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SUSTAINABLE HARVESTING OF *TERMINALIA ARJUNA*(ROXB.) WIGHT & ARNOT (ARJUNA) MAYOKPHA IN MANIPUR

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ABSTRACT

Terminalia arjuna *("Arjuna") in the family Combretaceae is a well-known medicinal tree whose bark is extensively used in Ayurvedic medicine, particularly as a cardiac tonic. Demand for Arjuna bark, both in India and abroad, has been growingrapidly for over a decade.* Litsea glutinosa *("Maida") in the family Lauraceae is a medium size tree. Its bark is used to treat joint pain,fracture, sprain, arthritis, back pain, and indigestion. Presently thebark of Arjuna and Maida is being extracted through unscientific and destructive harvesting practices. This is the first study on devel- opment of sustainable harvesting practices of Arjuna bark. The stages of bark recovery varied from tree to tree. Age of tree, harvesting method, and season of harvest influenced bark regeneration. This study recommends that for sustainable harvest, mature bark from only one fourth to one third of the total girthof the tree should be stripped by removing only outer and middle bark, leaving the inner bark for regeneration. However, strip har- vesting was found to be the best method in younger trees having a girth at breast height (GBH) of less than 60 cm. Sustainable bark Harvesting can be done after every 2 yr for Arjuna and 1 yr forMaida by removing opposite quarters of trunk bark.*

KEYWORDS: *Sustainable Harvesting Terminalia arjuna Mayokpha Tannins Oxalic acid Cardiac glycosides.*

INTRODUCTION

With the commercialization of traditional systems of medicine, the demandof medicinal plants has gone up exponentially. To meet the burgeoning demand, the supply chain of medicinal plants has become a multi-stakeholder's activity. In the process, the principles of sustainability, which are an intrinsic part of traditional systems, were overlooked. This has resulted in overexploitation, habitat loss, threat to plant species, and even extinction. At the same time, the demand versus supply disparity resulted in lower quality medicinal plant produce. All these factors contributed to the need for conservation and sustainable use of wild medicinal plants onone hand and to achieve the optimum quality on the other. The basic idea behind sustainable harvesting is that a biological resource should be har- vested within limits of its capacity for self-renewal. More than that, the manner of its harvest should not degrade the environment in any way (Hamilton, 2005). Millions of people worldwide derive a significant por-tion of their subsistence needs and income from plant and animal products collected from the wild.

In present harvesting practices, generally the collectors harvest medic- inal plants without considering sustainability. Most bark harvesters girdle the trees, sometimes remove the bark from the entire trunk and even upper branches, or cut down the entire tree to harvest bark. Systems for sustainable bark harvesting largely depend on the response of the target species to bark stripping or blaze making. Moreover, volume of bark that can be harvested under different harvest prescriptions largely depends on the growing stock and growth of the target species, bark characteristics (especially bark thick- ness), and the rate of bark regrowth after harvesting. Different tree species behave differently to bark stripping, both in terms of wound closure and susceptibility to insect and fungal attack. Thus the systems of sustainable bark harvesting for medicinal uses should be species specific. To ensure a sustainable supply of medicinal bark, blaze and strip harvesting are good options for those species that recover after bark stripping through sheet or edge development. Key variables for sustainable bark harvesting systems include blaze and strip size (width and length), harvest rotation, minimum diameter of trees, and percentage of the trees in the population to be exposed to bark harvesting. The methods and season of bark harvesting directly affect bark regeneration and quality.

The availability of important medicinal trees—viz. *Terminalia arjuna* and *Litsea glutinosa* in the forests of Manipur and local area also—has decreased alarmingly due to unsustainable and excessive bark harvesting. Tree bark provides pro- tection against external attack and desiccation and plays a key role in the transport of water and nutrients from leaves to roots through phloem tissues. Bark removal induces internal stress and may lead to progressive or instant death depending on the extent of harvest. Ring-barking by completely removing a strip of bark around a tree's outer circumference may lead to more or less immediate tree death. However, some species may survive ring- barking: e.g., *Quercus suber*, *Eucommia ulmoides* (Li & Cui, 1988), *Prunus africana*, *Warburgia salutaris*, *Ficus natalensis* (Cunningham & Mbenkum, 1993). These studies have proven that it is important to test various bark har- vesting treatments to determine the harvest limit. Through non-destructive harvesting practices, quality produce can be obtained on a sustainable basis without destroying trees. In India, no studies have been carried out on this aspect. In light of this knowledge gap, this study was carried out to develop sustainable bark harvesting practices for *T. arjuna* (Mayokpha).

