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Pre-Treatment condition and preservative treatment quality of Eucalypt electricity distribution poles in Uganda

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Abstract:
The durability of wooden poles is important for reliable electricity distribution. In Uganda, premature failure of treated poles has caused substantial replacement costs, yet the condition of poles presented for treatment and the consistency of preservative treatment achieved by treatment plants have not been sufficiently characterized as potential quality-control concerns. This study assessed moisture content, sapwood depth and drying defects in seasoned *Eucalyptus* poles before preservation, and preservative penetration and retention after treatment. Two separate and independent sets of poles were assessed. The first comprised 338 untreated, air-seasoned poles awaiting preservative treatment, while the second comprised 338 treated poles, consisting of 278 CCA-treated and 60 creosote-treated poles. Thus, a total of 676 poles were assessed**.** The poles, obtained from six treatment companies in Uganda, were 9 m, 10 m, 12 m and 14 m in length. Among the untreated poles, mean moisture content was 28,5% at the theoretical ground line (TGL) and 30 % at the midpoint, while mean sapwood depth was 23,75 mm. Sapwood depth was moderately positively correlated with surface-check depth. Among the treated poles, mean CCA penetration was 23 mm at TGL and 21 mm at midpoint, while mean CCA retention was 21,8 kg/m³ and 18,3 kg/m³, respectively. For creosote-treated poles, mean penetration was 27 mm at TGL and 21 mm at midpoint, while mean retention was 254,7 kg/m³ and 173,3 kg/m³, respectively. The results demonstrate variability in pole conditioning, drying defects and preservative-treatment quality among the sampled plants. These conditions may be relevant to subsequent durability, but the study did not follow the sampled poles in service and therefore does not establish them as direct causes of premature failure. The findings support stronger quality control of pole conditioning, drying defects, and preservative penetration and retention before poles enter service.

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Keywords: Eucalyptus, moisture content, preservative penetration, preservative retention, utility poles, wood preservation.

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Introduction

Wood utility poles are an important asset that represent a significant product of the forest resource for electricity transmission (Butler and Sass 2023). If properly maintained, poles are estimated to have a life span of 50 years or more when installed in the field (Salman and Li 2016). The durability of wooden poles in the electrical power distribution network is vital, as it directly affects the entire power system network connected to them. Wooden poles support power line conductors and carry electrical equipment for electricity to be transmitted and distributed safely from the power company to consumers (Boreman 2020). Wood utility poles are, therefore, regarded as valuable components of a power distribution network and have been utilized for many years to support power lines all over the world due to their low installation and maintenance cost, excellent durability and high strength per unit weight when they are accurately treated with good preservatives (Gezer *et al.* 2015). These poles are also considered normal aspects of our day-to-day landscape and are the most visible components of distributing electricity. Therefore, power companies are expected to continue with substantial investment in wooden poles worldwide (Ryan *et al.* 2015).

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According to Otuko *et al.* (2024), premature pole failure is attributed to mostly fungal decay and termite damage. *Eucalyptus* which is the most planted fast-growing hardwood genus is largely used for utility poles in Uganda (Ribera *et al.* 2017). In 2002, the National Forestry Resources Research Institute (NaFORRI) in Uganda introduced *Eucalyptus* hybrids from South Africa which are fast-growing and more resistant to harsh climatic conditions (Mugabi and Otuko 2019). The hybridization and introduction of fast-growing *Eucalyptus* as supplements to rose gum (*Eucalyptus grandis* W.Hill) was aimed at increasing the supply of wooden poles to meet the increasing national electrification demands, among others reasons. It should be noted that the use of fast-growing *Eucalyptus* hybrids requires a special preservation procedure since they tend to have higher proportions of sapwood and are generally less durable (Poonia *et al.* 2015).

These *Eucalyptus* poles are primarily treated with coal tar creosote as a preservative. However, there has been an increasing adoption of Copper Chrome Arsenate (CCA) preservative as an alternative treatment chemical. The treatment methods used involve pressure/vacuum processes to ensure good preservative penetration and retention (Ssemaganda *et al.* 2011, Mugabi and Thembo 2018).

