Mahadi Mussa, Getachew Desalegn, Gemechu Kaba, Anteneh Tesfaye[1]

Physical and Chemical Properties of Highland Bamboo (*Yushania alpina*) Culms Grown in Ethiopia

Fizička i kemijska svojstva gorskog bambusa (*Yushania alpina*) uzgojenoga u Etiopiji

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ABSTRACT • *Bamboo is the fastest growing plant currently known on earth, a property that enables it to be the best alternative as a future source of wood fiber. This study investigated the effect of site and culm height on the physical and chemical properties of Yushania alpina culms grown in Ethiopia. Matured Yushania alpina 3 to 5-year-old samples were harvested from Hagere-Selam and Rebu-Gebeya sites. The culms were subdivided into three equal lengths (bottom, middle, and top), and the variations in physical and chemical properties between the two sites and the culm heights of Yushania alpina were investigated. The results showed that the average values of MC, basic density, tangential and longitudinal shrinkage of Yushania alpina culms for Hagere-Selam and Rebu-Gebeya sites were (91.78 and 80.32 %), (0.65 and 0.63 g/cm^3), (6.63 and 5.84 %) and (0.63 and 0.56 %), respectively. The average values of cellulose, lignin, extractive and ash contents in the culms for Hagere-Selam and Rebu-Gebeya sites were (52.84 and 50.71 %), (26.55, and 26.04 %), (8.41 and 8.02 %) and (1.95 and 2.17 %), respectively. The results revealed that the site affected the MC, basic density, cellulose, lignin, extractive, and ash contents of Yushania alpina culms but not the tangential and longitudinal shrinkage. The culm height of Yushania alpina affected MC, basic density, tangential shrinkage, longitudinal shrinkage, cellulose, lignin, extractive, and ash contents. In the case of both sites, the highest percentages of MC, tangential and longitudinal shrinkage, and ash content were observed at the base and lowest at the top of the culms. On the contrary, both sites observed the highest magnitude of basic density, cellulose and extractive at the top and lowest at the base of the culms. The variations in physical and chemical properties at different sites and culm heights influence the utilization of Yushania alpina culms for industries and end products.*

KEYWORDS: *bamboo (Yushania alpina), basic density, cellulose, lignin, moisture content, shrinkage*

SAŽETAK • *Bambus je trenutačno najbrže rastuća biljka u svijetu, što je čini najboljom alternativom za budući izvor drvnih vlakana. Ovom je studijom istraživan utjecaj staništa i visine bambusa Yushania alpina, uzgojenoga u Etiopiji, na fizička i kemijska svojstva njegove stabljike. Uzorci Yushania alpina stari tri do pet godina skupljeni su sa staništa Hagere-Selam i Rebu-Gebeya. Stabljike su podijeljene na tri jednake duljine (baza, sredina i vrh) na kojima su istraživane varijacije fizičkih i kemijskih svojstava stabljike s obzirom na dva staništa i visinu bambusa. Rezultati su pokazali da su prosječne vrijednosti sadržaja vode, gustoće te tangentnoga i uzdužnog utezanja*

[1] Authors are researchers at Forest Products Innovation Centre, Ethiopian Forestry Development, Addis Ababa, Ethiopia. https://orcid.org/0000-0002-4276-5760; https://orcid.org/0000-0002-3157-2875; https://orcid.org/0000-0003-2019-1513; https://orcid.org/0000-0002-6952-5548; https://orcid.org/0000-0003-1747-9322

stabljike Yushania alpina sa staništa Hagere-Selam i Rebu-Gebeya bile 91,78 i 80,32 %; 0,65 i 0,63 g/cm³; 6,63 i 5,84 % te 0,63 i 0,56 %, a prosječne vrijednosti sadržaja celuloze, lignina, ekstraktiva i pepela sa staništa Hagere-Selam i Rebu-Gebeya bile su 52,84 i 50,71 %; 26,55 i 26,04 %; 8,41 i 8,02 % te 1,95 i 2,17 %. Rezultati su pokazali da je stanište utjecalo na sadržaj vode, gustoću te sadržaj celuloze, lignina, ekstraktiva i pepela u stabljikama Yushania alpina, ali ne i na tangentno i uzdužno utezanje. Visina stabljike Yushania alpina utjecala je na sadržaj vode, gustoću, tangentno i uzdužno utezanje te na sadržaj celuloze, lignina, ekstraktiva i pepela. Za oba staništa utvrđen je najveći sadržaj vode, tangentno i uzdužno utezanje te sadržaj pepela u bazi stabljike, a najmanji u vrhu stabljike. Nadalje, u vrhu stabljike s oba staništa primijećena je najveća gustoća, sadržaj celuloze i ekstraktiva, a najmanje su vrijednosti izmjerene u bazi stabljike. Varijacije fizičkih i mehaničkih svojstava s obzirom na stanište i visinu stabljike utječu na upotrebu stabljike Yushania alpina u industriji i za završne proizvode.

