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EFFECTS OF EUCALYPTUS GALL WASP, *Leptocybe invasa* FISHER & LA SALLE (HYMENOPTERA: EULOPHIDAE) ON WOOD BASIC DENSITY OF THREE *Eucalyptus* SPECIES IN TANZANIA

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Abstract
A study was conducted to examine the effects of Leptocybe invasa infestation on wood basic density of Eucalyptus camaldulensis, E. saligna, and E. tereticornis grown in Coastal agro-ecological zone of Tanzania. A total of six trees (three infested and three uninfested by L. invasa) from each of three species aged six years were selected. Three disks, each measuring 5 cm thick were cut at 25%, 50% and 75% of total tree height from each tree. Preparation of test samples and laboratory procedures to determine basic density followed standard methods. T-test was used to determine significant differences in mean diameter at breast height (DBH), total height and basic density between infested and uninfested trees while Analysis of Variance was done to determine significant differences in wood density between species, radial and axial variation of infested and uninfested species. Results showed that there were no significant diferences in mean DBH and total height between infested and uninfested species. The mean basic density values of infested species were relatively higher by 2.7, 5.3 and 7.3% than uninfested for E. tereticornis, E. camaldulensis and E. saligna respectively although their differences were not statistically significant. There were significant variations in wood basic densities between the three species. In axial and radial directions, basic densities showed different patterns of variation in different eucalypt trees. It is recommended that, infested and uninfested eucalypt woods to be assigned similar uses although detailed studies are required on physical, mechanical and fibre properties in order to arrive at plausible recommendations.

Key Words: *Leptocybe invasa; Blue gum chalcid; Wood basic density; Eucalyptus species; Tanzania.*

Introduction

Eucalyptus which is native to Australia is the most valuable and widely planted hardwood in the world (18 million hectares (ha) in 90 countries) (FAO, 2005). Eucalypts are grown extensively as exotic plantation species in tropical and subtropical regions throughout Africa, South America, Asia and in more temperate regions of Europe, South America and North America (Rockwood *et al*., 2008). In Tanzania, it is estimated that there are 4,665 ha of eucalypts in government plantations and an unknown area owned by the private sector and small-scale farmers

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(Ngaga, 2011). *Eucalyptus* species that are commonly planted in Tanzania are *E. saligna*, *E. grandis, E. camaldulensis, E. globules, E. viminalis, E. citriodora, E. regnas, E. microtheca, E. tereticornis*, *E. maidenii. E. maculata, E. botryoides, E. paniculata, E. resinifera, E. alba (urophylla),* and *E. robusta* (Schabel, 1990; Nshubemuki, 1998). However, *E. saligna*, *E. camaldulensis,* and *E. tereticornis* were more widely planted in the study area.

Leptocybe invasa Fisher & La Salle (Hymenoptera: Eulophidae) is a new gall forming invasive wasp, commonly called blue gum chalcid (Mendel *et al*., 2004) presumed to have originated from Australia and was first reported in the Middle East countries since 2000 (Mutitu, 2003; Mendel *et al.,* 2004; Thu, 2004). The wasp was introduced to Africa, Asia, Pacific region, America and Europe (Aytar, 2003; FAO, 2009) and is wreaking havoc on *Eucalyptus* plantations and nurseries throughout the tropical and subtropical countries of the world. The biology of *L. invasa* has been studied in detail (Mendel *et al*., 2004). Adult female of *L. invasa* lays hundreds of eggs in the petiole and midrib of leaves and stems of young shoots. The larva grows by feeding on tender portion of the plant and releasing oxalic acid resulting in the formation of galls. Gall formation by *L. invasa* damages growing shoot tips and leaves of eucalypts, resulting in quicker abscission of leaves and drying up of shoots. Severely infested eucalypts show gnarled appearance, stunted growth, die back and sometimes tree death (Mendel *et al.,* 2004; Nyeko, 2005; Protasov *et al.,* 2008; Kumarin *et al.,* 2010; Karunaratne *et al*., 2010). The infestation is more severe on seedlings in the nursery and young (1- 3 years old) plantations than on older trees (Mendel *et al*., 2004; Nyeko, 2005; Petro *et al*., 2014). Suitable hosts of the wasp include several *Eucalyptus* species and their hybrid clones (Mendel *et al.,* 2004; FAO, 2009; Thu *et al*., 2009, Mutitu *et al*., 2010).