METHODOLOGY

Description of the Species

Terminalia arjuna (Roxb.) Wight & Arnot ("Arjuna") belongs to the family Combretaceae and is a large tree with fissured bark and numerous drooping branches. The bark is gray or greenish white in color, thick, smooth exter- nally, and flakes off in large flat pieces. The middle layer of the bark is pink or flesh colored with a mealy coating while the inner layer is reddish brown. Arjuna is a water loving species and typical of dry deciduous forests of cen- tral India. During April 2005–March 2006 the consumption of "Arjuna bark" by India's herbal industry was more than 2,000 tons whereas the present annual estimated demand of Arjuna bark is between 2,000 to 5,000 tons.

The bark of *T. arjuna* has been used in traditional Ayurvedic herbal-ism for generations, primarily as a cardiac tonic. Clinical evaluation of this botanical medicine indicates that it can be beneficial in the treatment of coronary artery disease; heart failure; biliousness; sores; as an antidote to poison; for congenital, venereal, and viral diseases; and possibly for hyper- cholesterolemia (Alpana, Laurai, Gupta, Kumar, & Sharma, 1997; Chander et al., 2004). It has also been found to possess antibacterial, antioxidant,and antimutagenic properties (Dwivedi & Udupa, 1989). The pharmacol-ogy of *T. arjuna* has been discussed by Kumar and Prabhakar (1987) and pharmacological activities are mainly due to the presence of polyphe- nols, tannins, and cardiac glycosides. Tannins contribute to the hypotensive, wound healing, and antioxidant activity (Chaudhari & Mengi, 2006) whereas; cardiac glycosides are a potential cardiotonic used for alleviating angina and other cardiovascular conditions (Dwivedi, 2007). Concentration of these phytoconstituents is primarily responsible for the quality of bark. Besides pharmacological activities, *T. arjuna* bark is also a potent source of oxalic acid with many industrial applications particularly in dyeing and textile industry (Bhatia & Ayyar, 1980).

Litsea glutinosa (Lour.) Robinson ("Maida") is in the family Lauraceae and is one of the commercially important medicinal plants of Chhattisgarh, India. It is a small- to medium-sized tree up to 15 m tall, bole straight or curved, up to 60 cm in diameter, bark surface grayish-brown and innerbark yellowish. Roots of Maida are cooling; an aphrodisiac; a galactagogue; and useful in treatment of joint pain, arthritis, fractures, biliousness, burning sensation, bronchitis, fever, leprosy, etc. According to the Unani system of medicine, roots are astringent; an expectorant; and useful in treatment of inflammations, throat troubles, spleen diseases, paralysis, etc. The bark of *L. glutinosa* plays a key role for the survival of the agarbatti (incense stick) industry in India. A combination of powdered stem bark from *L. glutinosa* and *Machilus macrantha*, known as JIGAT in trade, works as an adhesive or binder in agarbatti manufacturing. When mixed with water, it forms an ideal material to bind wood charcoal, powdered aromatic roots and herbs to the bamboo splint. Mucilage is an important ingredient of Maida bark and the quality of bark is assessed on the basis of it. *Litsea* contains several chemical constituents such as alkaloids, volatile oils, fatty oils, tannins, mucilage, etc.

Tannins, β-sitosterol, and actinodaphnine are the common constituents of *L. glutinosa* (Chatterjee & Parkashi, 1994).

Study Site

The state of Chhattisgarh, India, lying between 17° 46′ N to 24° 6′ N latitude and 80° 15′ E to 84° 51′ E longitude, has about 44% of its geographical area (135,224 km^2) under forests and provides catchments to at least four main river systems—i.e., Mahanadi, Godavari, Indravati, and Narmada. Rainfall in this region occurs mainly from July to September with a mean annual rainfall between 1,200–1,500 mm (Chhattisgarh State Minor Forest Produce Federation, 2006). The surveys were conducted in different areas of the state (Dhamtari, Marvahi, Sarguja, and Bilaspur forest divisions) to identify growing areas of designated species. Populations of Arjuna and Maida were identified with the help of local people and forest officials. Study areas are shown in Figure 1.

