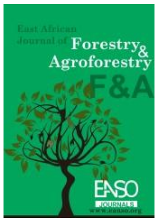

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Original Article

Production Capacity, Efficiency and Recovery Rates of Cupressus lusitanica and Pinus patula Lumber from Selected "WoodMizer" Band Sawmills in Kericho County, Kenya

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ABSTRACT

Conservation of forests is slowly shifting into a more proactive approach such as efficient lumber conversion in sawmills. This suggests a need to explore the use of modern sawmilling machinery in lumber conversion that produces low residues, wastage, and hence high recovery. This study looked into the production capacity, efficiency, and recovery rates of Cupressus lusitanica and Pinus patula lumber from selected "WoodMizer" band saws (LT15, 20, and 40) sawmilling machinery in Kericho County, Kenya. Wood logs delivered to each respective sawmill yard were categorized into ten diameter classes, ranging from 10 to 59 cm for both species. Volume of four logs from each class and species was evaluated using Huber's formula, (1995) and converted using through and through sawing techniques into lumber with each "WoodMizer" band saw. Volume of the lumber pieces and residues obtained were measured. The time taken during the conversion process was also recorded in order to determine the efficiency and lumber production capacity of each sawmill machines. Recovery of C. lusitanica gave average empirical values of 43%, 49%, and 53% in comparison with 39%, 34%, and 60% for P. patula using WoodMizer LT15, LT20, and LT40 respectively. P. patula produced the most residues at 61% and 66% compared to C. lusitanica at 57% and 51% per log volume for LT15 and LT20 respectively but less from LT40 (47%) for C. lusitanica and 40% for P. patula logs. WoodMizer LT40 recorded the highest daily production capacity for both C. lusitanica and P. patula (15.9 m3/day and 16.2 m3/day) respectively. This was followed by WoodMizer LT20 at 11.2 m3/ day and 9.6 m3/day for C. lusitanica and P. patula respectively. WoodMizer LT15 had the least production capacities of 8.8 m3/ day and 9.9 m3/ day for C. lusitanica and P. patula respectively. These results suggest adoption of "WoodMizer" band sawmilling in Kenya for sustainable forest resource.

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INTRODUCTION

Most of the sawmills in Kenya are characterized by small scale operators who mostly process lumber using inefficient sawing machinery such as hand-held chainsaws (FAO, 2010). Chain saws leave a wider kerf during the cutting process resulting to huge losses on volume (Marfo, 2009). Additionally, such saws are poorly adapted to dealing with logs affected by defects and log taper hence generate wood residues and wastes of significant economic importance (Ekhuemelo, 2015). In Kenya, sawmills normally acquire round logs from both public and private forests, transport them to sawmill yards and convert them into lumber according to market requirements (Ministry of Forestry and Wildlife, 2016).

Trees are a renewable resource; however, have a long rotation age of up to half a century to mature (Matiru, 1999). The practicality of sustainable utility in this regard becomes theoretical; hence to make a continuous harvest of such species, a model that puts into consideration both the rotation period and efficiency in utilization must be given priority over all other models. Improving utility efficiency and recovery will lead to relative forest conservation (FAO, 2010; Ekhuemelo, 2015). The turnover of log supply in saw mills increases with poor conversion techniques, due to high wastages and constant demand, resulting to harvesting trees above the specific annual allowable cuts (Ištvanić et al., 2009). This has necessitated a close examination of sawmilling activities.

On the other hand, tree species like eucalypts that take a relatively shorter period of time to be market ready experience over-demand (Langat et al., 2015), which consequently impact on their sustainability, as efficient sources of lumber for the current and future generations. Normally, trees both on private farms and government gazetted forests are usually harvested at rotation age. This explains why it is rare to find over mature trees with large Diameters at Breast Height (DBH) growing on privately owned farms (Langat *et al*., 2015). In Kenya, emphasis has conventionally been placed on the impact of conservation of forest resources. However, efficient machinery led to raw-material savings that lead to conservation hence sustainability holds constant the rate of raw material intake. This means that the saw millers will stick to the same intake of trees but

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ensure that the output per tree is improved through intensive efficient utilization. This is not always the case as most sawmills like any other business employ technology in order to improve on their intake of raw materials and minimize labour costs and time. The Study was therefore carried out to understand a need to explore the use of modern sawmilling machinery in lumber conversion that produces low residues, wastage, and hence high recovery. This study looked into the production capacity, efficiency, and recovery rates of *Cupressus lusitanica* and *Pinus patula* lumber from selected "WoodMizer" band saws (LT15, 20, and 40) sawmilling machinery in Kenya.