KLJUČNE RIJEČI: *bambus (Yushania alpina), gustoća, celuloza, lignin, sadržaj vode, utezanje*

1 INTRODUCTION
1. UVOD

Bamboo is the fastest growing plant currently known on earth, a property that enables it to be the best alternative as a future source of wood fiber (Liese and Köhl, 2015). Unlike timber, bamboo culms need short rotation (3-5 years) to mature before they can be harvested and utilized (Liese and Köhl, 2015). Bamboo is a perennial plant that belongs to the subfamily Bambusoideae of the family Poaceae (Gramineae), and it contains more than 1,500 species. It provides more than 1,500 applications, from traditional utilization in rural areas to industrial production, construction, and other versatile uses (Liese, 1987; Zhaohua, 2011; Hinde and Kaba, 2018). Bamboo has a higher strength-to-weight ratio than wood, enabling easy harvesting, transporting, and manufacturing of products (Wahab *et al.*, 2009; Anokye *et al.*, 2014). The above characteristics of bamboo have encouraged and intensified bamboo research in recent years.

The utilization of bamboo for various applications is governed by its properties, like any wood material. Moisture content, density, and shrinkage are physical properties that influence the dimensional stability, toughness, strength, working properties, and durability of bamboo and bamboo products (Liese and Köhl, 2015). The basic chemical properties found in bamboo are cellulose, hemicellulose, and lignin, which influence its utilization for different applications (Liese, 1985). The properties of bamboo culms are mainly affected by culm position, age, topography, and climate (Liese and Köhl, 2015; Tolessa *et al.*, 2019). The physical and chemical properties of bamboo vary between species, sites, age, and different parts of culm positions (Santhoshkumar and Bhat, 2015; Liese and Köhl, 2015; Tolessa *et al.*, 2019). Information on the physical and chemical properties of bamboo is necessary for assessing its suitability for various end products (Kamruzzaman *et al.*, 2008; Tolessa *et al.*, 2019). Such information will also enable increasing the utilization of bamboo species as substitutes for solid wood in wood-based industries.

Recently, *Yushania alpina* (*Y. alpina*) culms and splints have been used to construct traditional houses, rudimentary furniture, handcrafts, mats, fencing, beehive, and household utensils (baskets, winnowing trays) (Desalegn and Tadesse, 2014; Desalegn, 2015). The highland bamboo (*Y. alpina*) is indigenous to Ethiopia and available in the highlands of Kenya, Sudan, Zambia, Zaire, Burundi, Rwanda, Cameroon, and Tanzania (Embaye *et al.*, 2003). This bamboo species is the most cultivated and widespread throughout the country. It is preferred mainly because of its suitability and ease of processing and converting into different products.

In Ethiopia, the multiple uses of bamboo in industrial applications are not getting the most economic advantage, and its utilization is limited to domestic services (Mulatu and Kindu, 2010; Zenebe *et al.*, 2014). This is due to insufficient basic information on its properties. Previously, few studies have been done on physical and chemical properties (Muche and Degu, 2019; Tsegaye *et al.*, 2020; Dessalegn *et al.*, 2021). There is still limited information about the variation of physical and chemical properties between sites, within culms, and along the culm heights of *Y. alpina* grown in Ethiopia. Therefore, this study investigated the effect of site and culm heights on the physical and chemical properties of *Y. alpina* grown at Hagere-Selam (Sidama Region) and Rebu-Gebeya (Amhara Region).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

A total of twenty matured *Yushania alpina* culm samples (3-5 years old) were harvested from potential sites of Hagere-Selam (Sidama Region) and Rebu-Gebeya (Amhara Region). First, the bamboo culms were harvested, and their branches were removed from the top parts of the culms leaving the entire length to be about 9 m. After that, the culms were subdivided into three equal lengths, labeled bottom, middle, and top portions, with lengths of 3 m (Liese and Köhl, 2015).

Table 1 Climate and altitude of Hagere-Selam and Rebu-Gebeya where *Y. alpina* culm samples were harvested
Tablica 1. Klima i nadmorska visina Hagere-Selama i Rebu-Gebeye, na kojima su prikupljeni uzorci stabljika *Y. alpina*

Parameters / *Parametri*	**Sites** / *Staništa*	
	Hagere-Selam	**Rebu-Gebeya**
Altitude m.a.s.l, m / *nadmorska visina,* m	1500-2850	2300-4100
Annual average precipitation range, mm/year *raspon prosječnih godišnjih padalina*, mm/god.	1000-1600	900-1500
Annual average temperature range, °C *raspon prosječne godišnje temperature*, °C	11-22	0-15

Table 2 Description of *Y. alpina* culms grown at Hagere-Selam and Rebu-Gebeya
Tablica 2. Svojstva stabljika *Y. alpina* sa staništa Hagere-Selam i Rebu-Gebeya

Parameters *Parametri*	**Sites** / *Staništa*	
	Hagere-Selam	**Rebu-Gebeya**
Height / *visina,* m	13	12
Diameter / *promjer,* mm	70-90	50-80
Culm thickness / *debljina stabljike*, mm	7.2	6

Hagere-Selam site lies on geographical coordinates of 6°29'0" North, 38°31'0" East; whereas Rebu-Gebeya coordinates are 10°33'0" North, 37°46'0" East.