Bark Harvest

For each species, 84 healthy trees (no previous bark harvesting) were selected for the experiment. For each individual, bark was harvested from the trunk base up to 120 cm stem height. The trees were grouped according to girth class representing different age groups. In Arjuna the girth class ranged from 50 to 201 cm and above. However, in Maida it ranged from 10 to 101 cm and above as trees of higher girth classes were not found. Three methods of bark harvesting were experimented with for each girth class. In Method 1, tree girth was divided into three equal parts and the bark was extracted from one part, in Method 2 tree girth was divided into four equal parts and the bark was extracted from one part, and in Method 3 strip bark harvesting was done by removing longitudinal blazes/strips on the main trunk of the tree. Longitudinal blazes ranging from 45–120 cm long and 15–45 cm wide were made over the trunk and bark was extracted. Alternate strip harvesting (5–8 cm wide) was also conducted on younger trees having a girth at breast height (GBH) of less than 60 cm. Only outer and middle layers of the bark were harvested leaving the inner layer for regeneration. To assess the impact of harvesting tool, the bark was harvested by using a conven- tional tool (an axe) and an indigenously designed sharp tool especially for blaze. To optimize the harvesting season, experiments were laid out in different months of the year (September, December, March, and June) using Method 2. All the experimental treatments were laid out in a randomized design with three replications.

Data on regrowth (regeneration of bark) and GBH were recorded at 6-month intervals. The physical appearance of bark regeneration was recorded and its regenerative properties were determined by the time taken to regenerate the bark. The harvested bark samples were brought to labora- tory for chemical analysis. Fresh and dry weight were recorded to determine the moisture content. Tannins content was estimated using the Folin-Denis method (Schanderi, 1970). Oxalic acid and cardiac glycosides content in Arjuna bark were estimated by using method of Bhatia, Lal, and Swalesh (1977) and Rajpal (2005), respectively. Mucilage content in Maida bark was estimated by using the method of Klein (1932). The data obtained was subjected to multivariate statistical analysis using Statistical Package for the Social Sciences, Version 14.0 (SPSS, Inc., Chicago, IL, USA).

RESULTS

Table 1 represents bark regeneration percentage in *T. arjuna* with respect to GBH, bark harvesting methods, and time taken for regeneration. Bark regrowth was represented as regeneration percentage observed at 6-month intervals. In the 50–100 cm GBH group, bark regeneration percentage was faster in Method 3 strip harvesting (39.59±0.58%) followed by Method 2 (38.30±0.49%) during the initial 6-month period. Similar trends were observed during consecutive periods and complete regeneration was achieved within 18 months after harvest. With respect to the 101–150 cm GBH group, a similar bark regeneration pattern was observed. However, trees with a larger GBH of 151 cm showed higher bark regeneration during the 6- to 12-month period after harvest. In all the GBH groups, bark regen- eration was faster in harvest Method 3, concluding within 18–24 months, followed by Methods 2 and 1, concluding in 30 months.

Table 1: Bark Regeneration Percentage with Respect to GBH, Blaze Size, and Time in *Terminalia arjuna.*

