branch The maximum crown cover was 38.47 m^2 and the minimum was 0.79 m^2 (Table1).

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Table (1) height (m), diameter (cm), crown diameter (m), numbers of branches and crown cover (m) ^{2} for Hashab trees in *Nawa* site, Acacia Company, North Kordofan

	Height (m)	Stem Diameter (cm)	Crown Diameter (m)	No of Branches with gum	Crown cover m^2
Average	3.4±1.4	8.2 ± 3	2.9 ±1.2	4.6 ± 2.3	7.8 ± 6.9
Minimum	1.30	2.90	1.00	1.0	0.79
Maximum	6.50	18.50	7.00	13.0	38.47

3.2 Gum Picking and time of picking

The results of table (2) explained the average, minimum and maximum time of picking gum nodules (minutes), collected nodules, fallen gum nodules and the gum weight (g) using gum harvester. The average, minimum and maximum time for picking nodules using the harvester was 1.3, 0.12 and 5.4 minutes respectively. Also the result showed that the average, minimum and maximum time of collected gum nodule was 11, 2 and 41 gum nodules respectively. The average and maximum of gum nodule fallen out harvester was 1.7 and 8 respectively. Regarding gum weight, the average, minimum and maximum was 193g, 3.3g and 557.8g respectively.

Table (2) Picking time (minutes) of gum collection, collected of gum nodules, fallen nodules and gum weight (g) in *Nawa* site, Acacia Company, North Kordofan.

Parameter	Picking time (min)	Collected Nodules in harvester	fallen Nodules out harvester	Gum weight (g)
Average	1.33±0.9	11.03±6.2	1.70±1.8	193±116.6
Min	0.12	2.00	0.00	3.30
Max	5.40	41.00	8.00	557.80

3.3 Development of Mathematical Models of Gum Arabic Harvesting

1- Models Building

i- Development of a model for relationship between harvester picking time and number of branches with nodules

It is assumed that time of picking is directly proportional with number of branches with nodules, therefore:

$$\frac{dN}{dt} \alpha N$$

Where:

N = number of branches with nodules

t = time required to pick the nodules from the branches.

$$\frac{dN}{dt} = kN$$

k = proportionality constant

By separating the variables and integrating two sides:

$$kdt = \frac{dN}{N}$$

$$\int kdt = \int \frac{dN}{N}$$

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Accordingly:

$kt = ln(N) + C$

C = integration arbitrary constant.

Dividing by k:

$$t = \frac{\ln(N)}{k} + \frac{C}{k}$$

Then the general solution of the model will be as follow

$$t = a\ln(N) + b..................(1a)$$

a and b are constants, where a $\neq 0$

By applying empirical boundary conditions the intended particular solution of the model will be as follow:

$$t = 1.214\ln(N) + 0.661.........(2a)$$

Model validity test:

Table (3) Harvester empirical and simulated harvesting time

Number of branches with nodules	Empirical time of picking (mi)	Simulated time of picking (min)	Error %
2	0.46	0.71	54.3
3	1.20	1.34	11.7
4	2.27	2.34	3.1
5	2.36	2.61	10.6
6	2.44	2.84	16.4
8	3.23	3.19	1.2
9	3.55	3.34	5.9
10	4.00	3.47	13.3

Mathematical models were developed using differential equations modelling method to build relationship between empirical and simulated harvesting time and number of branches with gum nodules (Equation 2a) and also to build the fallen nodules with respect to tree height (Equation 2b). The error in simulated time was found to be accepted for most number of branches with gum nodules and it is ranging from 1.2 % to 16.4 % except for 2 branches, the error in such case was very high as demonstrated in Table (3).

ii- Development of a model for relationship between tree height and falling nodules

It is assumed that number nodules fall are directly proportional to height of the tree therefore:

$$\frac{dH}{dNF} \alpha H$$

Where:

H = tree height

NF = number of fallen nodules

$$\frac{dH}{dNF} = kH$$

k = proportionality constant

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By separating the variables and integrating two sides:

$$kdNF = \frac{dH}{H}$$

$$\int kdNF = \int \frac{dH}{H}$$

Accordingly:

kNF = ln(H) + C

C = integration arbitrary constant.

Dividing by k:

$$NF = \frac{\ln(H)}{k} + \frac{C}{k}$$

Then the general solution of the model will be as follow

$$NF = a\ln(H) + b..........(1b)$$

a and *b* are constants, where a $\neq 0$

By applying empirical boundary conditions the particular solution of the model will be as follow:

$$NF = 1.464\ln(H) - 0.311..................(2b)$$

Model validity test:

Table (4) Harvester empirical and simulated fallen nodules

Height of tree (m)	Number of nodules actually fallen	Simulated number of fall nodules	Error %
1.90	1.0	1.0	0
2.00	1.0	1.0	0
2.40	1.0	1.0	0
3.10	*2.0*	1.0	50
3.70	*2.0*	2.0	0
4.00	*3.0*	2.0	33
5.10	*2.0*	2.0	0
5.80	*3.0*	2.0	33
6.10	*4.0*	2.0	50

Tree height of 1,9 m, 2 m, 2.4 m, 3.7 m, 5.1 m demonstrated 0 value of error in simulated number of fallen nodules but tree height of 3.1, 4 m, 5.8 m and 6.1 m showed very high error with values of 50 % and 33 % as represented in Table (4).