For effective preservative treatment, utility poles need to be seasoned sufficiently to reduce free water in the sapwood and facilitate preservative penetration and retention (Kirker and Lebow 2021). Wood can develop defects, particularly surface checks and end splits, after harvesting and during processing, which can complicate seasoning and subsequent utilization (Mugabi 2007, Mugabi *et al.* 2010). High initial moisture content has also been associated with increased checking and collapse during drying of Eucalyptus wood (Sargent *et al*. 2017).

Pressure treatment of wooden utility poles with copper chrome arsenate (CCA) and creosote is widely used in Uganda to improve durability (Mugabi and Otuko 2019). Otuko *et al.* (2024)

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reported an average service life of about 10 years for treated wooden distribution poles in Uganda and identified fungal decay and termite damage as major causes of failure in service. Previous studies further show that adequate seasoning is necessary for preservative uptake and that drying defects can expose less-protected wood to biological deterioration (Kirker and Lebow 2021, Mugabi *et al.* 2010). However, it remains unclear whether poles presented for treatment in the sampled Ugandan plants consistently meet conditioning requirements, how sapwood depth and drying defects vary among plants, and whether preservative penetration and retention are achieved consistently after treatment. Resolving this uncertainty is important because these are measurable quality-control attributes before poles enter service and are known to influence durability, even though their direct effect on subsequent pole failure was not tested in this study. Accordingly, the objectives were to: i) assess moisture content, sapwood depth and drying defects in seasoned poles at the time of treatment; and ii) evaluate preservative penetration and retention after treatment.

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Materials and methods

The study involved two separate and independent sets of Eucalyptus utility poles obtained from six pole treatment companies in Uganda. A total of 338 untreated, air-seasoned poles awaiting preservative treatment were selected for assessment of their condition before treatment. A separate sample of 338 treated poles, comprising 278 CCA-treated poles and 60 creosote-treated poles, was selected for assessment of preservative penetration and retention. Thus, a total of 676 poles were

assessed across the two sampling groups. The untreated and treated poles were different individual poles and, therefore, the study did not involve repeated measurements of the same poles before and after preservative treatment.

Sampling and measurements on seasoned poles

Six pole treatment companies operating in Central Uganda were purposively selected based on accessibility. A total of 338 untreated *Eucalyptus* poles were randomly selected from air seasoned poles awaiting treatment from the six treatment companies. The *Eucalyptus* poles selected were of an average age of 10 years with varying lengths of 9 m, 10 m, 12 m and 14 m and top diameter range of 150 - 220 mm. For each pole specimen, moisture content was measured using a digital electrical moisture meter. The electrodes were driven into each selected pole at 1,5 meters (TGL) and the midpoint (MP) positions to a depth of 25 mm so that the line between the tips of the electrodes is in the direction along the grain (Mugabi and Thembo 2018). Three measurements were made and the average MC recorded at each measuring point for further analysis. The depth of sapwood was measured at both the top and butt ends of each pole using a ruler. Three measurements were taken at each end by placing the ruler horizontally against the pole cross section (Figure 1) and the sapwood depth at each pole end (D) determined as the average of the three readings (Arisandi *et al.* 2023).

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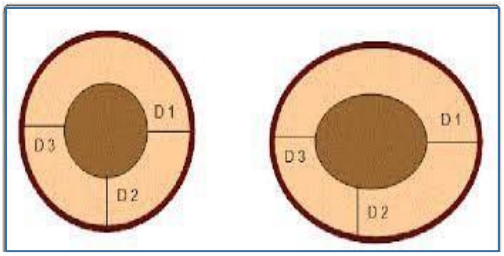


Figure 1: Measurement positions for sapwood depth (content)

The overall sapwood depth per pole was calculated as the average of the top and butt sapwood depth readings. The number of surface and end checks present on each sample pole were counted and recorded. The lengths of individual checks were measured using a ruler whereas the depth was measured using an improvised gauge and ruler (Mugabi *et al.* 2010).