GBH group (cm)	Method	Bark regeneration percentage				
		6 months	12 months	18 months	24 months	30 months
50–100	1	31.55 ± 0.41^c	28.27 ± 1.01^c	25.56 ± 0.51^b	14.45 ± 0.53^a	
	2	38.30 ± 0.49^b	35.12 ± 0.58^b	26.31 ± 0.46^b		
	3	39.59 ± 0.58^a	33.3 ± 0.65^a	26.71 ± 0.61^a		
101–150	1	23.73 ± 0.28^c	32.72 ± 0.29^c	25.89 ± 0.06^c	17.39 ± 0.21^a	
	2	31.40 ± 0.57^b	38.43 ± 0.39^b	28.74 ± 0.17^b		
	3	33.76 ± 0.34^a	38.86 ± 0.08^a	25.03 ± 0.34^a		
151–200	1	16.89 ± 0.18^b	30.23 ± 0.55^c	24.74 ± 0.46^c	17.49 ± 0.34^a	10.62 ± 0.44^a
	2	23.38 ± 0.68^a	32.63 ± 1.86^b	27.12 ± 0.63^b	16.23 ± 0.29^b	
	3	23.97 ± 0.48^a	34.43 ± 0.60^a	28.56 ± 0.36^a	12.98 ± 0.71^b	
>200	1	13.23 ± 0.41^c	25.80 ± 0.24^c	23.53 ± 0.32^c	24.31 ± 0.18^b	13.11 ± 0.25^a
	2	15.48 ± 0.35^b	29.52 ± 0.32^b	23.65 ± 0.17^b	21.42 ± 0.31^a	9.49 ± 0.28^b
	3	18.60 ± 0.51^a	31.89 ± 0.73^a	25.38 ± 0.35^a	23.63 ± 0.41^a	

Mean values within each column for a GBH group followed by different letters differ significantly at $p < .05$,

Table 2 represents the effect of harvesting season on bark regenera- tion in *T. arjuna*. Significant difference in bark regeneration was observed with respect to different harvesting season. The data revealed that the bark regeneration was faster when the harvest was done in the month of March followed by December, irrespective of girth classes. In smaller girth classes— i.e., 50–100 and 101–150 cm—bark regeneration was completed within 18 months of bark harvest whereas in larger girth classes—i.e., 151–200 and >200 cm—it was completed in 24 to 30 months.

Tannins, oxalic acid, and cardiac glycosides contents of *T. arjuna* bark are presented in Table 3. It provides concentration (percentage) of these compounds in different age groups of Arjuna trees harvested in dif- ferent months (season). The data revealed significant variation in tannins with regard to different GBH groups. However, oxalic acid and cardiac glycosides did not show any significant variation. Tannins were found at.

Table 2: Seasonal Variation in Bark Regeneration of *Terminalia arjuna.*

GBH group (cm)	Harvesting season	Bark regeneration percentage				
		6 months	12 months	18 months	24 months	30 months
50–100	March	39.25 ± 0.19^{a}	34.32 ± 0.21^{a}	25.93 ± 0.10^{b}		
	June	35.21 ± 0.08^{bc}	32.12 ± 0.52^{b}	24.28 ± 0.15^{c}	08.30 ± 0.23^{a}	
	September	36.51 ± 0.22^{b}	33.52 ± 0.15^{ab}	29.80 ± 0.12^{a}		
	December	37.63 ± 0.12^{ab}	35.36 ± 0.23^{a}	26.82 ± 0.29^{b}		
101–150	March	38.52 ± 0.32^{a}	33.63 ± 0.21^{b}	27.52 ± 0.09^{a}		
	June	35.52 ± 0.10^{c}	30.38 ± 0.24^{c}	24.5 ± 0.16^{b}	9.52 ± 0.07^{a}	
	September	36.63 ± 0.07^{ab}	33.53 ± 0.18^{b}	27.41 ± 0.17^{a}	2.43 ± 0.03^{b}	
	December	35.24 ± 0.17^{b}	35.63 ± 0.55^{a}	28.34 ± 0.26^{a}		
151–200	March	29.42 ± 0.09^{a}	35.53 ± 0.42^{a}	23.35 ± 0.12^{b}	11.52 ± 0.47^{b}	
	June	15.28 ± 0.43^{b}	34.52 ± 0.35^{a}	25.13 ± 0.75^{a}	19.14 ± 0.72^{a}	5.25 ± 0.40^{b}
	September	17.52 ± 0.06^{b}	25.64 ± 0.41^{b}	27.85 ± 0.65^{a}	18.81 ± 0.91^{a}	10.45 ± 0.64^{a}
	December	26.25 ± 0.27^{a}	34.56 ± 0.29^{a}	26.53 ± 0.31^{a}	12.52 ± 0.21^{b}	
>200	March	20.15 ± 0.14^{a}	35.96 ± 0.43^{a}	28.56 ± 0.65^{a}	15.23 ± 0.78^{c}	
	June	14.42 ± 0.41^{c}	26.51 ± 0.21^{b}	24.25 ± 0.32^{b}	27.85 ± 0.43^{a}	6.85 ± 0.25^{b}
	September	14.68 ± 0.08^{c}	28.54 ± 0.65^{b}	22.65 ± 0.21^{c}	21.25 ± 0.32^{b}	13.52 ± 0.07^{a}
	December	17.63 ± 0.36^{b}	27.45 ± 0.24^{b}	25.12 ± 0.31^{b}	24.53 ± 0.26^{ab}	5.16 ± 0.41^{b}