2- Performance variables determination

i- Theoretical material capacity

$$\text{MTC} = \frac{N_T}{T} \times 60................(1)$$

Where:

MTC = Material theoretical capacity, number nodules / h

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N_T = total number of nodules assumed to be collected.

T = collection time, min

Total number of nodules assumed to be collected by harvester = 1528 nodules

Time required for collection = 160 min

$$MTC_{Har} = \frac{1528}{160} \times 60 = 573 \text{ nodules / h.}$$

Where,

MTC_{Har} = harvester theoretical material capacity.

Total number of nodules assumed to be collected by hand = 285 nodules

Time required for collection = 36.69 min

$$MTC_H = \frac{285}{36.69} \times 60 = 466 \text{ nodules / h}$$

Where,

MTC_H = hand material theoretical capacity, number nodules / h

ii- Effective material capacity

$$MEC = \frac{N_{Act}}{T} \times 60.................(2)$$

Where:

N_{Act} = number of nodules actually collected by harvester

Actual number of nodules actually collected by harvester = 1324 nodules

$$MEC_{Har} = \frac{1324}{160} \times 60 = 497 \text{ nodules / h}$$

Where,

MEC_{Har} = harvester effective material capacity.

Total number of nodules actually collected by hand = 245 nodules

$$MEC_H = \frac{245}{36.69} \times 60 = 401 \text{ nodules / h}$$

Where,

MEC_H = hand effective material capacity.

iii- Material efficiency

$$ME = \frac{EC}{TC} \times 100...................(3)$$

$$ME_{Har} = \frac{497}{573} \times 100 = 86.6 \%$$

$$ME_H = \frac{401}{466} \times 100 = 85.0 \%$$

iv- Collection efficiency

$$CE = \frac{N_{Act}}{N_{Act} + N_F} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where:

CE= collection efficiency, %

N_F = number of nodules fall on the ground.

Number of nodules actually collected inside the harvester = 1324 nodules.

Number of nodules fallen on the ground = 204 nodules.

$$CE_{\text{Har}} = \frac{1324}{1324 + 204} \times 100 = 86.6\%$$

Where,

CE_{Har} = harvester collection efficiency.

Number of nodules actually collected by hand = 245 nodules.

Number of nodules fallen on the ground = 40 nodules.

$$CE_{\text{H}} = \frac{245}{285} \times 100 = 85\ \%$$

Where,

CE_{H} = hand collection efficiency.

v- Time efficiency

$$TE = \frac{T_P}{T_P + T_L} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where:

TE = time efficiency, %

T_P = productive time, min

T_L = time losses, min

Productive field time to harvest 120 trees by harvester = 160 min

Time losses as 20 % of productive field time = 32 min

$$\text{TE}_{\text{Har}} = \frac{160}{160 + 32} \times 100 = 83.3\%$$

Where,

TE_{Har}= harvester time efficiency.

Productive field time to harvest 20 trees by hand = 36.69 min

Time losses as 25 % of productive field time = 9.2 min

$$\text{TE}_{\text{H}} = \frac{36.69}{36.69 + 9.2} \times 100 = 80.0\%$$

Where,

TE_{H}= hand time efficiency.

3.4 Comparison between harvester and hand performance variables

Table (4.7) showed that the harvester theoretical material capacity was higher than hand theoretical capacity by 107 nodules / h. It was also recorded that the harvester effective material capacity was higher than hand effective material capacity by 96 nodules/h. With respect to efficiency, it was recorded that collection efficiency of harvester was higher than that of hand by 1.6 % and time efficiency of harvester was higher than that of hand by 3.3 % while material efficiency recorded no significant difference between two methods of harvesting at 0.05 level of significance.

Table (5) Performance variable of gum arabic harvester

Method of harvesting	Performance variable				
	MTC (nodules / h)	MEC (nodules / h)	ME (%)	CE (%)	TE (%)
Harvester	573[a]	497[a]	86.6[a]	86.6[a]	83.3[a]
Hand	466[b]	401[b]	85.0[a]	85.0[a]	80.0[b]

MTC = material theoretical capacity, MEC = material effective capacity, ME = material efficiency, CE = collection efficiency and TE = time efficiency.

*Each value in case of harvester is mean of 120 trees while each value of hand method is mean of 40 trees.

*Values in column share same superscript letter showed no significant differences as evaluated by New-mankuel test at 0.05 level of significance.

Table (6) empirical time versus lost time

	Empirical time	Lost time (min)	Total
Time of picking (min)	159.97	24	183.97
Percentage	86.96	13.04	100%
Average	1.33	0.20	

From the results the time efficiency was found 86.96%

Usual lost time when using machinery is 15%

iv- Picking percentage

$$Pp = \frac{Ni}{Ni + No} \times 100$$

Pp= Picking percentage (%)

Ni= Nodules fall in the harvester

No= Nodules fall out the harvester

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

The study concluded the followings: developed harvesting tool for gum arabic is very important in terms of efficiency, time saving, protection against hazards and gum quality, however the lack of experience and means of affordability might remain the most important challenge for adoption. The developed harvesting tool for gum arabic is very suitable and effective with the high trees. The possibility of simulation and fabrication of the tool using different materials was insured, although the material of the current tool was highly acknowledged.

4.2 Recommendations

The paper recommended the use of the gum Arabic harvester for clean and quality. Further research on economic feasibility of the gum Arabic harvester is needed. Dissemination of the research findings and adoption of gum harvester by farmers is also important for quality of the produce.

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