2.1 Determination of physical properties
2.1. Određivanje fizičkih svojstava

2.1.1 Determination of moisture content
2.1.1. Određivanje sadržaja vode

Three centimeters long specimens representing two sites (Hagere-Selam and Rebu-Gebeya) and three culm heights (base, middle, and top) were cut from fresh *Y. alpina* to determine its initial moisture content. Green weight of each specimen was measured using an analytical balance with a 0.01g accuracy (IS 6874, 2008). The specimens were then oven-dried at a temperature of (103±2) °C until attaining constant weight. The moisture content was calculated using Eq 1.

$$Moisture\ content\ (\%) = \frac{W_g - W_{od}}{W_{od}} \cdot 100 \qquad (1)$$

Where W_g is the green weight of specimens and W_{od} is the oven-dry weight of the specimen

2.1.2 Determination of basic density
2.1.2. Određivanje nominalne gustoće uzoraka

Three centimeters long specimens, (representing 2 sites and three culm heights), were cut from fresh *Y. alpina* culms for the determination of basic density. The green weights of all specimens were measured using an analytical balance with an accuracy of 0.01 g. The water displacement method was used to determine the volume of each specimen. The specimens were then oven-dried at a temperature of (103±2) °C. The repeated measurement of weight was recorded until the constant weight was reached. Basic density was determined based on ISO 22157-2:2004 and IS 6874 (2008). Basic density was calculated using Eq 2.

$$Basic\ density = \frac{Ovendry\ weight\,[gm]}{Green\,volume\,[cm^3]} \qquad (2)$$

2.1.3 Determination of shrinkage
2.1.3. Određivanje utezanja

Specimens representing 2 sites and three culm heights were prepared from round-shaped *Y. alpina* culms, 3-cm in length, to determine tangential and longitudinal shrinkage. For each specimen, the green weight and dimensions of wall thickness at four points and lengths at four points in green conditions were measured using an analytical balance and digital caliper with an accuracy of 0.01g and 0.01 mm, respectively (Figure 1). The specimens were oven-dried at a temperature of (103±2) °C. The repeated measurements for weight were recorded until constant weight was reached. Shrinkage was determined based on ISO 22157-2:2004 and IS 6874 (2008). The shrinkage was calculated using Eq 3.

$$Shrinkage\,(\%) = \frac{D_i - D_f}{D_i} \cdot 100 \qquad (3)$$

Where D_i is the initial dimension of the specimens before oven-drying (mm) and D_f is the final dimension of the specimens after oven-drying (mm)

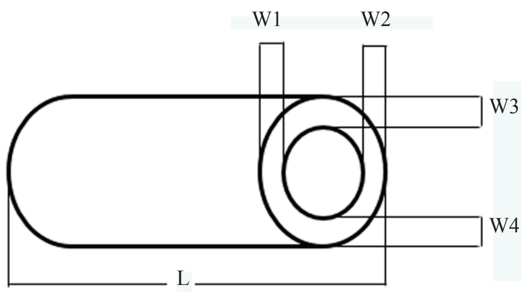


Figure 1 Position and direction measurement for wall thickness and longitudinal shrinkage
Slika 1. Mjerna mjesta i smjer mjerenja debljine stijenke i uzdužnog utezanja

Table 3 Standard methods used for chemical analysis of bamboo culms
Tablica 3. Standardne metode primijenjene za kemijsku analizu stabljika bambusa

Chemical composition *Kemijski sastav*	**Standard** *Standard*
Cellulose content *sadržaj celuloze*	Kurschner-Hoffer method
Klason lignin content *sadržaj Klasonova lignina*	ASTMD 1106-56
Alcohol-toluene solubility *topljivo u smjesi alkohola i toluena*	ASTMD 1107-56
Ash content / *sadržaj pepela*	ASTMD 1102-84

2.2 Determination of chemical composition
2.2. Određivanje kemijskog sastava

The harvested bamboo culms were dried and converted into small-size strips suitable for further milling processes. Thereafter, they were placed in a hammer mill and Willey mill to reduce it to the appropriate size. Then the milled powder bamboo samples were filtered using a 40 mesh size (425 µm) and 60 mesh sieve (250 µm). The particles were stored in an airtight container labeled with the appropriate code for chemical analysis.

The chemical composition including extractive (alcohol-toluene solubility), ash, and lignin content were determined using the standard procedures of the American Society for Testing Materials (ASTM) (Table 3). Cellulose content was determined according to alkali extraction and Kurchner-Hoffer method (Brown, 1975). Toluene was used instead of benzene and reported as alcohol-toluene extractive (Tolessa *et al*., 2017). The amounts were expressed on a percentage basis of the starting oven-dry mass. The lignin content test was performed with extractive-free bamboo derived from the alcohol-toluene extractive test.