Mean values within each column for a particular GBH group followed by different letters differ significantly at $p < .05$.

Table 3: Tannins, Oxalic Acid, and Cardiac Glycosides Content of *Terminalia arjuna.*

GBH group (cm)	Harvesting season	Tannins (%)	Oxalic acid (%)	Cardiac glycosides (%)
50–100	March	14.83 ± 0.32^{a}	12.03 ± 0.25^{a}	0.25 ± 0.01^{a}
	June	8.78 ± 0.21^{c}	9.78 ± 0.14^{ab}	0.16 ± 0.05^{a}
	September	11.89 ± 0.09^{b}	10.52 ± 0.31^{a}	0.20 ± 0.03^{a}
	December	12.56 ± 0.11^{b}	11.04 ± 0.08^{a}	0.24 ± 0.10^{a}
101–150	March	13.83 ± 0.07^{a}	12.03 ± 0.16^{ab}	0.25 ± 0.05^{a}
	June	9.55 ± 0.07^{c}	9.32 ± 0.06^{bc}	0.22 ± 0.06^{a}
	September	10.05 ± 0.04^{b}	10.45 ± 0.13^{b}	0.23 ± 0.02^{a}
	December	11.50 ± 0.10^{b}	11.23 ± 0.11^{b}	0.24 ± 0.07^{a}
151–200	March	10.57 ± 0.25^{a}	12.46 ± 0.21^{a}	0.82 ± 0.08^{a}
	June	5.85 ± 0.05^{bc}	9.99 ± 0.01^{a}	0.59 ± 0.03^{b}
	September	6.55 ± 0.01^{bc}	10.88 ± 0.11^{a}	0.70 ± 0.06^{ab}
	December	8.42 ± 0.11^{b}	11.40 ± 0.09^{a}	0.75 ± 0.02^{a}
>200	March	8.89 ± 0.08^{a}	12.26 ± 0.12^{a}	0.76 ± 0.04^{a}
	June	4.80 ± 0.05^{c}	9.98 ± 0.10^{b}	0.55 ± 0.03^{b}
	September	5.89 ± 0.01^{c}	10.99 ± 0.08^{b}	0.60 ± 0.06^{b}
	December	6.45 ± 0.08^{b}	11.21 ± 0.12^{a}	0.70 ± 0.08^{a}

Mean values within each column for a particular GBH group followed by different letters differsignificantly at $p < .05$.

maximum levels (14.83±0.32%) in 50–100 cm GBH group, followed by the 101–150 cm GBH group (13.83±0.07%), and at minimum levels in the >200 cm GBH group (4.80±0.05%). Tannins content showed remarkable decrease with increase in girth of the tree—i.e., it is higher in younger trees and decreases with the age of the tree. Oxalic acid content was observed at maximum levels (12.46±0.21%) in the 151–200 cm GBH group, followed by 12.26±0.12% in the >200 cm GBH group, and minimum levels (9.32±0.06%) in the 101–150 cm GBH group. However, it did not show any correlation with girth (age) of the tree. Cardiac glycosides content was found at maximum levels (0.82±0.08%) in the >200 cm GBH group and minimum levels (0.16±0.05%) in the 50–100 cm GBH group. All the phy- tochemicals (i.e., tannins, oxalic acid, and cardiac glycosides) were found at maximum levels when the bark was harvested in the month of March and minimum levels when bark harvesting was done in the month of June.