Leptocybe invasa was first reported in Tanzania in 2005 (FAO, 2009; Petro, 2009), posing great threat of damage on young eucalypts particularly in Tabora, Shinyanga and Coastal regions (Petro, 2009). Since then, several concerns have been raised about the pest infestation on eucalypts in the country. Inspite of the rapid global spread of the pest and the importance of *Eucalyptus* species to individual livelihoods and national economies in the tropics, nothing has been documented on the effects posed by *L. invasa* on qualities of host trees, growth rates and mechanical properties of poles and timber and economic analysis of the implications of the pest infestation. The objective of this study was therefore to assess the effects of *L. invasa* infestation on wood basic density of *E. camaldulensis, E. saligna,* and *E. tereticornis* grown in Kibaha district in Coastal agro-ecological zone of Tanzania. The results from this study will be used in making recommendations which will lead to efficient utilization of *L. invasa* infested and uninfested eucalypts.

Methodology

Description of Study Area

Sample trees were collected from private woodlots located in Kibaha District, Pwani region in the Coastal agro-ecological zone of Tanzania. The district lies between latitude 6.42° and 7.03° South and longitude 38.2° and 38.5 East (Kilongozi *et al*., 2005). The area has bimodal rainfall pattern falling in two seasons. Long rains fall between March and May and short rains fall between November and December. The mean annual rainfall ranges between 800 and 900 mm, falling on an average for 81 days per year. Average temperature ranges between 23°C and 27°C tending to be highest (33°C) in January and lowest (18°C) in July. Mean annual relative humidity ranges between 53%

and 65%, being highest in April and lowest in August and September (Petro *et al*., 2014). Soils are free draining, primarily sand, sandy loam and gravel, varying substantially over short distances. The vegetation is semi deciduous open to partially closed woodlands dominated by coastal forests and miombo woodlands.

Sampling and Collection of Study Materials

Coastal agro-ecological zone was purposefully selected for data collection than other agro-ecological zones because of dominance of *Eucalyptus* species and the fact that the Coastal zone is more infested by *L. invasa* compared to other agro-ecological zones (Petro *et al*., 2014). Samples were collected purposively from eucalypts stands which were established between 2006 and 2007 (aged six years) because of the fact that *L. invasa* infestation is most severe on young trees (Mendel *et al*., 2004). Samples were collected from three *Eucalyptus* species namely *E. camaldulensis, E. tereticornis,* and *E. saligna.* Only eucalypts with good form (cylindrical) and free from visible defects were selected. The sampled trees (infested and uninfested) of the same species were selected from the same stand and same age. Eucalypt trees were termed as uninfested if there were no visible galls on shoots/leaves and infested if galls were visible in more than 50% of total shoots. A total of six trees (three infested and three uninfested ones) from each *Eucalyptus* species were marked for felling. Diameter at breast height (Dbh) of the felled trees and their total heights were measured and recorded using vernier calliper and measuring tape respectively. The measurements of sampled trees are as summarized in Table 1. For each felled sample tree, three 5cm thick disks were cut at 25%, 50% and 75% of the sampled total height. Samples were labelled to indicate species and position of the sample (disk) in the tree. Samples were immediately wrapped in polythene bags and transported to the wood utilization laboratory at Sokoine University of Agriculture, Morogoro, Tanzania where laboratory work was carried out.

Table 1: Measurements of sampled trees of *Eucalyptus* species in Coastal agro-ecological zone of Tanzania.