2.3 Statistical analysis
2.3. Statistička analiza

The data were analyzed statistically to assess significant differences between the two sites (Hagere-Selam and Rebu-Gebeya) and along the three culm heights (base, middle, and top) using descriptive statistics and analysis of variance (ANOVA) by R software, version 4.1.3. The least significant difference (LSD) was used for mean comparison at $p<0.05$.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Physical properties
3.1. Fizička svojstva

3.1.1 Moisture content
3.1.1. Sadržaj vode

Analysis of variance for the initial moisture content of *Y. alpina* culms harvested from Hagere-Selam and Rebu-Gebeya sites is presented in Table 4. The results revealed that *Y. alpina* culms harvested from Hagere-Selam had a higher value of initial MC than those harvested from Rebu-Gebeya. These differences may be associated with the age and season of felling of bamboo culms (Liese, 1985). For this study, the culms 3 to 5 years old were harvested during the dry season but in different months.

The results revealed that the values of initial MC for the two sites decreased from the base to the top position of the culms (Table 4). Similar trends to this finding were seen in *Bambusa balcooa*, *Bambusa tulda*, *Bambusa salarkhanii*, and *Melocanna baccifera*, grown in Bangladesh (Kamruzzaman *et al*. 2008). Other researchers also found similar variations in their studies (Wahab *et al*., 2009; Anokye *et al*., 2016; Zakikhani *et al*., 2017). According to Wahab *et al*. (2009), the variation of MC along the culm height was due to differences in anatomical structure and chemical composition between locations along the bamboo culms. On the other hand, the decreasing trend of initial *MC* might be due to a smaller proportion of vascular bundles at the bottom when compared to the top position of culms (Anokye *et al*., 2014).

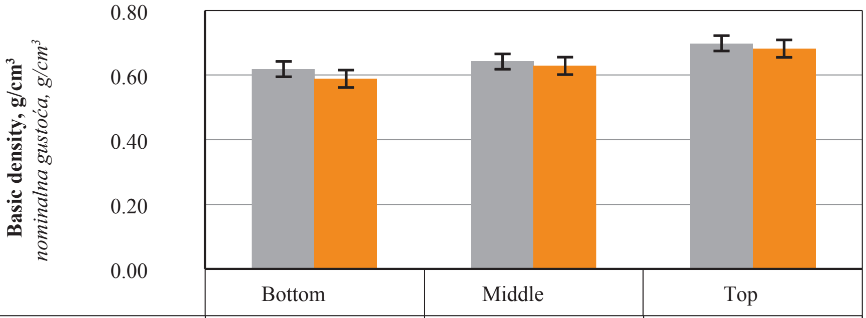
3.1.2 Basic density
3.1.2. Nominalna gustoća

Density is among the main factors that affect the utilization of bamboo culm as raw material. The over-

Table 4 Analysis of variance for basic density and shrinkage at different sites and culm heights of *Yushania alpina*
Tablica 4. Analiza varijance nominalne gustoće i utezanja uzoraka *Yushania alpina* s različitih staništa i različite visine stabljike

Mean-squares and statistical significances / *Srednji kvadrati i statistička značajnost*						
Basic density, g/cm³ and shrinkage of oven-dry, % / *Nominalna gustoća,* g/cm³ *i utezanje nakon sušenja, %*						
Source of variation *Izvor varijacije*	**DF**	**Initial MC** *Početni sadržaj vode*	**Basic density** *Nominalna gustoća*	**Tangential** *Tangentno utezanje*	**Longitudinal** *Uzdužno utezanje*
Site (S) / *stanište (S)*	1	3272***	0.013**	0.298^{ns}	0.009^{ns}
Culm high (P) / *visina stabljike (P)*	2	7904***	0.030***	17.626***	1.940***
S:P	3	31**	0.000^{ns}	0.014^{ns}	0.000**

^{ns} Not significant at p>0.1, * significant at p<0.05, ** significant at p<0.01, *** significant at p<0.001, DF-degree of freedom / ^{ns} *nije značajno za p>0,1, * značajno za p<0,05, ** značajno za p<0,01, *** značajno za p<0,001, DF – stupanj slobode*



	Bottom	Middle	Top
Hagere-Selam	0.62	0.64	0.70
Rebu-Gebeya	0.59	0.63	0.68

Figure 2 Basic density variation in *Y. alpina* culms at different sites and culm heights
Slika 2. Varijacije nominalne gustoće stabljike *Y. alpina* za različita staništa i visine stabljike

all mean values of basic density for the Hagere-Selam and Rebu-Gebeya sites were 0.65 and 0.63 g/cm^3, respectively. This shows that the culms harvested from the Hagere-Selam site were significantly denser than those from the Rebu-Gebeya site (Table 4). Generally, the density of bamboo ranges from about 0.4 to 0.9 g/cm^3 depending on the anatomical structure reflected in the quantity and distribution of fibers around the vascular bundles (Zakikhani *et al*., 2017). The density of this finding was in the range of generally recognized values of bamboo density. The result shows that the culm height had significant effects on the basic density at $p<0.001$ level, whereas the site had a significant effect on basic density at $p<0.01$ level (Table 4). However, the table shows that the interaction effect between the site and culm height did not significantly affect the basic density at $p>0.05$ level (Table 4).

