The Pharma Innovation Journal 2022; SP-11(12): 1138-1143

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(12): 1138-1143

www.thepharmajournal.com
Received: 09-10-2022
Accepted: 16-11-2022

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Floristic diversity, aboveground biomass, and carbon stock in coffee-based agroforestry system and adjoining natural forests of Central Western Ghats, India

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Abstract
Kodagu is one of the greenest landscapes in India, with 81% of the geographical area under tree cover contributing to the rich biodiversity representing about 8% of India's plant wealth. The study aimed to assess and compare the floristic diversity, biomass, and carbon stock in coffee-based agroforestry and adjoining natural forests. Using the random sampling technique, sample plots were laid for field data collection in the different study areas. A total of 102 tree species in coffee agroforests and 50 tree species in adjoining forests were recorded. Shannon's diversity was highest in coffee agroforests (3.60) compared to the natural forest (3.32). Higher tree density (351±19.35 stems ha^{-1}) was recorded in coffee agroforests compared to natural forests (287±13.53 stems ha^{-1}). Conversely, the basal area was higher in natural forests (39.53±0.38 m^2 ha^{-1}) compared to coffee agroforests (29.54±1.34 m^2 ha^{-1}). Similarly, the amount of carbon stored in natural forests was to the tune of 88.84±2.90 Mg ha^{-1}, while in a coffee-based agroforestry system, it was found to be 77.39±3.30 Mg ha^{-1}. Management of coffee agroforests, mainly shade tree management plays an essential role in carbon storage and dynamics. *Artocarpus integrifolia* (23.11%) was the dominant tree species in coffee agroforests, whereas *Elaeocarpus tuberculatus* (28.25%) was dominant in natural forests. Girth class distribution showed the pattern of an inverted J shape curve in the natural forest, while in agroforests, it was positively skewed, indicating the dominance of a few diameter classes. Based on the results of this study, we conclude that traditional coffee-based agroforests are floristically richer than adjoining natural forests. These land-use systems offer greater opportunities for biodiversity conservation and higher carbon storage in this region.

Keywords: Western Ghats, coffee-based agroforestry system, floristic diversity, above-ground biomass, carbon stock

Introduction

Western Ghats landscape in peninsular India is the unique matrices of natural forests and human-modified production landscapes such as coffee-based agroforests. Other elements of these matrices are tea plantations, monoculture, and mixed-species forest plantations, which are diverse and very complex systems (Devagiri *et al*. 2019) [11]. Among the 36 global biodiversity hotspots identified worldwide, the majority occur within tropical regions, and the Western Ghats in South India is one among them. The forests of Western Ghats are biologically richer than any other ecosystems, with the highest number of species (350-400 per ha). Studies have shown the higher floristic diversity in natural forests in Central Western Ghats (Murthy *et al*. 2016; Sathish, 2005) [22, 29]. The biological diversity of the Indian sub-continent is one of the richest in the world owing to its diverse geographical area, topography, climate, and juxtaposition of several bio-geographical regions. A very few regions of the world possess high species richness and are recognized as mega diversity countries, which attract special international attention.

Kodagu is one such region in India and is part of the Western Ghats, with 81% of the geographical area under tree cover. The district harbors diverse ecosystems such as natural forests, sacred groves, coffee agroforests, and forest plantations that contribute to species diversity, representing 8% of India's plant wealth. This diverse landscape is transforming concerning biodiversity and canopy density due to the changed production system under the current liberalized market situation (Devagiri *et al*. 2012) [12]. There is a gradual increase in area under coffee agroforests, rubber, and other tree species plantations. A study by Nath *et al*. (2016) [23] in the coffee agroforestry landscape of the Western Ghats revealed that the exotic species *Grevillea robusta* was planted 5.4 times more often than native trees.