Sampling and measurements on treated poles

A total of 278 CCA treated and 60 creosote treated poles from the six treatment plants were assessed. The preservative treatment method used in all the treatment plants assessed was full cell pressure treatment. Two increment sample cores of approximately 40 mm depth were extracted from each treated pole at TGL and the other at the midpoint, then taken to the laboratory. The extracted wood core samples were then spread on a graduated plate, and the length of the part covered by the preservative measured to determine the penetration. CCA retention was determined according to the SANS 673:2017 (2017) standard using the X-ray fluorescence spectrometry

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(XRFS). The results for each element from the three sample analyses were averaged and the copper, chromium, and arsenic content recorded in g/l. To determine creosote retention, the sections of the samples with visible preservative were weighed. The borings were weighed and placed in an extraction cup in a flask where toluene, used as a solvent, was boiled. Toluene and water vapors condensed into a calibrated water trap, with toluene forming a top layer. Condensed toluene cycled over the borings, extracting the chemical until the solvent was clear and water ceased collecting. The samples were oven-dried to evaporate toluene and then reweighed to obtain the weight difference between the initial and final weights of the borings. The amount of creosote extracted was calculated as the difference between the initial weight of the borings and their final oven-dry weight. This mass of extracted oil, expressed per unit volume of wood sampled, provided the measure of creosote retention in kilograms per cubic metre (kg/m^3) (Mugabi and Thembo 2018).

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Data analysis

Descriptive statistics i.e. the mean was determined for: moisture content; sapwood depth; drying defect parameters; and preservative penetration and retention. Levene's test for equality of means was used to test the difference in moisture content at TGL and mid-point positions for the poles measured. Pearson's correlation coefficient (r) was used to determine the relationship between sapwood depth and surface check depth, length, and width. One-way ANOVA was used to show

the variation of: drying defect parameters; and CCA, creosote penetration and retention among pole treatment companies. A paired-samples t-test was used to test for variation in the mean moisture content at TGL and MP. The T-test was also used to test variation in CCA and creosote penetration and retention at TGL and MP.

Results and discussions

Moisture content in air seasoned poles at treatment

The 338 air-seasoned poles had mean moisture contents of 28,51 % at the theoretical ground line (TGL) and 30,02 % at the midpoint (MP) (Table 1). Company midpoint means ranged from 25,07% (Company 5) to 38,56 % (Company 6), while TGL means ranged from 23,42 % to 34,57 %. Against the DEAS 322:2023 (EAC, 2023a) criteria cited in this study, the overall batch mean exceeded the 25 % requirement at both positions. All six individual company midpoint means exceeded 25 %, whereas five of the six TGL company means exceeded 25 %; only Company 5 had a TGL mean below this threshold. At the individual-pole level, 172 of 338 poles (50,9 %) exceeded 28 % at MP and 131 (38,8 %) exceeded 28 % at TGL. Considering both measurement positions, 195 poles (57,7 %) exceeded 28 % at one or both positions. Because MP and TGL were

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measured on the same poles, a paired-samples t-test was used. Moisture was on average 1,51 percentage points higher at MP than at TGL (95 % CI 1,07–1,95; t (337) = 6,72, p < 0,001). The observed non-compliance indicates inconsistent conditioning before treatment. This is relevant to preservative treatment because excessive free water can restrict preservative uptake, although this study did not directly test moisture content as a cause of later pole failure (Kirker and Lebow 2021, Wood *et al.* 2020).

Table 1: Moisture Content at MP and TGL positions for the different treatment companies.

Treatment company	N	Moisture at MP, mean ± SD (%)	Moisture at TGL, mean ± SD (%)
1	65	29,08 ± 4,34	29,28 ± 5,83
2	43	28,07 ± 3,31	27,19 ± 4,07
3	67	30,22 ± 5,79	28,96 ± 4,90
4	63	29,25 ± 3,66	27,38 ± 3,53
5	50	25,07 ± 2,81	23,42 ± 2,57
6	50	38,56 ± 7,54	34,57 ± 5,51
Overall	338	30,02 ± 6,21	28,51 ± 5,53

N = sample size; SD = standard deviation; MP = midpoint; TGL = theoretical ground line.

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Sapwood depth

The 338 untreated poles had a mean sapwood depth of 23,75 mm (SD = 4,52 mm) as shown in Table 2, and it was ranging from 15 to 39 mm. This mean was below the 25 mm minimum sapwood

thickness required by DEAS 322:2023 (EAC, 2023a) from the butt to 1 m above the proposed ground level, indicating that, on average, the sampled poles did not attain this requirement. The standard also requires at least 20 mm sapwood thickness along the remainder of the pole. The finding supports the importance of retaining adequate sapwood during pole preparation because sapwood is the principal treatable zone for preservative penetration. This agrees with Mugabi and Thembo (2018), who demonstrated that preservative penetration and retention in Ugandan Eucalyptus utility poles vary with pole characteristics.