Tree No.	*Eucalyptus* species	*Leptocybe invasa* infestation status	Dbh (cm)	Total height (m)
1	*E. camaldulensis*	uninfested	7.4	8.5
2	*E. camaldulensis*	uninfested	10.6	11.5
3	*E. camaldulensis*	uninfested	6.5	5.8
4	*E. camaldulensis*	infested	9	9.6
5	*E. camaldulensis*	infested	7.4	8.4
6	*E. camaldulensis*	infested	6.2	6.1
7	*E. tereticornis*	uninfested	10.4	11.6
8	*E. tereticornis*	uninfested	10.5	10.8
9	*E. tereticornis*	uninfested	8.4	7.2
10	*E. tereticornis*	infested	12.7	9.6
11	*E. tereticornis*	infested	8	9.8
12	*E. tereticornis*	infested	8	7.4
13	*E. saligna*	uninfested	7.7	11.0
14	*E. saligna*	uninfested	8.4	10.0
15	*E. saligna*	uninfested	7.5	4.8
16	*E. saligna*	infested	7.8	12.4
17	*E. saligna*	infested	5.3	7.4
18	*E. saligna*	infested	7.3	5.0

Preparation of Test Specimens

Basic density was determined in accordance with procedure described in BS 373 (1957), Lavers (1969) and ISO 3131 (1975). A wedge running from pith to bark was cut from each disk. Three samples were cut at 25%, 50% and 75% of wedges' total length. All specimens were soaked in distilled water till they attained green volume condition. Green volume was obtained using the displacement method in accordance with Archimedes' principle (Olesen, 1970). The test specimens were then oven dried at a temperature of 103 ± 2°C until constant weight and then cooled in desiccators. Specimens were reweighed and the weights recorded. Basic density (BD) in Kg/m^3 was then calculated from the relationship:

BD (Kg/m^3) = [Oven dry weight (grams) / Green volume (cm^3)] × 1000

Data Analysis

Data obtained were analysed using Excel computer software to get basic statistical descriptors such as means, standard deviation and standard error. T-test was employed to determine significant differences in mean diameter at breast height, total height and basic density between the two means of infested and uninfested trees. Analysis of variance (ANOVA) was done to determine significant differences in wood density between species, radial and axial variation of infested and uninfested *Eucalyptus* species.

Results

Diameter and height variation between infested and uninfested Eucalyptus species

Mean diameter at breast height (Dbh) and height of infested and uninfested *E. camaldulensis, E. saligna* and *E. tereticornis* are presented in Table 2. The mean Dbh and height of all uninfested were relatively higher than infested eucalypt trees though their differences were not statistically significant ($P > 0.05$). Results showed that both infested and uninfested *E. tereticornis* had higher Dbh and height than other *Eucalyptus* species.

Wood density variation between infested and uninfested Eucalyptus species

Density ranged from 357 to 583 Kg/m^3 (infested) and 347 to 550 Kg/m^3 (uninfested) in *E. camaldulensis*, 300 to 575 Kg/m^3 (infested) and 300 to 533 Kg/m3 (uninfested) in *E. saligna* and 375 to 593 Kg/m^3 (infested) and 300 to 560 Kg/m^3 (uninfested) in *E. tereticornis*. Results showed that infested wood had mean density of 2.7%, 5.3%, and 7.3% higher than uninfested wood for E. tereticornis, E. camaldulensis and E. saligna respectively. However, there were no significant differences ($P > 0.05$) in mean basic densities between infested and uninfested eucalypt trees by Leptocybe invasa for all *Eucalyptus* species (Table 3).

Table 2: Mean Diameter at breast height (Dbh) and total height of infested and uninfested eucalypt trees by *Leptocybe invasa* in Coastal agro-ecological zone of Tanzania.

Eucalyptus species	Mean Dbh (cm)			Mean height (m)		
	infested	uninfested	P-Value	infested	uninfested	P-Value
E. camaldulensis	7.533 (1.40)	8.167 (2.155)	0.692	8.03 (1.778)	8.60 (2.85)	0.785
E.tereticornis	9.567 (2.71)	9.767 (1.18)	0.913	8.933 (1.33)	9.867 (2.34)	0.581
E. saligna	6.80 (1.32)	7.867 (0.47)	0.259	8.267 (3.78)	8.60 (3.33)	0.914