MATERIALS AND METHODS

Target Population

The study targeted *C. lusitanica* and *P. patula* round logs of top diameter class range 15-60 cm delivered to the log yard of each of the three selected WoodMizer band saws (LT15, 20, and 40).

Sampling

Twelve (12) logs of both *C. lusitanica* and *P. patula* tree species were chosen randomly from each of the top diameter class ranges (10-14 cm, 15-19 cm, 20-24 cm, 25-29 cm, 30-34 cm, 35-39 cm, 40-44 cm, 45-49 cm, 50-54 cm, and 55-59 cm). Length of selected logs varied from 6 to 7 m long.

Sawing of the Logs

Four (4) logs from each diameter class were sawn separately using each of the three different WoodMizer machines ((LT15, LT20, and LT40) in a through and through sawing pattern. After each sawing, the amount of resultant products and residues was evaluated. The time taken (min) to complete each task was also measured and recorded.

Estimating Lumber Recovery

Initial volume of each round log was measured by determining its length (L) and cross-sectional area at mid-point (equation 1). The logs were then sawn and measurements of the resultant lumber recorded. The total number (N) of the lumber pieces obtained, their width (W) and thickness (T) being recorded was used to determine the total volume of lumber produced (equation 2). The volume of Lumber produced from each diameter class, sawing method, and tree species was evaluated and used to determine the lumber recovery rate (equation 3) according to Antobre (2010).

Log Volume estimation was computed using Huber's formula;

$$V = L * gmid \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Equation\ 1$$

Where; V = Volume of log in cubic meters, L = Length of log in meters, Gmid = Cross-sectional area at midpoint.

Volume of lumber (V_1), was computed as follows;

$$V1 = L * W * T * N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 2$$

Where; V_1 = Volume of lumber in cubic meters, L = Length of lumber in meters, W = Width of lumber in meters, T = Thickness of lumber in meters and, N = Total number of pieces from each log.

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Recovery rate was computed as follows;

$$\text{Recovery rate} = \frac{Total\ volume\ of\ lumber\ produced\ (m3)}{Total\ volume\ of\ logs\ used\ (m3)} * 100 \ldots\ldots\ldots\ldots Equation\ 3$$

Volume of sawdust generated was computed as described below, (Babatola, *et al*., 2012).

$$Vsd = b.1 \int_{1}^{n} w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 4$$

Where; Vsd – Volume turned to dust, m^3, *b* – Kerf of the saw blade, *l* – Length of the log, *w* – Width of each plank at the point of cut,

Volume of off-cuts was computed as follows;

$$Voff = Vl - (Vt + Vsd) \ldots\ldots\ldots\ldots\ldots\ldots Equation\ 5$$

Where; *Voff* – Volume of offcuts, *Vl* – Volume of log, *t* – Total volume of lumber, *Vsd* – Volume of sawdust

Estimating Lumber Production Capacity

Lumber production capacity was determined as follows: At the start of lumber conversion, initial time (t_1) was recorded. Consequently, final time (t_2) was recorded at the end of lumber conversion. With volumes (V) of lumber and the time input, production capacity was estimated using the following production rate formula (equation 6):

$$P = \frac{V}{t2 - t1} \ldots\ldots\ldots\ldots\ldots\ldots Equation\ 6$$

Whereby; P = Lumber Production rate (m^3/hour), V = the total volume of lumber produced in cubic meters, t_1 = initial time in hours and; t_2 = the final times in hours.

RESULTS AND DISCUSSION

Lumber Recovery Rates

Table 1 reports the % lumber recovery rates of *C. lusitanica* and *P. patula* from WoodMizer band saws LT15, LT20, and LT40. In each experiment four (4) logs of *C. lusitanica* and *P. patula* were separately converted into lumber and recovery calculated as a percentage of the initial log volume.