The results revealed that the basic density significantly increased along with the height of *Y. alpina* culms for both sites (Figure 2). Many researchrs reported similar trends to this finding. They found an increase in basic density with increasing height of bamboo culms from the base to the top (Wahab *et al*., 2009; Santhoshkumar and Bhat, 2015; Vetter *et al.,* 2015). The increase of basic density from the base towards the top position of culms was also reported for thirteen bamboo species grown in Malaysia (Siam *et al*., 2019). This variation is associated with anatomical structure variations at different bamboo culms heights (Liese, 1985). According to Santhoshkumar and Bhat (2015), the increase in the magnitude of density from the bottom to the top position of the bamboo culm was due to the increase in the proportion of fibrous tissue and increased frequency of the occurrence of vascular bundles.

3.1.3 Shrinkage
3.1.3. Utezanje

Shrinkage is another main factor that affects the utilization of bamboo culm as a raw material in different wood industries. Unlike wood, bamboo begins to shrink from the very beginning of drying. The results revealed that the overall mean tangential or culm-wall shrinkage for the Hagere-Selam and Rebu-Gebeya sites was 6.63 % and 5.84 %, respectively (Figure 5). The overall mean longitudinal shrinkage for the Hagere-Selam and Rebu-Gebeya sites was 0.63 % and 0.56 %, respectively (Figure 5). Shrinkage of the *Y. alpina* culm grown at Hagere-Selam was higher in both tangential (culm-wall thickness) and longitudinal direction when compared to the Rebu-Gebeya site (Figure 5). This variation may be related to the initial MC and the culm-wall thicknesses of the bamboo culms (Siam *et al*., 2019).

The tangential and longitudinal shrinkage of *Y. alpina* culm at different heights for Hagere-Selam and Rebu-Gebeya sites is presented in Figure 3 and Figure 4, respectively.

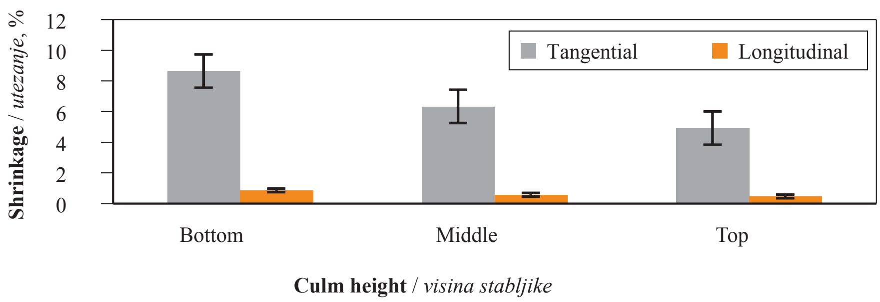


Figure 3 Tangential and longitudinal shrinkage at different culm height of *Y. alpina* grown at Hagere-Selam
Slika 3. Tangentno i uzdužno utezanje uzoraka za različite visine stabljike *Y. alpina* sa staništa Hagere-Selam

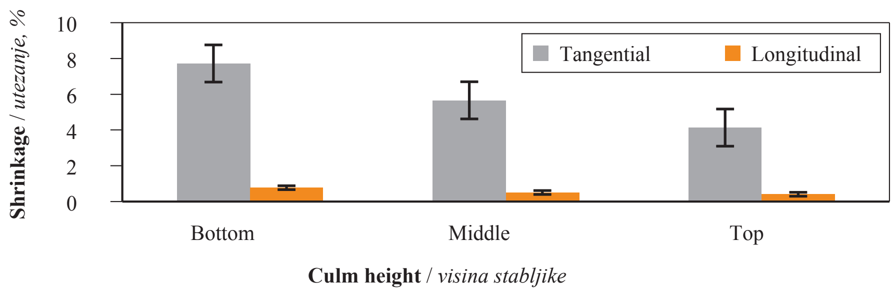


Figure 4 Tangential and longitudinal shrinkage at different culm height of *Y. alpina* grown at Rebu-Gebeya
Slika 4. Tangentno i uzdužno utezanje uzoraka za različite visine stabljike *Y. alpina* sa staništa Rebu-Gebeya