Numbers in brackets are standard deviation

Table 3: Mean basic density values of infested and uninfested eucalypt trees by Leptocybe invasa in Coastal agro-ecological zone of Tanzania

Eucalyptus species	Mean basic density (Kgm^{-3})		DF	P- value
	infested	uninfested		
E. camaldulensis	466.858[a] (74.01)	442.097[a] (50.90)	42	0.207
E. saligna	420.038[b] (74.11)	389.227[b] (66.85)	40	0.165
E. tereticornis	466.009[a] (58.82)	453.249[a] (70.37)	42	0.518

Numbers in brackets are standard deviation. For each basic density values followed by the same letter within column are not significantly different at 5% probability level.

Wood density variation between species

The results showed that infested *E. camaldulensis* produced the heaviest wood and *E. saligna* the lightest while uninfested *E. tereticornis* produced the heaviest wood and *E. saligna* the lightest (Table 3). The mean wood densities of both infested and uninfested *E. camaldulensis* and *E. tereticornis* were significantly higher than those of *E. saligna* ($F_{2, 63} = 3.206$; $P = 0.047$ for infested and $F_{2, 61} = 6.187$; $P = 0.0036$ for uninfested).

Wood density variation within trees

Axial variation

Axial variation in basic densities of infested and uninfested *E. camaldulensis, E. saligna* and *E. tereticornis* are presented in Figure 1. The basic density of infested *E. camaldulensis* increased from the bottom to the middle and then decreased towards the top while that of uninfested decreased from the bottom to the middle and then increased toward the top (Figure 1a). However, their differences were not statistically significant ($F_{2, 20} = 2.639$; $P = 0.096$ for infested and $F_{2, 18} = 2.733$; $P = 0.092$ for uninfested). Basic density of infested *E. saligna* increased from bottom upward while that of uninfested decreased from bottom upward (Figure 1b). These variations were not statistically significant ($F_{2, 18} = 0.015$; $P = 0.985$ for infested and $F_{2, 18} = 0.919$; $P = 0.417$ for uninfested). The wood basic density of *E. tereticornis* decreased from the bottom to the top of tree in uninfested while that of infested decreased from the bottom to the middle and then increased toward the top (Figure 1c). However, these variations were not significant different ($F_{2, 19} = 2.369$; $P = 0.121$ for infested and $F_{2, 19} = 3.376$; $P = 0.0556$ for uninfested).