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Table 1: Recovery Rates (%) of *C. lusitanica* and *P. patula* Lumber from Different Sawmills

	Recovery Rates (%)			
Lumber Species	**WoodMizer Type**	**LT15**	**LT20**	**LT40**
C. lusitanica	Mean	43.13	49.42	52.77
	Std. Dev (±)	10.52	15.35	12.38
	Minimum	24.53	12.46	26.8
	Maximum	66.99	74.02	73.58
P. patula	Mean	38.77	33.61	60.32
	Std. Dev (±)	6.07	4.82	15.41
	Minimum	30.77	24.91	32.16
	Maximum	57.85	40.78	87.36

The average lumber recovery rate for *C. lusitanica* logs while using LT15 was 43.1% and compares well with the yield of 49.4 % and 52.8% from LT20 and LT40 respectively. On the other hand, the average lumber recovery rate for *P. Patula* ranged from 38.8% to 60.3% from LT15 and LT40 respectively. The low recovery rates recorded for LT15 in comparison to LT20 and LT40 is explained by the fact that this machine operates on manual log handling and a mobile control centre that can lead to fatigue of the sawmilling crew hence poor decision making. In comparison with *P. patula, C. lusitanica* had a higher rate of recovery while using LT15 and LT20 which is attributed to ease in workability among *C. lusitanica* logs (USDA Forest Service, 2010). Similarly, *P. patula* trees emit terpenes which are responsible for the trees' sticky resin and pine scent that is reported to reduce ease in workability and slow down the rate of lumber conversion by altering tensile strength and modulus of elasticity (Yang *et al.*, 2020).

In all cases, lumber conversion rate using WoodMizer LT40 was the highest irrespective of wood species. Increased level of automation in the WoodMizer LT40 machine involving automatic log loading arms, an automatic log turner and a static control centre contributes to its better performance (WoodMizer, 2018). Generally, increased automation in sawmilling machines reduces errors emanating from decision making by the sawmilling crew (WoodMizer, 2018).

C. lusitanica and *P. patula* lumber recovery rates across the three different WoodMizer machines (LT15, 20, and 40) are weakly correlated and not statistically significant $p \geq 0.0001$. *C. lusitanica* mechanical properties such as density, shear parallel to grain, and tensile strength make it harder to convert into lumber than *P. patula,* however, the presence of sticky resins in pines also serves as a hindering factor (Yang *et al.,* 2020).

Effect of Log Diameter on Lumber Recovery Rates

Table 2 reports the minimum and maximum lumber recovery rates across different diameter classes of both *C. lusitanica* and *P. patula* logs. Lumber recovery (%) from the three WoodMizers (LT15, 20, and 40) varied with the diameter classes of the logs and species. For the smaller diameter classes, the % recovery was characteristically low due to the high surface to volume ratio of the logs. Normally, large diameter logs yield more lumber per volume of input than small diameter logs (Steele, 1984).

Logs with lesser diameters gave high wastages and hence lesser recovery rates whereas logs with large diameters had high recovery rates. The general trend is that an increase in the diameter of logs and hence volume across species, lead to an increase in lumber recover rate. The conversion efficiency for *C. lusitanica* is however generally higher than that of *P. patula* due to differences in mechanical and

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chemical properties between the two species (Yang *et al.*, 2020).

Table 2: Comparative Recovery Rates for Logs with Varying Sizes

Lumber Recovery (%) min and max						
WoodMizer Type	**LT15**		**LT20**		**LT40**	
Species **Diameter Class (cm)**	***C. lusitanica***	***P. patula***	***C. lusitanica***	***P. patula***	***C. lusitanica***	***P. patula***
0 – 14	40	38	23	27	40	32
	48	31	12	27	42	41
15-19	31	58	60	25	44	39
	33	44	53	29	43	46
20-24	43	50	57	28	46	50
	42	38	55	31	27	56
25-29	46	42	34	32	48	56
	25	39	48	33	52	83
30-34	43	37	54	33	54	69
	36	34	74	34	57	76
35-39	44	36	50	35	59	75
	46	37	60	34	61	81
40-44	32	37	31	36	42	87
	48	40	62	37	62	64
45-49	29	34	45	35	68	53
	67	35	58	37	62	72
50-54	44	35	40	39	40	54
	49	35	67	41	67	53
55-59	60	37	42	40	69	58
	56	39	64	41	74	62
Average	43	39	49	34	53	60

Lumber Conversion Efficiency

Table 3 reports lumber conversion efficiency and recovery from LT15, 20, and 40 WoodMizers. Lumber conversion efficiency was ranked in a 3-point Likert scale as Moderate (30-40% recovery), good (41-55% recovery), and excellent (56- 70%). *C. lusitanica* exhibited better conversion efficiency than *P. patula* when using WoodMizers LT15 and LT20 but vice versa on WoodMizer LT40.