India is currently the 5th largest coffee-growing country in the world, where most of the coffee is shade-grown, and Karnataka is the largest coffee-growing state in the country. In Karnataka, the Kodagu district has the largest area under shade coffee, accounting for 38% of national production, mainly by smallholder farmers (Coffee Board of India, 2016). Coffee plantations in Kodagu cover an area of 33% of the landscape of Kodagu, one of the country's highly wooded regions harbouring rich biodiversity. Earlier studies by Elourd *et al*. (2000) [14], Bhagwat (2002) [3], and Sathish (2005) [29] have made an intensive comparison between coffee agroforests and adjoining natural forests. These studies have shown that coffee agroforests' species richness and diversity were on par with natural forests, and in some cases, higher species diversity has been noticed in coffee agroforests. As a result of this rich biodiversity, farmers have successfully integrated many cash crops like pepper, cardamom, orange, and other NTFP-yielding trees. A study by CAFNET (2011) [4] in the Western Ghats has reported 109 bird species from shaded coffee agroforests, a much higher number than natural forest ecosystems (56 bird species). Therefore, improving the opportunities for biodiversity conservation and ensuring functional stability on lands other than protected areas remain crucial. This study's important objective includes assessing floristic diversity and above-ground biomass carbon in coffee-based agroforests and adjoining natural forests to compare these land uses. The study will help understand to what extent coffee agroforests host diversity and carbon concerning natural forests *vis-a-vis* their sustainability.

Material and Methods

Study area and sampling

The investigation was carried out in forests-coffee agroforests landscape mosaics of Kodagu district, which lies in the Central Western Ghats region (70° 25' - 76° 14' E and 12° 15' - 12° 45' N), covering an area of 4106 km^2. The district shares a common border with Kerala in the south and is surrounded by three other districts of Karnataka *viz*., Dakshina Kannada, Hassan, and Mysore. It has steep West to East climatic gradients, especially for temperature and rainfall from the edge of the Ghats (Elourd, 2000) [14]. The study area, with an altitudinal range of 300-1300 m.a.s.l., receives average annual rainfall ranging from 1500 to 3500 mm, with maximum rainfall during the monsoon season (June to September). April and May record the highest mean maximum temperature (32 ℃), while December and January will have the lowest mean minimum temperature (15 ℃). Soil is lateritic to red loamy, which has a mature profile, and the primary rock formation belongs to the most ancient Archaean system with rock composed of peninsular gneiss, gneissic granites, and gneiss (Pascal, 1986).

Land-use pattern

Kodagu district is the largest coffee-growing region in India, producing about 38% of India's coffee, and is also known as the land of river Cauvery. The pioneering farmers of Kodagu have adopted a shade-grown agroforestry system for cultivating coffee, cardamom, and other plantation crops, as well as paddy cultivation in low-lying areas. Over time, coffee intercropped with black pepper and orange has been established as a significant cropping pattern in the district. Currently, the coffee plantations of Kodagu are recognized as one of the world's most diverse coffee production systems. The shade-grown coffee plantations cover 33% of the district's landscape, complimenting the other forested landscapes like reserve forests and protected areas, sacred forests, and other wooded areas. In addition to hosting spectacular biodiversity, the landscape provides a range of ecosystem services that sustains the livelihood of the local communities (Devagiri *et al*. 2012) [12].

Site selection and sampling design

The study area was divided into three bio-climatic zones mainly based on the different vegetation types: dry deciduous, moist deciduous, and evergreen forests. In the evergreen vegetation type, coffee-based agroforestry systems were identified and stratified so that the coffee farms are geographically interspersed with adjoining natural forests. In the above selected land-use types 50, sample plots of 40 m x 40 m (0.16 ha) were laid to conduct the tree inventory. Out of 50 sample plots, we laid 45 plots in coffee agroforests and five in adjoining natural forests for data collection. In each of 0.16 ha. plots, all the woody plants were counted and identified as far as possible *in-situ* at species level using field keys of Pascal and Ramesh (1987) [25], Flora of Coorg (Keshavamoorthy and Yoganarasimhan (1989) [18], and Flora of Karnataka. Voucher specimens of species, which could not be identified in the field, were collected for identification at the College of Forestry, Ponnampet. Height and girth at breast height (GBH) of all the trees with ≥30 cm GBH in each sample plot were measured by using Blume Leiss Hypsometer (which is based on trigonometric principles) and measuring tape, respectively.