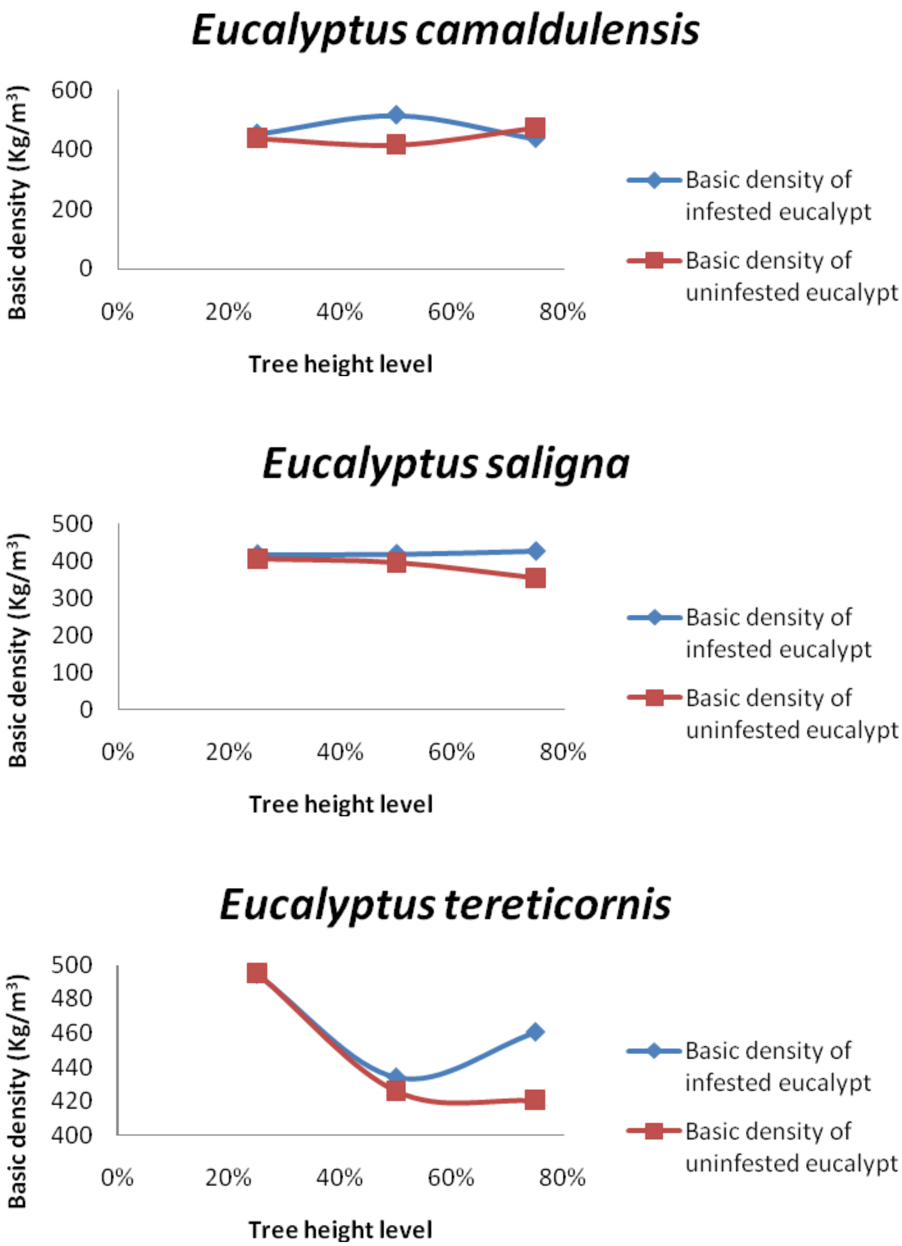

Figure 1: Axial variation in basic density of Eucalypt trees infested and uninfested by *Leptocybe invasa* in Coastal agro-ecological zone of Tanzania

Radial variation

Radial basic density variations for infested and uninfested *E. camaldulensis, E. saligna* and *E. tereticornis* are presented in Figure 2. Basic density of both infested and uninfested *E. camaldulensis* increased from the pith to the middle of the stem radius then decreases toward the bark (Figure 2a). There were no significant radial variation in basic densities shown by *E. camaldulensis* ($F_{2,22}$ = 0.785; P= 0.469 and $F_{2,18}$ = 0.531; P= 0.597 for infested and uninfested respectively). The basic density of infested *E. saligna* decreased from pith to the bark while that of uninfested increased from pith to the bark (Figure 2b). These variations were however not statistically significant ($F_{2,19}$ = 0.799; P= 0.464 for infested and $F_{2,18}$ = 1.342; P= 0.286 for uninfested). Basic densities of both infested and uninfested *E. tereticornis* were lower near the pith than near the bark (Figure 2c). However, these variations were not statistically significant ($F_{2,19}$ = 0.706; P= 0.506 and $F_{2,19}$ = 0.218; P= 0.806 for infested and uninfested respectively).

