Wood specific gravity of trees in hot semi-arid zone of India: diversity among species and relationship between stem and branches

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Wood specific gravity (WSG) is an important parameter in allometric equations for accurate estimation of C-sequestration and other functional properties of a tree. However, WSG of many tree species especially of arid and semi-arid regions is poorly reported. Further, identifying indirect methods for determination of stem WSG from branches may be rapid and relatively easy. The present study determined WSG of stem and branches of 21 tree species in the hot semi-arid region of Western India. Three individual trees from each species were randomly selected and sampled for determination of WSG of stem, primary and secondary branch. WSG varied significantly among the species ($F = 42.83$, $P < 0.001$) and sampling locations (stem and branches) ($F = 29.43$, $P < 0.001$). In stem (at DBH), it ranged from 0.42 ± 0.04 to 0.74 ± 0.03 among the species while within an individual tree it varied in order of stem > primary branch > secondary branch in most species. WSG of stem and branches showed linear relationship and branches were found a good predictor of stem WSG ($R^2 > 0.83$).

Keywords: Arid region, branch, tree biomass, wood specific gravity.

INCREASING level of greenhouse gases (GHGs) especially CO_2 is a major cause of global warming and climate change[1]. Tree plantation provides a potential mitigation option for arresting climate change by absorbing and converting CO_2 into biomass through photosynthesis. However, direct method of estimating C-sequestration potential of a tree species is destructive, requiring harvesting of trees for determination of biomass and carbon. Cutting of trees in many countries is an environmental issue and legally not allowed especially in areas with scarce vegetation like semi-arid and arid zones. Allometric equations and models provide better option for non-destructive, indirect methods of tree biomass determination. These allometric equations have been reported to be more accurate when wood specific gravity (WSG) is included into the equation[2]. The wood carbon content is also highly correlated with WSG[3]. Thus, estimation of tree biomass and C-content depends critically on reliable information on WSG of trees. Research is being carried out to quantify potential of tree based C-sequestration in arid and semi-arid regions[4]. However, data on WSG of tree species found and grown in arid and semi-arid environment is scarce, leading to the choice of destructive methods of estimation. WSG of a tree varies with species and climatic condition[2,5,6]. The documentation of WSG of hot semi-arid zone of India is required for enhancing accuracy of allometric equation for better prediction of above ground biomass without harvesting of the tree. Further, variation in WSG has also been reported within the main stem and branches of a tree[7–9]. Determination of WSG of branches and developing relationship is useful and avoids the tedious process of wood core sampling and tree harvesting. With this background, the present study was undertaken to determine WSG of prominent tree species of hot semi-arid regions and to develop a relationship between WSG of stem and branches for the indirect estimation of stem WSG.

The study was conducted at ICAR-Central Arid Zone Research Institute, Regional Research Station, Pali-Marwar under the hot semi-arid zone of Rajasthan, India. The research station was spread over 450 ha land (25°47′–25°49′E and 73°17′–73°18′N) at 217–220 m amsl. Most of the land (>80%) was under range land management with large diversity of planted and naturally grown trees and shrub species. The region receives about 460 mm average annual rainfall with annual maximum mean temperature of 42°C and a minimum of 7°C. The soil was shallow in depth (30–45 cm) with sandy clay loam to sandy loam texture, 1.35–1.5 mg m^{-3} bulk density and 7.7–8.4 pH and 0.15–0.55 dS m^{-1} electrical conductivity. Wood samples were collected from three locations (main stem, primary branch and secondary branch) during July 2016 from three randomly selected individual trees (with clear bole and similar diameter at breast height) of 21 tree species (>20 years old) at the station (25°47′–25°49′E and 73°17′–73°18′N). The wood cores from the main stem was obtained at breast height (1.37 m above ground) while, in branches from basal portion (10 cm away from joint) using an incremental borer and wood cutter respectively. The fresh weight, diameter and volume of the sampled wood core with bark were recorded on the day of sampling by digital calliper, electronic balance and water displacement method respectively[10]. The wood cores were then dried in a hot air oven at 100 ± 2°C till constant weight was obtained followed by recording of dry weight, diameter and volume of wood samples[11]. The WSG of stem and branches was reported as mean of the three sampled trees of a species. The following equation was used for determination of WSG

$$\text{Wood specific gravity (WSG)} = \frac{W_d}{V_f}$$

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Table 1. Results of analysis of variance for the effects of species and sampling location (stem and branches) on wood specific gravity