Table 2: Descriptive and one sample t-test statistics for sapwood depth.

Variable	N	Mean (mm)	SD	SE	Test value (mm)	t	df	p-value (2-tailed)	Mean difference (mm)
Sapwood depth	338	23,75	4,516	0,246	25,00	−5,095	337	<0,001	−1,251

N = sample size; SD = standard deviation; SE = standard error; CI = confidence interval. The one-sample t-test used a test value of 25 mm.

Drying defects

The average surface-check length per pole was 421,55 mm, ranging from 315,26 mm in Company 1 to 538,98 mm in Company 2. Total surface-check length per pole averaged 1930,01 mm and ranged from 70 to 8299 mm (Table 3). Average surface-check length represents the typical length of checks on each pole, while total surface-check length represents their cumulative length.

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DEAS 322:2023 (EAC, 2023a) recognizes checks as seasoning-related defects and emphasizes proper seasoning and control of defects in utility poles. The findings align with Mugabi *et al.* (2010) and Sargent *et al.* (2017), who reported checking as an important drying defect in *Eucalyptus*. Such checking is therefore a quality-control concern before treatment, although this study did not establish it as a direct cause of premature pole failure.

Table 3: Surface check parameters in the different treatment companies.

Parameter	Company	N	Mean (mm)	SD	SE	Minimum (mm)	Maximum (mm)
ISCL	1	65	315,26	129,667	16,083	95	611
ISCL	2	43	538,98	206,732	31,526	273	1179
ISCL	3	67	471,82	226,785	27,706	70	1210
ISCL	4	63	447,00	188,571	23,758	76	1093
ISCL	5	50	404,20	101,057	14,292	245	689
ISCL	6	50	376,66	181,314	25,642	70	980
ISCL	Overall	338	421,55	190,538	10,364	70	1210
TSCL	1	65	1608,91	1111,933	137,918	100	4885
TSCL	2	43	2231,67	1286,320	196,162	570	5895
TSCL	3	67	1349,03	1056,740	129,101	70	4531
TSCL	4	63	1921,75	1344,471	169,387	76	6559
TSCL	5	50	3647,80	1618,222	228,851	744	7583
TSCL	6	50	1159,14	1360,535	192,409	70	8299
TSCL	Overall	338	1930,01	1505,577	81,893	70	8299

ISCL = individual surface-check length; TSCL = total surface-check length per pole; N = sample size; SD = standard deviation; SE = standard error. All length measurements are expressed in millimeters (mm).

For a pole with several checks, individual surface-check length (ISCL) was interpreted as the arithmetic mean of the lengths of its recorded checks, whereas total surface-check length (TSCL) is their sum. Surface checking was evaluated using individual surface-check length (ISCL) and total surface-check length per pole (TSCL) to distinguish the severity of individual checks from cumulative checking. Across the 338 poles, mean ISCL was 421,55 ± 190,54 mm, while mean TSCL was 1930,01 ± 1505,58 mm per pole. Company 2 recorded the highest mean ISCL (538,98

mm**)**, whereas Company 5 had the highest mean TSCL **(**3647,80 mm per pole**)** as highlighted in Table 3. Mugabi and Thembo (2018) reported an average butt-end diameter of 261 mm for Eucalyptus utility poles in Uganda. Using this as a representative butt-end diameter, the DEAS 322:2023 (EAC, 2023a) limit of eight times the pole diameter gives a maximum individual surface-check length of approximately 2088 mm at the butt end. The maximum ISCL recorded in the present study (1210 mm) was below this limit, indicating compliance with the individual surface-check length requirement. Nevertheless, the high TSCL observed in some poles, particularly from Company 5, indicates considerable cumulative checking and highlights the importance of controlling drying defects during seasoning.