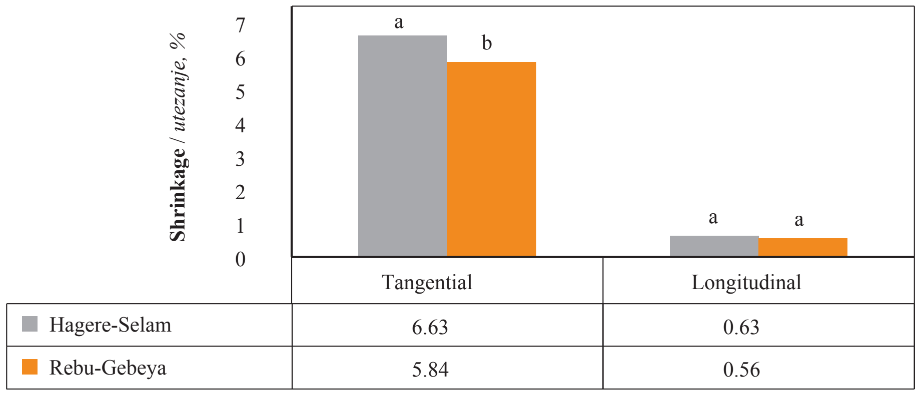


Figure 5 Tangential and longitudinal shrinkage in *Y. alpina* culms at different sites
Slika 5. Tangentno i uzdužno utezanje uzoraka *Y. alpina* s različitih staništa

The statistical analysis of variance revealed that site and culm height had a highly significant effect on tangential shrinkage at $p<0.001$ (Table 4). The same table shows that the culm height had a significant effect on longitudinal shrinkage at $p<0.001$, whereas the site had a significant effect on the longitudinal shrinkage at $p<0.05$. However, the interaction between the site and the culm height position had an insignificant effect on the tangential and longitudinal shrinkage at $p>0.05$ (Table 4).

The results showed that the tangential and longitudinal shrinkage of the culm decreased from the base to the top positions of *Y. alpina* for both sites (Figure 3, Figure 4). A similar trend was observed in *Bambusa balcooa*, *Bambusa tulda, Bambusa salarkhanii,* and *Melocanna baccifera* species grown in the Philippines (Kamruzzaman *et al.*, 2008). These variations are associated with higher parenchyma cell content and fewer vascular bundles at the base positions. On the other hand, lower parenchyma cell content and a higher number of vascular bundles are found at the top positions of bamboo culms (Wahab *et al.*, 2009).

3.2 Chemical composition
3.2. Kemijski sastav

3.2.1 Cellulose content
3.2.1. Sadržaj celuloze

Cellulose is the main constituent of lignocellulosic wood material, and it is located predominantly in the secondary cell wall. The analysis of variance shows that the site and culm height had a significant ($p<0.001$) effect on the cellulose content of *Y. alpina* bamboo (Table 5). The same table shows that the interaction effect between site and culm height did not show a significant ($p>0.05$) effect on cellulose content (Table 5). The overall mean value of cellulose content in *Y. alpina* culms grown at Hagere-Selam was 52.84 %, which is statistically higher than the bamboo culms collected from the Rebu-Gebeya site, which was 50.71 %. The results obtained from this study were higher than those found in the previous study on the same bamboo species (46.76 %) (Tsegaye *et al.*, 2020). The cellulose content of this finding was in the range of softwood (40 – 52 %) and hardwoods (38 – 56 %). Normally, the cellulose content of bamboo ranges from 40 – 50 % (Fengel and Wegener, 1984). The results obtained in this study were in the range of the values mentioned above for woods and other bamboo species. Bamboo species with cellulose content in this range are suitable for pulp and papermaking, bioenergy, and biobased composite production (Hammett *et al.*, 2001; Li *et al.*, 2007). It can also be used for applications similar to those of softwood and hardwood.

In the case of both sites, statistically, the highest cellulose contents were observed at the top; followed by the middle and lowest at the bottom position (Figure 8, Figure 9). The percentage cellulose content of *Y. alpina* culms for both sites showed an increasing trend from the base to the top (Figure 8, Figure 9). The same trend to this finding was reported for the same bamboo species at age of three (Tolessa *et al.*, 2019). The increased cellulose content was associated with the increase in cell wall thickness (Tolessa *et al*., 2017).

3.2.2 Klason lignin content
3.2.2. Sadržaj Klasonova lignina

Lignin is a phenolic substance consisting of an irregular array of variously bonded hydroxyl- and methoxy-substituted phenylpropane units. Statistically, the overall mean values of lignin content of *Y. alpina* culms collected from the Hagere-Selam (26.55 %) differed insignificantly from the culms collected from the Rebu-Gebeya site (26.04 %) (Figure 7). The lignin content in different tropical bamboo species was reported in the range of 24.84 to 32.65 % (Razak *et al*., 2013). Fengel and Wegner (1984) investigated the ranges of lignin for softwoods (24 – 37 %) and hardwoods (17 – 30 %). The results obtained from this study were in the range of the above reports for bamboo, softwood, and hardwood. According to Zhang *et al*. (2022), the high lignin content of bamboo culms can provide excellent physical and mechanical properties. On the other hand, the high lignin content contributes to bamboo rigidity and makes it suitable for structural applications, such as construction and furniture-making.