Source	Sum of squares	Degree of freedom	Mean square	F	P
Species	1.771	20	0.089	42.828	<0.001
Sampling location (stem, primary and secondary branch)	0.122	2	0.061	29.433	<0.001
Species * sampling location	0.044	40	0.001	0.528	0.989
Error	0.261	126	0.002		
$R^2 = 0.881$ (adjusted $R^2 = 0.823$)					

Table 2. Tree species and their mean wood specific gravity

Tree	Family	Stem WSG		
		Mean	SD	CV (%)
Acacia nilotica subsp *nilotica* (L.) Del.	Fabaceae–Mimosoideae	0.71	0.02	2.2
Acacia nilotica var. cupressiformis	Fabaceae–Mimosoideae	0.74	0.03	3.6
Acacia tortilis (Forssk) Hayne	Fabaceae–Mimosoideae	0.69	0.03	4.4
Acacia senegal (L.) Wild	Fabaceae–Mimosoideae	0.70	0.06	9.2
Albizia lebbeck (Benth.)	Fabaceae–Mimosoideae	0.58	0.04	7.5
Ailanthus excelsa Roxb.	Simaroubaceae	0.43	0.04	9.5
Azadirachta indica	Meliaceae	0.63	0.04	5.5
Balanites roxburghii Planch.	Zygophyllaceae	0.58	0.03	4.4
Bauhinia racemosa Lam.	Fabaceae–Caesalpinoideae	0.66	0.04	7.0
Capparis decidua (Forssk.) Edgew.	Capparidacea	0.68	0.03	5.1
Cassia fistula L.	Fabaceae–Caesalpinoideae	0.65	0.03	4.6
Colophospermum mopane	Fabaceae–Caesalpinoideae	0.69	0.05	7.9
Cordiamyxa L.	Boraginaceae	0.42	0.04	9.8
Hardwickia binata Roxb.	Fabaceae–Caesalpinoideae	0.72	0.04	5.0
Pongamia pinnata (L.) Pierre	Fabaceae–Papilionoideae	0.55	0.04	7.6
Prosopis cineraria (L.) Druce	Fabaceae–Mimosoideae	0.73	0.05	6.9
Prosopis juliflora (Sw.) DC.	Fabaceae–Mimosoideae	0.71	0.03	4.2
Tamarindus indica (L.)	Fabaceae–Caesalpinoideae	0.73	0.01	1.6
Tecomella undulata D. Don	Bignoniaceae	0.68	0.04	6.2
Ziziphus mauritiana Lam.	Rhamnaceae	0.50	0.03	6.0
Ziziphus nummularia (Burm. F.).	Rhamnaceae	0.61	0.04	5.7

SD, Standard deviation; CV, Coefficient of variation.

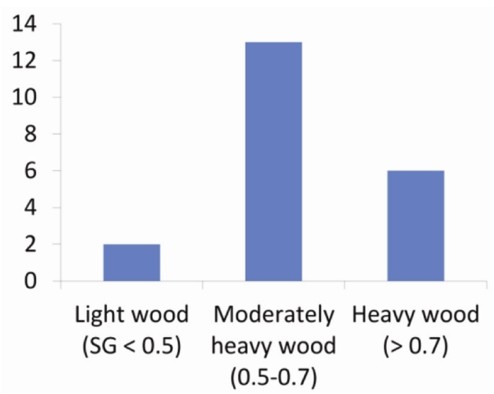

Figure 1. Frequency distribution of tree species within different wood specific gravity classes.

where W_d is the oven dry weight of wood sample and V_f is the weight of water displaced by fresh wood sample or volume of fresh wood sample.

Two-way analysis of variance (ANOVA) with species and location of wood sampling (DBH, primary branch and secondary branch) as factors was used to evaluate the effect of these on variation in WSG followed by Tukey HSD test at 95% confidence level to compare the difference among the species and sampling locations.