Across the 338 poles, total surface-check length averaged 1930 mm per pole, while individual surface-check length averaged 421,55 mm. Surface-check width and depth averaged 2,58 mm and 19,92 mm, respectively. End checks averaged 252,65 mm in length, 76,19 mm in depth and 3,02 mm in width (Table 4). DEAS 322:2023 (EAC, 2023a) permits surface checks up to 15 mm wide; therefore, the observed maximum width of 5 mm was within the standard. Using the 261 mm average pole diameter, the permissible individual surface-check length was approximately 2088 mm, above the observed maximum of 1210 mm. For end checks, DEAS 322:2023 (EAC, 2023a) limits their length according to their location on the pole, including twice the top diameter and five times the butt diameter. The findings therefore indicate generally acceptable surface-check dimensions, although the maximum end-check length of 1617 mm suggests severe end checking in some poles.

Table 4: Descriptive statistics for surface and end checks.

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Defect Parameter (mm)	Minimum	Maximum	Mean
Total surface check length	70	8299	1930
Individual surface check length	70	1210	421,55
Surface check width	1	5	2,58
Surface check depth	3	99	19,92
End check length	22	1617	252,65
End check depth	5	260	76,19
End check width	2	12	3,02

SC = surface check; EC = end check. Values are expressed in millimeters.

One-way ANOVA indicated statistically significant differences among treatment companies for all reported drying-defect parameters (Table 5). The results demonstrate variability in observed defect levels among plants, but they do not by themselves establish which processing or seasoning practice caused that variation. Surface checking is practically relevant because severe checks can reduce mechanical performance and expose less-protected wood (Mugabi *et al.* 2010).

Table 5: Analysis of variance for drying defects.

Drying-defect variable	Between-groups SS	Between df	Between MS	Within-groups SS	Within df	Within MS	Total SS	Total df	F	p-value
SC width	9,009	5	1,802	100,350	332	0,302	109,359	337	5,96	<0,001
SC depth	1577,627	5	315,525	39058,657	332	117,647	40636,284	337	2,68	0,022
EC length	2580073,993	5	516014,799	51154305,400	332	154079,233	53734379,400	337	3,34	0,006
SC length	1653181,044	5	330636,209	10581500,600	332	31871,990	12234681,640	337	10,30	<0,001
EC depth	68383,785	5	13676,757	475938,715	332	1433,550	544322,500	337	9,54	<0,001
EC width	27,795	5	5,559	405,257	332	1,221	433,052	337	4,55	<0,001

Surface-check (SC) length was weakly but significantly positively correlated with SC width ($r = 0,274$, $p < 0,05$), while sapwood depth was moderately positively correlated with SC depth ($r = 0,507$, $p < 0,05$) (Table 6). The observed result therefore supports an association between greater sapwood depth and deeper surface checks. Previous literature indicates that sapwood proportion

and checking can vary with growth characteristics and age, which may provide a possible explanation for the observed association (Mugabi *et al.* 2010).

Table 6: Pearson Correlation Coefficients for selected surface checks.

Correlation pair	Pearson r	p-value (2-tailed)
SC length and SC width	0,274	<0,001
Sapwood depth and SC depth	0,507	<0,001
SC width and SC depth	0,156	0,004

SC = surface check. Pearson r indicates the direction and strength of the linear association.

Preservative penetration at TGL and midpoint

Preservative penetration results are presented in Table 7.

Table 7: Preservative penetration and independent-samples t-test results.

Preservative	TGL mean (mm)	Midpoint mean (mm)	Levene F	Levene p	t	df	p-value	Variance assumption
CCA	23	21	1,204	0,274	2,11	208	0,035	Equal variances assumed
Creosote	27	21	25,890	<0,001	3,913	115	<0,001	Equal variances not assumed

For CCA-treated poles, mean preservative penetration was 23 mm at the theoretical ground line (TGL) and 21 mm at the midpoint. The reported independent-samples t-test indicated a statistically significant difference between the two sampling positions (t = 2,11 df = 208, p = 0,035) (Table 7).

Because Levene's test was not significant (F = 1,204, p = 0,274), the equal-variances-assumed result is interpreted. Thus, CCA penetration was significantly greater at TGL than at the midpoint. The result indicates non-uniform preservative distribution along the assessed pole positions; it should not, however, be interpreted as proof that sampling position itself caused the difference.

Creosote-treated poles similarly recorded greater mean penetration at TGL (27 mm) than at the midpoint (21 mm). Levene's test was significant (F = 25890, p < 0,001), indicating unequal variances; consequently, the unequal-variances result is the appropriate statistic to interpret (t = 3,913 df = 115, p < 0,001).