Data analysis

Measurement of diversity and species assemblage

Species diversity (Shannon–Wiener diversity Index-*H'*) and dominance (Simpson's Index-D), Jacquard's index of similarity was calculated as per Magurran (2021) [20]. The Importance Value Index (IVI) for each species was computed and expressed as the sum of relative density, relative dominance, and relative frequency of the species within and among plots (Curtis and McIntosh, 1950) [10]. Based on IVI, the top ten tree species for estimation of density (stems ha^{-1}) and basal area m^2 ha^{-1} and their contribution to AGB (Mg ha^{-1}).

Estimation of AGB

Tree biomass was estimated indirectly, using stem volume and wood density, while the biomass of herbs and shrubs was assessed using the destructive method. Earlier studies have also indirectly estimated above-ground plant biomass using non-destructive methods based on wood density and stem volume (Chave *et al*. 2005; Vashum and Jayakumar, 2012; Devagiri *et al*. 2013) [6, 13, 35]. The data collected on tree parameters such as GBH (>30 cm) and height was used for volume estimations using volume equations published by the Forest Survey of India (FSI, 2006) [16]. Local as well as regional volume equations, were used depending on the availability of each species. The regional volume equation $V=0.16948-1.85075D+10.63682D^2H$ was used to estimate the volume of tree species for which species-specific volume equations are unavailable (FSI, 2006) [16]. Tree biomass was calculated by multiplying volume with wood density values of particular species obtained from the Forest Research Institute (FRI, 1996) [15]. All shrubs and herbs occurring in the sample plot of 5m x 5m and 1m x 1m, respectively, were harvested, and oven-dry weight was estimated. Biomass thus obtained in different stratum were summed up to obtain total AGB and expressed in Mg-dry wt. ha^{-1}. Biomass of coffee agroforests was estimated indirectly using non-destructive methods by (Segura *et al*. 2006) [31]

Analysis

The floristic diversity in different vegetation parameters (basal area, height, GBH density, and aboveground biomass. Species richness (S) was estimated by counting individuals of other species per unit area using a species-area accumulation curve, as Chazdon *et al*. (2009) [7] suggested. The diversity indices like (Shannon–Wiener diversity index - *H'*) and dominance (Simpson's index - D), Jacquard's index of similarity index by Magurran (2021) [20]. The Importance Value Index (IVI) for each species was computed and expressed as the sum of relative density, relative dominance, and relative frequency of the species within and among plots. The above-ground biomass (AGB) was analysed in MS-EXCEL using the aggregated value of sample plots in evergreen vegetation type. Estimation of carbon (C) and carbon dioxide equivalent (CO_2e) was calculated by using the formula suggested by IPCC (2007); the following formula calculated the carbon content

Carbon content (Mg C ha^{-1}) = 0.47 x Biomass weight (Mg dm ha^{-1})

Where, Mg dm = Mega gram dry matter

Carbon dioxide equivalent (CO_2e) is a term for describing different greenhouse gases as a standard unit. For any quantity and type of greenhouse gases, CO_2e signifies the amount of CO_2 sequestered by trees in biomass, which would have the equivalent global warming impact.

Quantification of CO_2 = the quantum of carbon is converted into the quantum of carbon dioxide using the following equation (Ajaykumar, 2003) [1].

$$\text{Quantum of } CO_2 = \frac{\text{Quantum of carbon} \times 44}{12}$$

Where,

44 is the molecular weight of CO_2

12 is the atomic weight of the carbon

Results and Discussion

Floristic diversity and species abundance in coffee-based agroforests and adjoining forests

Species richness and diversity varied in adjoining forests and coffee-based agroforests (Table1). A total of 102 tree species in coffee agroforests and 50 tree species in adjoining forests were recorded. Shannon–Wiener diversity index (*H'*) was highest in coffee agroforests (3.60) compared to the natural forest (3.32). Notably, the number of tree species in coffee agroforests was higher than that of adjoining natural forests. In a similar study conducted by Devagiri *et al*. (2019) [11] in coffee agroforests of the Central Western Ghats region, they reported that coffee agroforests resembled natural forests in terms of species richness and diversity.