Analysis of variance showed significant effect of species ($F = 42.83$, $P < 0.001$) and sampling location ($F = 29.43$, $P < 0.001$) on WSG, indicating that WSG depends on the species as well as the location within the individual tree (Table 1 and Figure 1)[12]. Stem WSG varied greatly among the species, ranging from 0.42 ± 0.04 to 0.74 ± 0.03 (Table 2). Out of 21 species from seven families, most (12 species) had moderately heavy stem wood (WSG 0.66–0.75) (Figure 2). *Acacia nilotica* var. *cupressiformis* (0.74 ± 0.023) followed by Hardwickia binata (0.73 ± 0.04) and *Tamarindus indica* (0.73 ± 0.01) showed highest WSG while *Cordia myxa* L. (0.42 ± 0.04) followed by *Ailanthus excelsa* Roxb. (0.43 ± 0.04) had

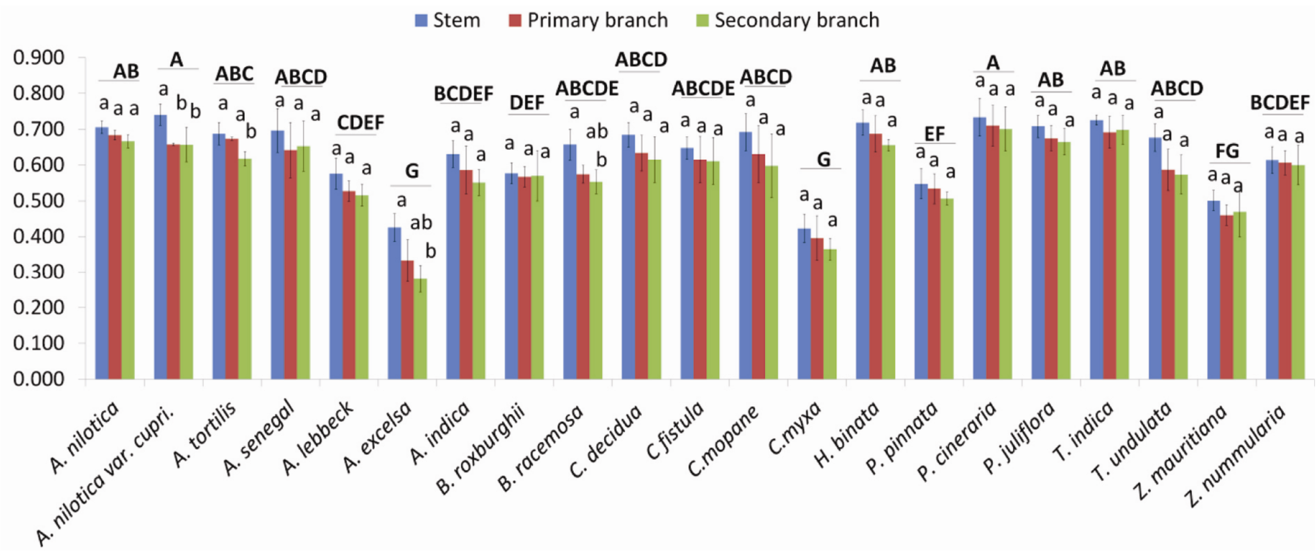

Figure 2. Wood specific gravity of tree species. Error bars indicate standard deviation while wood specific gravity of species with common letters were insignificantly different (Tukey's HSD, $P < 0.05$).