The observed variation is consistent with the broader understanding that preservative penetration is influenced by wood anatomy and pole characteristics. Mugabi and Thembo (2018) reported that pole size affects preservative penetration and retention in air-dried Ugandan-grown Eucalyptus utility poles, while Kirker and Lebow (2021) explain that effective pressure treatment depends on the permeability of the treatable wood and adequate conditioning before treatment. The present findings therefore reinforce the importance of assessing penetration through the treatable sapwood rather than relying on treatment application alone. Ssemaganda *et al.* (2011) further demonstrated the importance of preservative treatment for protecting Ugandan-grown *Eucalyptus grandis* against termite attack, supporting the practical importance of adequate preservative distribution.

Figure 2 shows company-level differences in CCA penetration relative to the cited standards.

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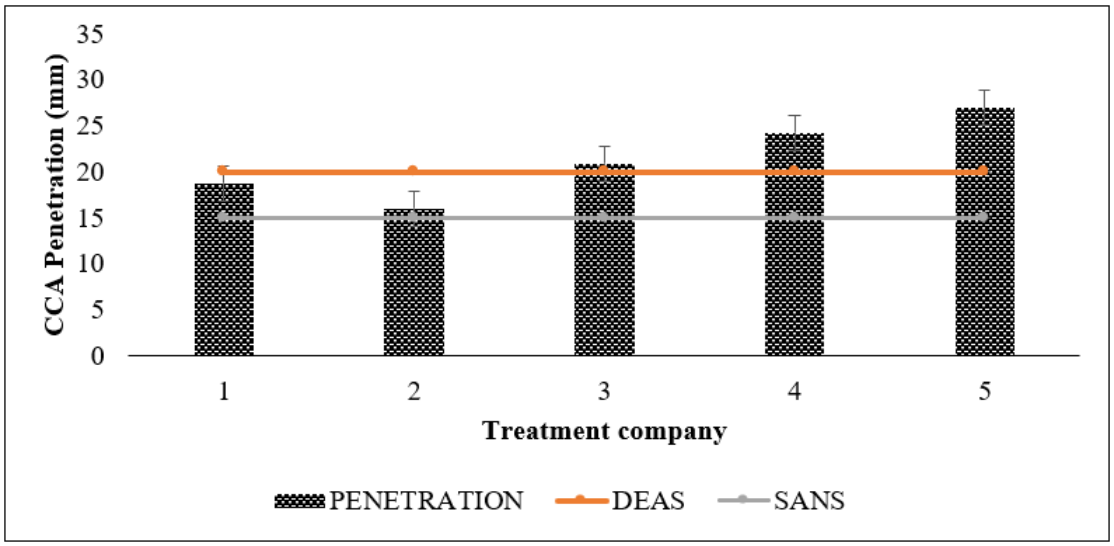


Figure 2: Comparison of CCA penetration with acceptable standards (DEAS 324:2023 (EAC, 2023b) and SANS 673:2017 (SABS, 2017).

Five sampled treatment companies reportedly met the cited SANS 673:2017 (SABS, 2017) penetration specification at midpoint, whereas three met the cited DEAS 324:2023 (EAC, 2023b) requirement. This means that statistical significance in Table 7 and standards compliance in Figure 2 describe different aspects of treatment quality: the t-test establishes whether mean penetration differed between TGL and midpoint, whereas the figure shows whether company-level penetration reached the specified acceptance threshold. The variation among companies is consistent with Mugabi and Thembo (2018), who found that Eucalyptus pole characteristics can influence penetration and retention.

Preservative retention at TGL and midpoint

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Retention results of CCA and creosote preservatives at both the TGL and midpoint are presented in Table 8.

Table 8: Preservative retention at TGL and midpoint and reported statistical interpretation.