Across the coffee farms and adjoining forests, tree density and basal area varied considerably (Table 1). Tree density of 287±13.53 stems ha^{-1} was recorded in coffee agroforests, while it was slightly higher in the natural forests (351±19.35 stems ha^{-1}). Conversely, the basal area was higher in natural forests (39.53±0.38 m^2 ha^{-1}) compared to coffee agroforests (29.54±1.34 m^2 ha^{-1}). This study revealed that many tree species are being managed and conserved in coffee agroforests. Compared to coffee agroforests in other regions, the number of tree species observed in the present study appears to be higher. Lopez-Gomez *et al*. (2008) found similar results, and they reported 107 tree species in coffee farms against 62 tree species in forests. On the other hand, tree species diversity was higher in the forests than in coffee farms in other studies (Correia *et al*. 2010; Lopez-Gomez *et al*. 2008). Murthy *et al*. (2016) [22] reported on the Western Ghats of India, where the more disturbed evergreen and moist deciduous forests had low species diversity compared to less disturbed forests.

The similarity in species composition between coffee-based agroforests and adjoining forests in evergreen vegetation type is presented in Table 1 and Fig. 1. Few studies were conducted on the similarity of species between the different landscape elements in Kodagu. The present study revealed that the species similarity recorded between adjoining forests and coffee-based agroforestry systems was 22.15%. The higher similarity in species composition is perhaps due to retaining of same trees in the adjoining natural forest as well in coffee farms by the farmers during the conversion of forest land into coffee farms, wildlings sprouted and also cross-pollination of trees caused similarity of species (Lopez-Gomez *et al*. 2008; Maheswarappa and Vasudeva, 2018) [21].

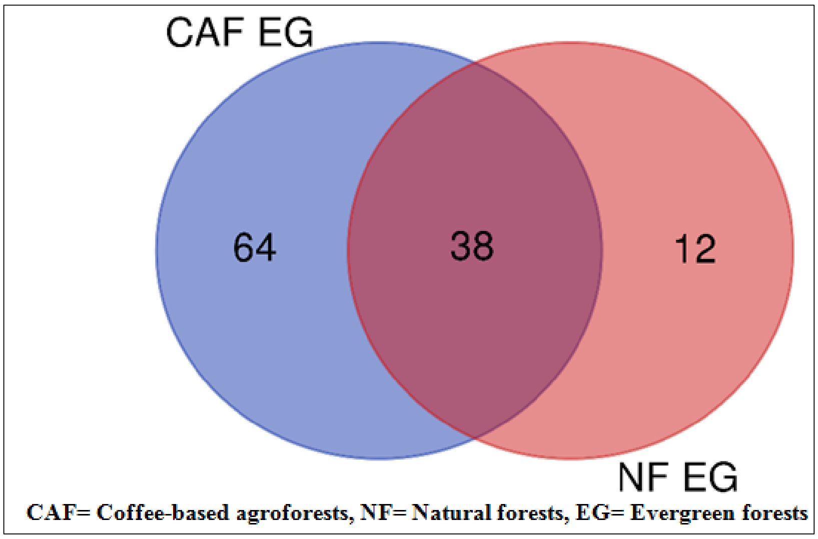

Fig 1: Sharing of species among coffee-based agroforestry systems and adjoining forest

Table 1: Vegetation structure, diversity composition, aboveground biomass, and carbon stock in coffee-based agroforestry and adjoining forest (Mean ± SE)

Parameters	Coffee agro forests	Adjoining forests
Species richness	102	50
Shannon–Wiener diversity index (*H′*)	3.60	3.32
Simpson index (D)	0.05	0.05
Jacquard's index of similarity	22.15	
Tree density (stems ha^{-1})	287.±13.53	351±19.35
Basal area (m^2 ha^{-1})	29.54±1.34	39.53±0.38
Aboveground biomass (t ha^{-1})	164.66±7.35	189.02±9.09
Carbon (Mg ha^{-1})	77.39±3.30	88.84±2.90
CO_2e (Mg C ha^{-1})	284.02±13.08	326.04±17.60