Table 3: Conversion Efficiencies and Recovery Percentages

WoodMizer Type	**Wood Species**	**Log Volume (m^3)**	**Lumber Volume (m^3)**	**Conversion Efficiency**	**Recovery (%)**
LT15	*C. lusitanica*	7.84	3.60	Good	46
	P. patula	10.40	3.86	Moderate	37
LT20	*C. lusitanica*	8.37	4.33	Good	52
	P. patula	9.77	3.60	Moderate	37
LT40	*C. lusitanica*	9.77	5.81	Excellent	59
	P. patula	9.20	5.87	Excellent	64

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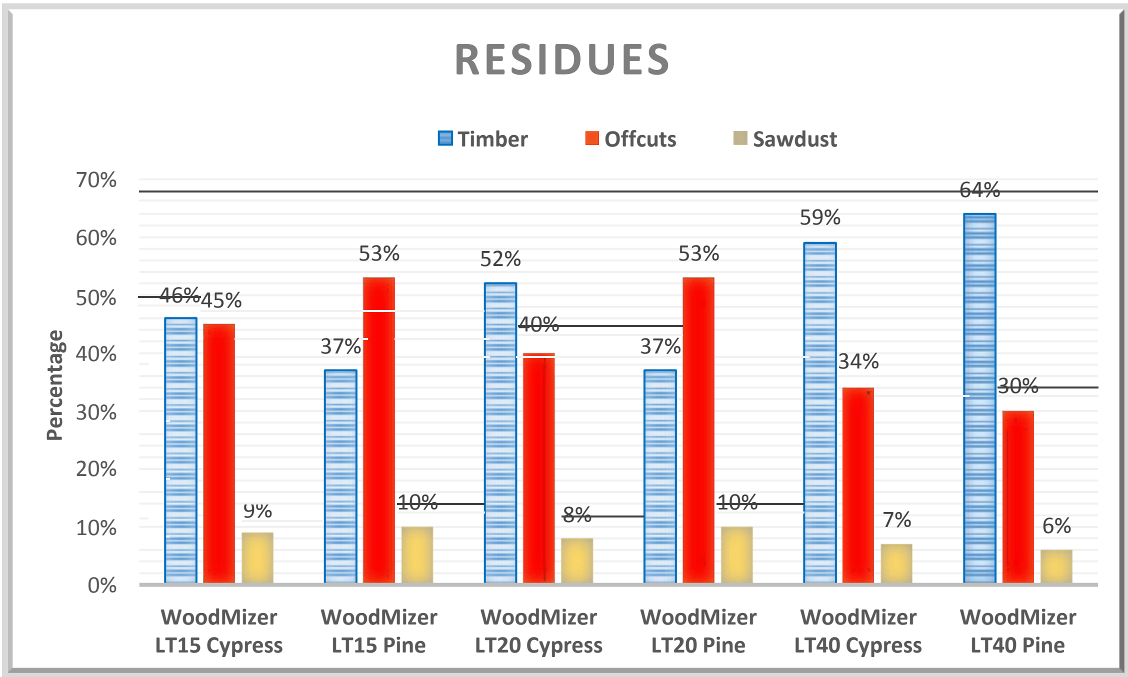
Estimating Volume of Residues and Lumber

A comparative study was carried out to evaluate the volume and type of residues generated during the sawing of *P. patula* and *C. lusitanica* logs using WoodMizers LT15, 20, and LT40. Results are presented in *Figure 1* and *Table 4.*

Figure 1: % of Lumber, Sawdust and Off-cuts Generated



WoodMizer LT15 saw machine, produced the most residues (at 63% of the *P. patula* log volume) compared to *C. lusitanica* (at 47% of the *P. patula* log volume). The same trend was observed when using WoodMizer LT20. This is attributed to the prohibitive chemical compounds such as resins in *P. patula* logs that offer resistance to the streamlined movement of saw blades through the *P. patula* logs hence interfering with ease of log control during sawmilling. WoodMizer LT40 produced the least residues at 41% of *C. lusitanica* and 36% of *P. patula* logs. When converting *P. patula* logs with both WoodMizers LT15 and LT20, the volume of residues was more than the volume of lumber (*Figure 1*).