Preservative	Position	Mean retention (kg/m^3)	p-value	Interpretation against the DEAS 322:2023 (EAC, 2023a) standard
CCA	TGL	21,8	<0,05	20 kg/m^3
CCA	Midpoint	18,3	<0,05	20 kg/m^3
Creosote	TGL	254,7	>0,05	115 kg/m^3
Creosote	Midpoint	173,3	>0,05	115 kg/m^3

Mean CCA retention was 21,8 kg/m^3 at TGL and 18,3 kg/m^3 at midpoint. The statistical test reports a significant positional difference ($p < 0,05$) (Table 8). When interpreted against the cited DEAS/EAS minimum retention of 20 kg/m^3, the TGL mean was above the benchmark whereas the midpoint mean was below it. This is important because adequate retention indicates that sufficient preservative has been introduced into the treated wood, while penetration describes how that preservative is distributed. Kirker and Lebow (2021) similarly emphasize that preservative performance depends on both adequate chemical loading and distribution within the treatable wood.

The company-level pattern in Figure 3 further demonstrates that the overall CCA mean does not describe all treatment plants equally.

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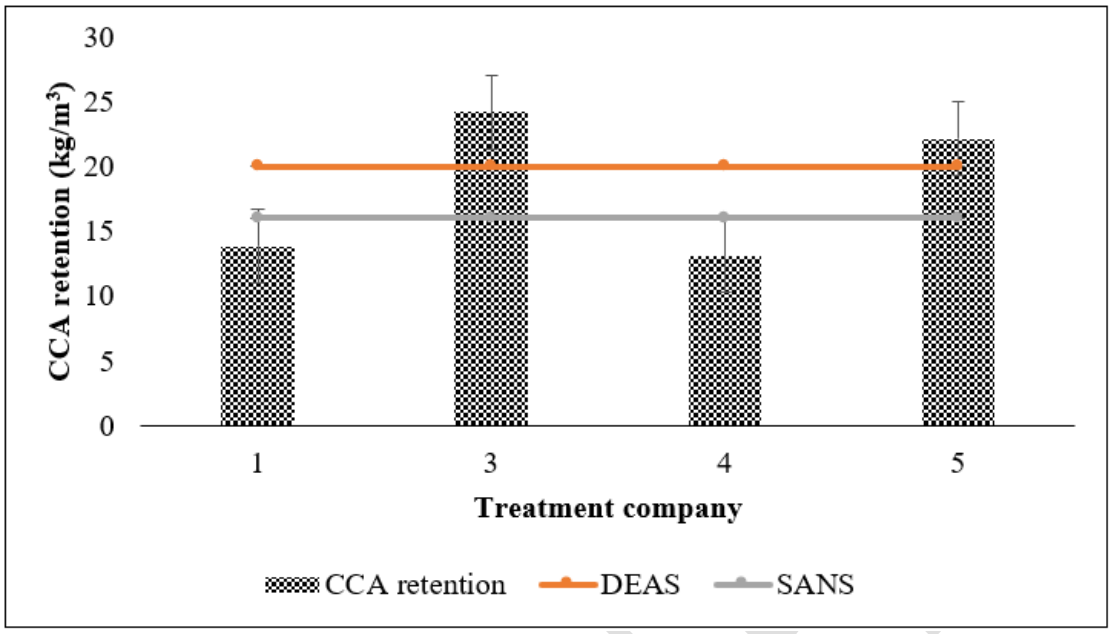


Figure 3: Comparison of CCA retention with DEAS 322:2023 (EAC, 2023a) (20 kg/m³) and SANS 673:2017 (SABS, 2017) (16 kg/m³) standards.

Two companies reportedly met the cited CCA retention requirements, two did not, while one company could not provide a retention measurement because its X-ray spectrometer was not functional. The inability to verify retention is itself a quality-control limitation because compliance cannot be demonstrated without a reliable measurement. This variation is consistent with Mugabi and Thembo (2018), who reported variation in preservative uptake in Ugandan-grown Eucalyptus utility poles and highlighted the influence of pole characteristics on treatment performance.

For creosote-treated poles, mean retention was 254,7 kg/m³ at TGL and 173,3 kg/m³ at midpoint. Although the TGL mean was numerically higher, the original analysis reports that the difference was not statistically significant ($p > 0,05$). Both means were nevertheless above the cited minimum retention requirement of 115 kg/m³. This illustrates the distinction between statistical significance and standards compliance: the two positions may not differ significantly while both still satisfy the specified minimum treatment requirement.

Figure 4 confirms that the reported mean creosote retention values were above the cited minimum at both sampling positions. This suggests adequate average chemical loading for the assessed creosote-treated poles according to the cited retention criterion.