Carbon stock assessment

Above-ground biomass (AGB) was higher in adjoining forests (189.02±9.09 Mg ha^{-1}) compared to coffee agroforests (164.66±7.35 Mg ha^{-1}). The total amount of carbon stored in natural forests was to the tune of 88.84±2.90 Mg ha^{-1}, and in coffee agroforests, it was found to be 77.39±3.30 Mg ha^{-1} with CO_2e of 326.04±17.60 Mg C ha^{-1} and 284.02±13.08, respectively (Table 1). Management of coffee agroforests, particularly shade tree management, plays an essential role in carbon dynamics in this region. In coffee agroforests, total carbon stocks are likely to depend more on non-coffee biomass with trees and their associated root biomass storage (Schmitt-Harsh *et al*. 2012) [30]. Earlier studies have also shown carbon stocks of shade-grown coffee systems to the tune of 82 Mg C ha^{-1} in Indonesia (Van Noordwijk *et al*. 2002) [34] and 167.4 to 213.8 Mg C ha^{-1} in Mexico (Soto-Pinto *et al*. 2010) [32]. The wide variation in carbon stock values may be attributed to the difference in management regimes, edapho-climatic factors (soil, temperature, rainfall, *etc*.), and land-use history. Coffee agroforest management, in particular, shade tree management, plays a vital role in determining the carbon sequestration potential of coffee agroforests. In our coffee agroforest plots, total carbon stock was governed by the non-coffee biomass mainly contributed by trees and their associated root biomass.

Tree species dominance and girth class distribution

The Importance Value Index (IVI) assessed tree species' dominance of the top ten species. It is a relative measure that considers species' relative density, dominance, and relative frequency in each land use type (Curtis and McIntosh, 1950) [10]. The most dominant species in coffee-based agroforests were *Artocarpus integrifolia,* with an IVI value of 23.11%, and *Grevillea robusta* and *Lagerstroemia lanceolata* (Table 2). In the adjoining forest, the dominant species recorded were *Elaeocarpus tuberculatus* with an IVI value of 28.25%, followed by *Dimocarpus longan* and *Mangifera indica*. The government has stringent laws on the harvesting, transportation, and marketing wild species. However, the law is less severe on *G. robust;* as a result, farmers prefer to grow because it can be harvested, and thus farmers without official permission from the forest department get additional income (Srinidhi and Lele, 2001). The higher IVI value of these tree species is probably due to the farmer's conscious retention of trees for various benefits. An earlier study by Negawo and Beyene (2017) [24] also indicated similar IVI results.

The number of individuals in different girth classes was compared between coffee-based agroforests and adjoining forests in evergreen vegetation types (Fig.2). The girth class distribution of tree species in adjoining forests and coffee-based agroforests was positively skewed, and a higher percentage of trees were present in the 60-120 cm size class. The girth class distribution pattern of tree species in adjoining forests showed relative normal distribution, while in coffee plantations, it was positively skewed. This showed that populations with many more juveniles (due to active transplantation by the coffee planters) than adults. The earlier study by Raghavendra (2003) [27] showed that the girth class distribution of tree species and threatened tree species in both large and small holdings in Kodagu had a normal inverted 'J' pattern indicating that majority of the stems were under the recruiting class. The girth class distribution of tree species in the evergreen forests of Gerusoppa (Raghu, 2003) [28] and Kaan forests of Uttara Kannada Chandrashekarareddy (2007) [5] also showed a typical 'J' shaped pattern. Similar results in coffee agroforests of Kodagu by Basavarajappa (2017) [2].

Table 2: Importance value index in coffee-based agroforests and adjoining forests

Species	Coffee-based agroforests	Adjoining forests
Acrocarpus fraxinifolius	12.07 (7)	-
Aporosa lindleyana	10.48 (9)	9.84 (10)
Artocarpus hirsuta	12.76 (4)	9.91 (9)
Artocarpus integrifolia	23.11 (1)	-
Bischofia javanica	-	16.97 (6)
Caryota urens	12.19 (6)	13.50 (8)
Dimocarpus longan	-	22.24 (2)
Elaeocarpus serratus	-	14.52 (7)
Elaeocarpus tuberculatus	-	28.25 (1)
Grevillea robusta	22.32 (2)	-
Lagerstroemia lanceolata	16.70 (3)	-
Mangifera indica	12.73 (5)	20.11 (3)
Olea dioica	-	18.08 (5)
Syzygium cumini	10.90 (8)	19.46 (4)
Terminalia bellirica	9.32 (10)	-
The value in the brackets indicated ranking based on IVI in the coffee-based agroforests and adjoining forest		