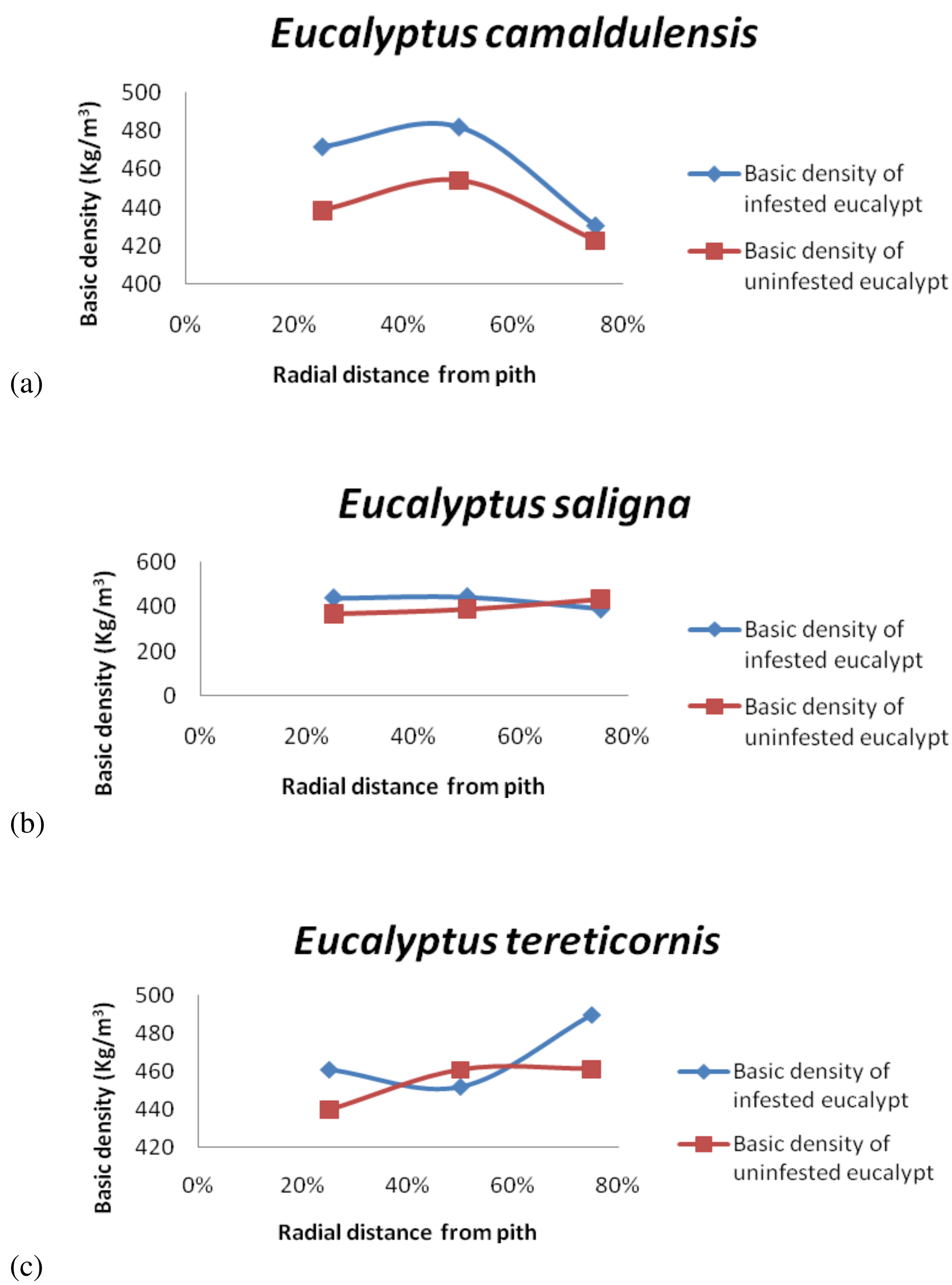

Figure 2: Radial variation in basic density of Eucalypt trees infested and uninfested by *Leptocybe invasa* in Coastal agro-ecological zone of Tanzania.

Discussion

Diameter, height and wood density variation between infested and uninfested Eucalyptus species