The analysis of variance shows that the culm height had a significant effect on lignin content at $p<0.01$ (Table 5). The site showed a significant ($p<0.1$) effect on lignin content (Table 5). However, the interaction effect between the site and culm height did not show a significant ($p>0.05$) effect on the lignin content of the culms (Table 5). The results revealed that the highest percentage of lignin content was observed at the bottom; followed by middle and minimum at the top culm positions for both sites (Figure 8, Figure 9). A similar variation pattern to this finding was observed in the same bamboo species (Tolessa *et al*., 2019). A similar variation pattern to this study was reported for *Melocanna baccifera* (Hossain *et al*., 2022).

3.2.3 Extractive content
3.2.3. Sadržaj ekstraktiva

Non-structural chemical compositions found in wood and bamboo materials are known as extractive substances. On the other hand, extractives in bamboo are non-cell wall components with diverse chemical compositions such as resins, lipids, waxes, tannins, pentosan, hexosan, starch, and silica (Fengel and Wegener, 1984). According to the analysis of variance, site and culm height showed a significant ($P<0.001$) effect on the extractive content (Table 5). However, the interaction effect between the site and culm height did not show a significant effect on the extractive content of *Y. alpina* at $p>0.05$ (Table 5).

The overall mean value of extractive content in *Y. alpina* culms collected from Hagere-Selam was 8.41 %, which is insignificantly higher than the culms collected from the Rebu-Gebeya site, which was 8.02 %. Extractives in bamboo can enhance the structural rigidity of its cell wall and effectively resist diseases and pests/decay (Zhang *et al*., 2022).

Statistically, in the case of both sites, the highest extractive contents were observed at the bottom position; followed by the middle and lowest at the top position (Figure 8, Figure 9). The same variation pattern to this finding was reported in *Y. alpina* culms (Tolessa *et al*., 2019).

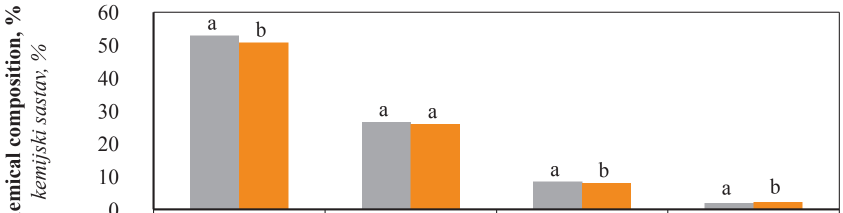
3.2.4 Ash content
3.2.4. Sadržaj pepela

Ash is a term generally used to refer to inorganic substances such as silicates, sulfates, carbonates, or metal ions. The analysis of variance shows that the main effects of site and culm height had a significant effect on ash content at $p<0.001$ (Table 5). However, the interaction effects between the site and culm height did not show a significant effect on ash content at $p>0.05$ (Table 5). The overall mean value of ash content in *Y. alpina* culms collected from Rebu-Gebeya was 2.17 %, which is significantly higher than the culms collected from the Hagere-Selam site, which was 1.95 %. Liese and Köhl (2015 stated that bamboo growth sites affect the amount of ash in bamboo. This difference might be due to the topography, soil, and climate of the area where the bamboo culms are grown. Values lower than those determined in this study were reported for highland bamboo, namely 1.87 % (Tolessa

Table 5 Analysis of variance for cellulose, lignin, extractive, and ash contents in *Y. alpina* culms at different sites and culm heights
Tablica 5. Analiza varijance sadržaja celuloze, lignina, ekstraktiva i pepela stabljike *Y. alpina* za različita staništa i visine stabljike

Mean-squares and statistical significances / *Srednji kvadrati i statistička značajnost*					
Chemical composition in *Yushania alpina* bamboo culms, % / *Kemijski sastav stabljike bambusa Yushania alpina, %*					
Source of variation *Izvor varijacije*	**DF**	**Cellulose** *Celuloza*	**Lignin**	**Extractive** *Ekstraktivi*	**Ash** *Pepeo*
Site (S) / *stanište (S)*	1	40.87***	2.38	1.37***	0.45**
Culm height (P) / *visina stabljike (P)*	2	149.72***	27.92***	1.89***	5.01***
S:P	2	74^{ns}	0.45^{ns}	0.039^{ns}	0.022^{ns}

^{ns} Not significant at $p>0.1$, * significant at $p<0.05$, ** significant at $p<0.01$, *** significant at $p<0.001$, ‘.’ is significant at p<0.1, DF-degree of freedom / ^{ns} *nije značajno za p>0,1, * značajno za p<0,05, ** značajno za p<0,01, *** značajno za p<0,001, ‘.’ značajno za p<0,1, DF – stupanj slobode*