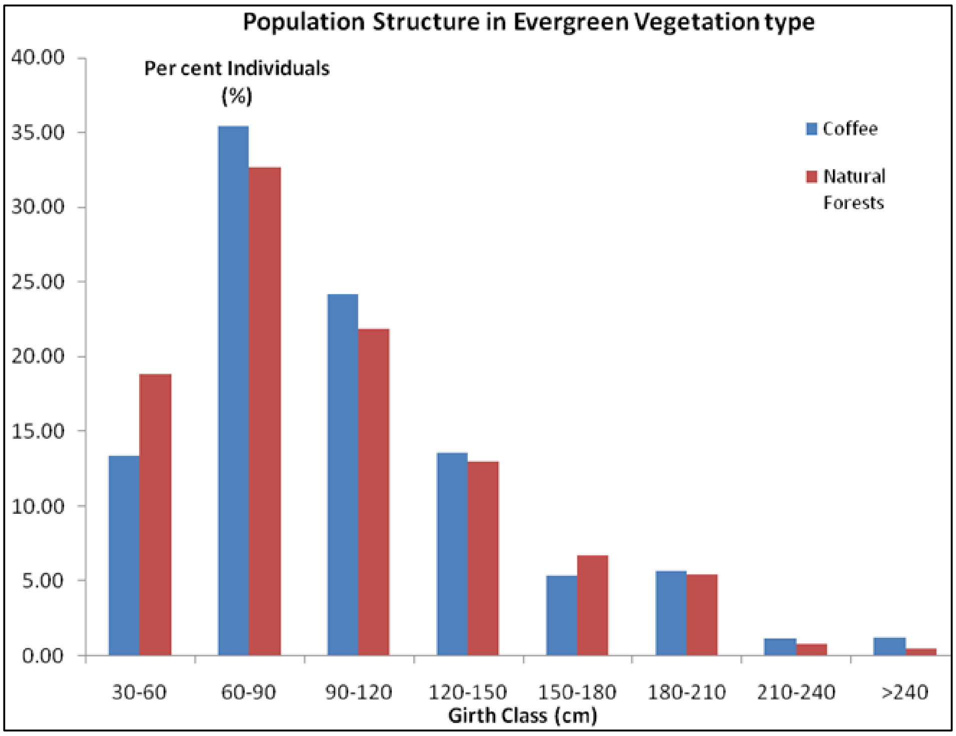

Fig 2: Girth class distribution in coffee-based agroforests and adjoining forests

Conclusion

The floristic diversity and species richness in the coffee-based agroforestry system were reasonably higher than that of adjoining natural forests. Shannon–Wiener diversity index (H′) was highest in coffee agroforests (3.60) compared to the natural forest (3.32). The similarity between forests and coffee agroforests in terms of species sharing was found to be 22.15%. Tree density was slightly higher in adjoining natural forests than in coffee farms. The total amount of carbon stored in adjoining natural forests was higher than that of coffee-based agroforests. The most dominant species were recorded in coffee farm *Artocarpus integrifolia* and natural forests, *Elaeocarpus tuberculatus*. Percent stems in coffee agroforests showed a positively skewed distribution wherein a higher number of stems were recorded in lower diameter classes ranging from 30 – 120 cm. This study suggests that traditional coffee agroforests in the Western Ghats region contain higher floristic diversity and these land-use systems offer more significant opportunities for biodiversity conservation and higher carbon storage in this region.

Acknowledgment

The authors thank KSNUAHS, Shivamogga for providing the opportunity to conduct the research. Thanks, are also due to Mr. Lingaraju. S.S., CCF. Madikeri for permission and support during the fieldwork in forest areas of Kodagu district.

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