The study revealed that the mean diameter at breast height (Dbh) and height of uninfested *Eucalyptus* species were higher than infested ones while the mean basic density of infested were higher than uninfested though not statistically significant (Table 2 and 3). The observed variations in growth differences might be attributed by *L. invasa* infestation as severe infestation interferes with photosynthesis, causing eucalypt leaves and shoots to wilt and die which leads to growth retardation, stunting and loss of vigour (Mendel *et al*., 2004). Retardation and stunted growth of trees results in the formation of reaction wood (tension wood in hardwood) which influences density. Tension wood has higher density in comparison to normal wood. The results of this study agree with that of Tsoumis (2009) that generally, the density of tension wood is 2-10% higher than normal wood. In tropical species, it has been observed that drier regions (where trees become retarded in growth) produce wood of higher density (Batajas-Morales, 1987). Tsoumis and Panagiotidis (1980) reported that suppressed trees produced high proportion of latewood than unsuppressed trees which could have also occurred in trees in this study. Late wood is made of cells which have thicker walls and small cavities in comparison to earlywood which results in a higher density of latewood as compared with earlywood. This explains why the density of wood increases with increasing proportion of latewood (Tsoumis, 2009). *Leptocybe invasa* infestation might results in the variation of chemical composition of cell walls within eucalypt trees which could results to variation in density. This was also reported by Tsoumis (2009) that variation of chemical components of cell walls for example cellulose, lignin contributes to density differences. The mean basic densities in this study did not vary significantly between infested and uninfested eucalypts probably because the duration of infestation *L. invasa* on eucalypt trees was too short to cause significant differences. However, this study did not explore the duration of *L. invasa* infestation on eucalypt trees. It is expected that the trends shown by basic density of infested and uninfested eucalypts will be shown by strength properties because basic density is considered to be the key indicator for most strength properties of all species (Ishengoma and Nagoda, 1991).

Wood density variation within trees

The trends of axial basic densities of all studied *Eucalyptus* species differed from the bottom to top of trees. The trends of wood basic densities shown by infested and uninfested *E. camaldulensis* are in contrast to the general trend of increasing density along longitudinal direction from the bottom to the top of the same species of 43 years old grown in Iran (Sadegh, 2012). Axial variation of basic densities shown by infested *E. saligna* is in agreement with that reported by Iddi *et al.* (1998) while the general trend of decreasing density with increasing height in the stem shown by uninfested *E. saligna* is in agreement with that reported by Hillis (1978) for the same species. The decreasing of basic density along longitudinal direction from the bottom to the top shown by *E. tereticornis* is similar to the one of axial variation pattern described by Panshin and de Zeeum (1970). This may be explained in terms of crown effect. Crown influence auxin production, which directly regulate cell dimensions in the stem both across the growth rings and spatially down the stem. Wood within the vicinity of the crown is mostly core wood whose proportion increase with height (Ishengoma *et al.,* 2007). Core wood or juvenile wood is significantly lower in density than mature wood (Ishengoma *et al.,* 2007). Axial basic density variation of both infested and uninfested eucalypts showed different patterns of variation with height within each tree. These results are in line with Panshin and de Zeeuw (1970) who noted that in hardwoods, specific gravity variations with height show very little consistency with no overall dominance of a single pattern.

Radial variation here is referred to the basic density variation from the pith to the bark of eucalypt trees. Results showed that the wood basic density of both infested and uninfested *E. camaldulensis* were higher at the pith than those near the bark. The decreasing of wood density along radial direction can be related to differences chemical composition and existing of heartwood. Heart wood has a high extractive material in the pith and near to the pith compared to sapwood (Zobel and van Buijtenen, 1989). This trend is similar to that reported by Sadegh (2012) for the same species grown in Iran. The wood basic density of uninfested *E. saligna* and both infested and uninfested *E. tereticornis* increased from pith to the bark. Similar trends have been observed Gashumba and Klem (1982) and Iddi *et al*. (1998). Generally, there were no clear differences in radial basic density between eucalypts infested and uninfested by *L. invasa* for all studied eucalypts.

Conclusions and Recommendations

The study has shown that there were no significant diferences in mean diameter at braest height and total height between infested and uninfested *Eucalyptus* species. The mean basic densities of infested species were relatively higher by 2.7, 5.3 and 7.3% than uninfested for *E. tereticornis, E. camaldulensis* and *E. saligna* respectively although their differences were not statistically significant. There were significant variations in wood basic densities between the three species. In axial and radial directions, basic densities showed different patterns of variation in different eucalypt trees. It is therefore, recommended that, infested and uninfested wood of *Eucalyptus* species to be assigned similar uses although more and detailed studies are required on physical, mechanical and fibre properties in order to arrive at plausible recommendations.

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