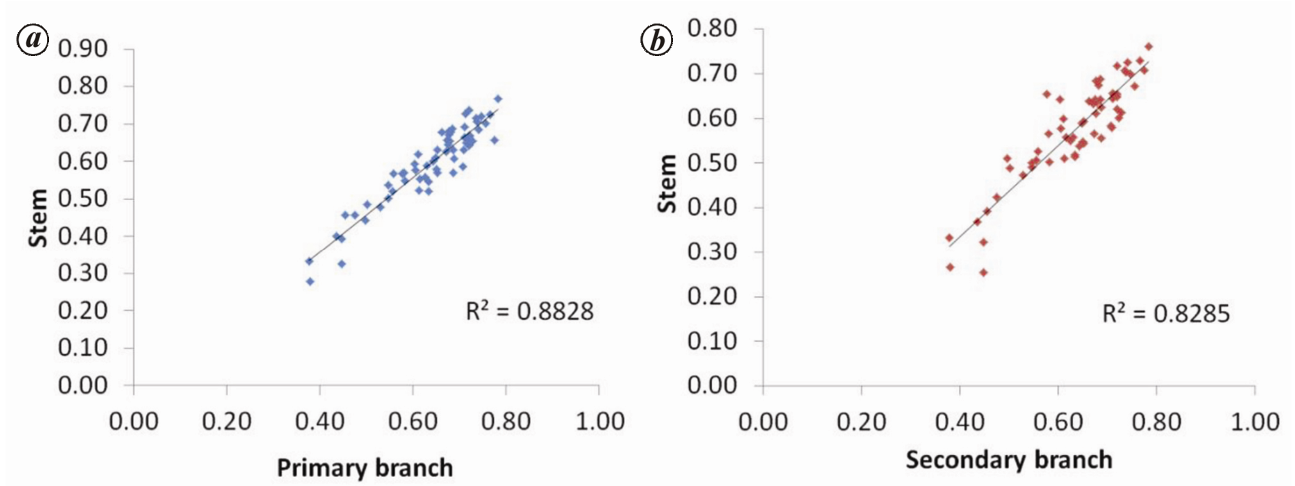

Figure 3. Relationship between WSG of stem and branches: ***a***, WSG of stem versus WSG of primary branch; ***b***, WSG of stem versus WSG of secondary branch.

the lowest WSG. The coefficient of variation (CV) for stem WSG within species ranged from 1.6% to 9.8% (Table 2). The low CV might be due to small sample size and less variability within the selected individuals because, individuals with similar DBH were selected for sampling within each species. Similar variation within species was reported[12–14].

The WSG of stem was higher than both primary and secondary branch and this relationship was fairly consistent across species in this study (Figure 1). The WSG of the primary branch was also higher than the WSG of the secondary branch, except in *Acacia nilotica* var. *cupressiformis*, *Balanites roxburghii*, *Tamarindus indica*, where it was lower or equal to the WSG of the secondary branch (Figure 1). Such variation has been reported in many tree species. Along the main stem of a tree, WSG varies from the base to the top of the stem[8]. Also stem WSG is generally higher than branch WSG[7,13,15]. However, WSG was also reported to decrease from the stump to half the total height of the tree, and later increase towards the top[16].

The scatter plot of stem WSG with primary and secondary branch showed a linear relationship, indicating the use of linear regression for determining the numerical relationship between them (Figure 3). The WSG of primary and secondary branches was a good predictor of stem WSG with high value of regression coefficient ($R^2 > 0.83$) and other statistical parameters (Table 3). Similar linear relationship was reported by many workers[7,15]. Thus, stem WSG can be indirectly estimated using primary/secondary branch sections avoiding the tedious process of core sampling or cutting the whole tree. However, this regression equation varied among species.

Table 3. Statistical parameters for determination of stem wood specific gravity from primary and secondary branch wood specific gravity

Model	R	R^2	F	Coefficients a	Coefficients b	t a	t b	Equation
Primary branch	0.937[a]	0.88	442.554	0.117	0.875	4.67	21.04	WSGs = $b + a$(WSGpb)
Secondary branch	0.911[a]	0.83	296.899	0.173	0.805	6.28	17.23	WSGs = $b + a$(WSGsb)

WSGs, WSG of stem; WSGpb, WSG of primary branch; WSGsb, WSG of secondary branch.

Taking all species into consideration, the following common equations were developed for the mixed population

$$\text{WSGs} = 0.875 + 0.117*\text{WSGpb},$$

$$\text{WSGs} = 0.805 + 0.173*\text{WSGsb},$$

where WSGs is the wood specific gravity of stem, WSGpb the wood specific gravity of primary branch and WSGsb is the wood specific gravity of secondary branch.

This study was undertaken to provide data on stem WSG of hot semi-arid zone tree species and its variation within tree, within and between species. WSG varied significantly among species, within tree and species. However, the extent of variation was low due to small sample size and uniformity in sampling. This study provided WSG of 21 tree species of hot semi-arid region of India and may be used for the given species grown under similar climatic condition. Significantly high linear regression coefficient between WSG of stem and branches was found, indicating that branch WSG can be good predictor of stem WSG. However, accuracy of equations will be a specific area that needs to be validated.

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