Table 4: Type and Amount of Residues

WoodMizer Machine	Lumber Species	Log Volume (m^3)	Lumber volume(m^3)	Off cuts volume(m^3)	Sawdust Volume(m^3)
LT15	*C. lusitanica*	7.84	3.6	3.56	0.68
	P. patula	10.4	3.86	5.50	1.04
LT20	*C. lusitanica*	8.37	4.33	3.40	0.64
	P. patula	9.77	3.6	5.19	0.98
LT40	*C. lusitanica*	9.77	5.81	2.50	1.46
	P. patula	9.2	5.87	2.82	0.51

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Lumber Production Capacity of WoodMizer Machines

Table 5 reports lumber production capacities of LT15, LT20, and LT40 WoodMizer machines. WoodMizer LT40 recorded the highest daily production capacity for both *C. lusitanica* and *P. patula* (15.9 m^3/day and 16.2 m^3/day) respectively. This was followed by WoodMizer LT20 at 11.2 m^3/ day and 9.6 m^3/day for *C. lusitanica* and *P. patula* respectively. The daily production capacity for WoodMizer LT15 was the least at 8.8 m^3/ day and 9.9 m^3/ day for *C. lusitanica* and *P. patula* respectively.

Table 5: Lumber Production Capacities of the WoodMizer machines.

WoodMizer Type	Log Species	Log Volume (m^3)	Lumber Volume (m^3)	Time (Hrs)	Log (m^3)/hr	Lumber (m^3) /hr	Log (m^3)/day	Lumber (m^3)/day
LT15	*C. lusitanica*	7.84	3.6	3.27	2.4	1.1	19.18	8.8
	P. patula	10.4	3.86	3.13	3.32	1.23	26.57	9.87
LT20	*C. lusitanica*	8.37	4.33	3.08	2.72	1.4	21.75	11.23
	P. patula	9.77	3.6	3.02	3.24	1.19	25.88	9.55
LT40	*C. lusitanica*	9.77	5.81	2.93	3.33	1.98	26.68	15.9
	P. patula	9.2	5.87	2.9	3.17	2.02	25.37	16.2

These results meant that WoodMizer LT40 was the most productive of the three WoodMizers with a production capacity of 1.8 times that of LT15 for *C. lusitanica* and 1.6 times when processing *P. patula.* A study on the sawmill production capacity in selected sawmills in Alaska, United States of America found out that Western Gold Cedar products Sawmill, while operating at 12% of the installed capacity produced 1.9 m^3 of lumber in a day (USDA Forest Service, 2016). At full capacity, this sawmill would produce 15.83 m^3 which is comparable with the WoodMizer LT40 production capacity in this study.

CONCLUSION

Conversion efficiency of WoodMizer LT15 was classified as moderate (38.7%), in comparison with LT20 which was classified as good (46%) and LT40 as excellent (60%). Recovery of *C. lusitanica* gave average empirical values of 43%, 49%, and 53% in comparison with 39%, 34%, and 60% for *P. patula* using WoodMizer LT15, LT20, and LT40 respectively. LT40 gave the highest recovery rates (74% and 87%) for different top diameter classes of *C. lusitanica* and *P. patula* respectively. *P. patula* produced the most residues (63%) compared to *C. lusitanica* (54%) per log volume from LT15 with the same trend being witnessed for LT20 but less from LT40 (41% for *C. lusitanica* and 36% for *P. patula* logs. WoodMizer LT40 recorded the highest daily production capacity for both *C. lusitanica* and *P. patula* (15.9 m^3/day and 16.2 m^3/day) respectively. This was followed by WoodMizer LT20 at 11.2 m^3/ day and 9.6 m^3/day for *C. lusitanica* and *P. patula* respectively. WoodMizer LT15 had the least production capacities of 8.8 m^3/ day and 9.9 m^3/ day for *C. lusitanica* and *P. patula* respectively. These results suggest that LT40 WoodMizer band saw is best suited for lumber production in Kenya.

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management to participate in this experimental study and playing a key role by availing the necessary WoodMizer machines and log materials.

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