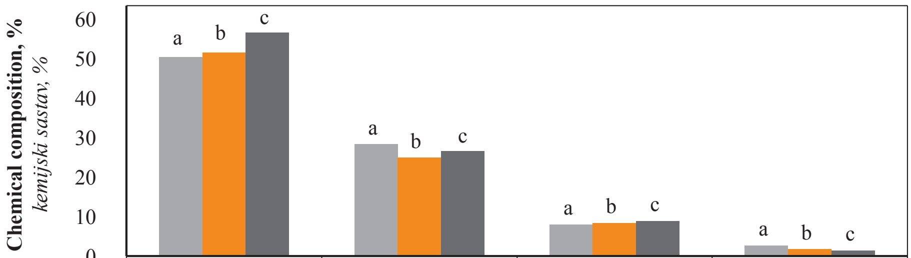


	Cellulose	Lignin	Extractive	Ash
Hagere-Selam	52.84	26.55	8.41	1.95
Rebu-Gebeya	50.71	26.04	8.02	2.17

Figure 6 Chemical composition variation in *Y. alpina* culms at different sites (within the same parameter having the same letters, there is no significant difference between the two sites at $p<0.05$)
Slika 6. Varijacije kemijskog sastava stabljika *Y. alpina* s različitih staništa (za iste parametre s istim slovima nema značajne razlike između dva staništa za $p<0,05$)

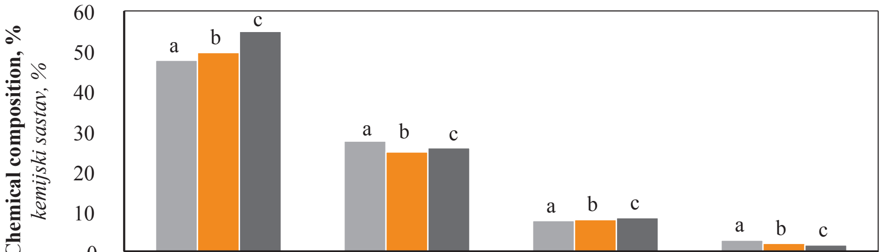
et al., 2019). However, higher than these values were reported for the same bamboo species, namely 3.77 % (Tsegaye *et al*., 2020).

Statistically, in the case of both sites, the highest ash contents were observed at the bottom position; followed by the middle and lowest at the top position (Figure 7, Figure 8). The same variation to this finding was reported in *Y. alpina* culms at the age of three (Tolessa *et al*., 2019). According to Tolessa *et al*. (2019), the ash content variation along the culm height varied with moisture content.



	Cellulose	Lignin	Extractive	Ash
Bottom	50.33	28.26	7.97	2.71
Middle	51.60	24.86	8.38	1.73
Top	56.60	26.53	8.87	1.40

Figure 7 Chemical composition variation in *Y. alpina* at different culm heights grown at Hagere-Selam (within the same parameter having the same letters, there is no significant difference between the two sites at $p<0.05$)
Slika 7. Varijacije kemijskog sastava *Y. alpina* pri različitim visinama stabljike za stanište Hagere-Selam (za iste parametre s istim slovima nema značajne razlike između dva staništa za $p<0,05$)



	Cellulose	Lignin	Extractive	Ash
Bottom	47.65	27.49	7.71	2.84
Middle	49.59	24.80	7.95	2.03
Top	54.90	25.83	8.39	1.64

Figure 8 Chemical composition variation in *Y. alpina* at different culm heights grown at Rebu-Gebeya (within the same parameter having the same letters, there is no significant difference between the two sites at $p<0.05$)
Slika 8. Varijacije kemijskog sastava *Y. alpina* pri različitim visinama stabljike za stanište Rebu-Gebeya (za iste parametre s istim slovima nema značajne razlike između dva staništa za $p<0,05$)

4 CONCLUSIONS
4. ZAKLJUČAK

This study investigated the variation of physical and chemical properties in Yushania alpina culm with site and culm height. The *Y. alpina* culms grown at the Hagere-Selam had higher values of green moisture content (*MC*) and basic density compared to the culms collected from the Rebu-Gebeya. The green *MC* of *Y. alpina* culms decreased from the base toward the top positions for both sites. Similarly, the tangential and longitudinal shrinkage from green to oven-dry conditions of *Y. alpina* culms showed a decreasing trend from the base to the top for both sites. In contrast, the opposite tendency was observed in the basic density, which decreased from the top to the base positions of the bamboo culms for the two sites. Density is the most important parameter affecting its practical utilization. Based on density, most of the other characteristics of bamboo culms can be predicted. A significant effect of site and culm height on chemical properties was observed. The amount of cellulose and lignin content found was in the range of wood and other bamboo species. Consequently, *Y. alpina* culm can be a potential source of pulp and paper, and bioenergy, and is suitable for structural applications, such as construction and furniture-making and biobased composite production. Further study should be carried out on other potential bamboo species abundantly available in Ethiopia, such as lowland bamboo (*Oxythenatera abyssinica*) and other introduced and exotic bamboo culms.

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Corresponding address:

MAHADI MUSSA USMAN

Ethiopian Forestry Development, Forest Products Innovation Centre, Addis Ababa, ETHIOPIA,
e-mail: mahadimussa20@gmail.com