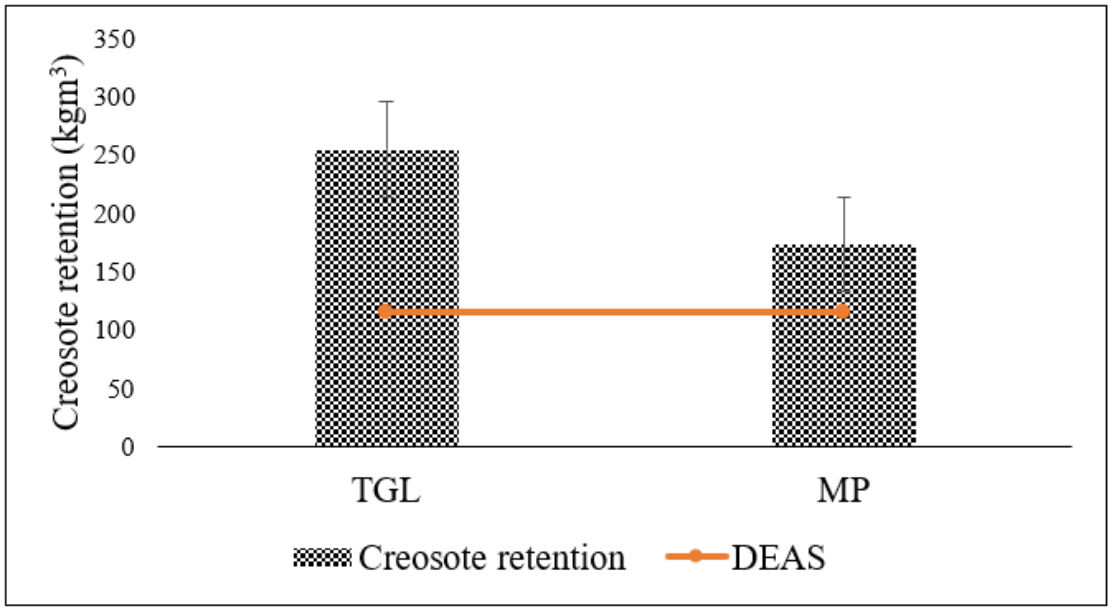


Figure 4: Comparison of creosote retention with the cited DEAS 322:2023 (EAC, 2023a) minimum requirement.

Conclusions

This study established that Eucalyptus poles sampled from six Ugandan treatment plants substantially varied in pre-treatment moisture condition, sapwood depth and drying defects. There was also variability in preservative penetration and retention after treatment among treatment plants. The overall midpoint moisture mean exceeded the cited DEAS 322:2023 (EAC, 2023a)

batch-mean criterion, drying-defect levels differed among companies, and greater sapwood depth was associated with deeper surface checking. These findings identify measurable quality-control issues at the conditioning stage.

Preservative-treatment assessment further showed that CCA penetration and retention were not uniformly compliant across the sampled companies, while, for creosote-treated poles, the pooled mean penetration and retention values at TGL and midpoint exceeded the cited minimum requirements; separate plant-level compliance was not demonstrated since only one treatment company dealt in Creosote preservative. The verified descriptive results showed higher mean penetration and retention at TGL than at midpoint for both preservative systems. These findings add evidence on the consistency of pole conditioning and preservative-treatment quality before poles enter service; they do not demonstrate that the measured conditions caused subsequent premature failure because the sampled poles were not followed in service.

For quality control, treatment companies should enforce the moisture requirements specified in the applicable standards, minimize drying defects during seasoning, and verify preservative penetration through the treatable sapwood rather than relying on bulk retention alone. Further research should link pre-treatment condition and treatment-quality measurements to subsequent field performance and evaluate pre-supply practices, including girdling and related seasoning interventions, for their ability to reduce checking.

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Author contributions

P. M.: Conceptualization, funding acquisition, methodology, supervision, writing – original draft. R. A.: Formal analysis, investigation, writing – original draft. B. M.: Investigation, software, formal analysis. E. O.: Validation, visualization, writing – original draft. J. N.: Formal analysis,

visualization, writing – review & editing. P. K.: Conceptualization, data curation, visualization. P. K.: Conceptualization, resources, validation. I. K.: Funding acquisition, project administration, resources.

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Conflict of interest

The authors declare no conflict of interest.

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