On analyzing different plant parts for tannins, oxalic acid and cardiac glycosides content, it was found that they were highest (14.23, 13.56, and 0.77%) in trunk bark, followed by branch bark (8.56, 10.54, and 0.32%), and lowest in twig bark (6.23, 7.04, and 0.14%). Thus, tannins, oxalic acid, and cardiac glycosides content were highest in trunk bark in comparison to other plant parts as represented in Figure 3.

Figure 4 represents tannins, oxalic acid, and cardiac glycosides con- tents in original and regenerated bark. The data revealed that original bark contains 14.68% tannins, 12.26% oxalic acid, and 0.74% cardiac glycosides; whereas in regenerated bark, 8.59% tannins, 7.49% oxalic acid, and 0.35% cardiac glycosides were found.

Bark regeneration percentage with respect to GBH, bark harvesting method, and time taken for recovery of *L. glutinosa* bark are depicted in Table 4. The data revealed that age of tree and bark harvesting method directly affects the bark recovery process. In all the selected girth classes, Method 3 showed faster regeneration followed by Method 2 and then Method 1. In girth classes 10–25 cm and 26–50 cm, bark regeneration was

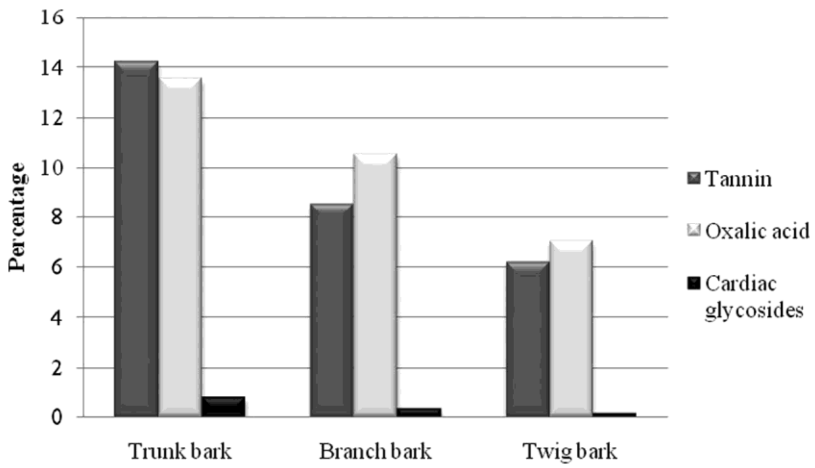

Figure 3: Tannins, oxalic acid, and cardiac glycosides content in bark of different parts of *Terminalia arjuna*.

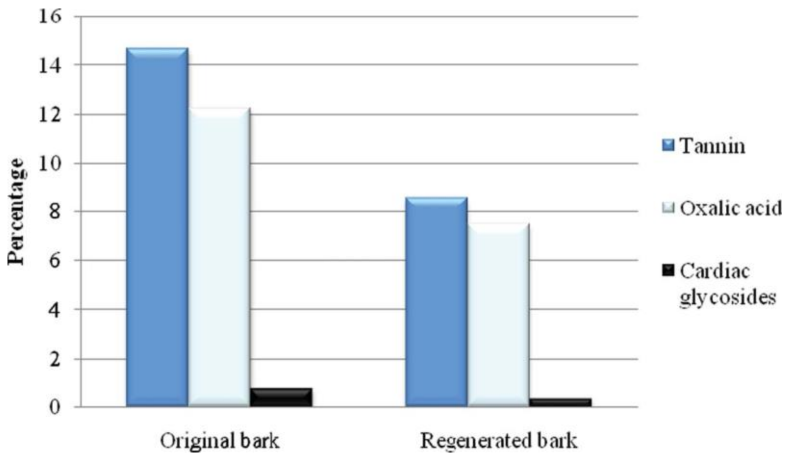

Figure 4: Chemical contents of original and regenerated *Terminalia arjuna* bark (color figure available online).

Table 4: Bark Regeneration Percentage with Respect to GBH, Blaze Size, and Time in *Terminalia arjuna*.

GBH group (cm)	Method	Bark regeneration percentage			
		6 months	12 months	18 months	24 months
10–25	1	45.25 ± 0.82^{c}	40.81 ± 0.18^{c}	13.55 ± 0.31^{a}	
	2	48.52 ± 0.40^{b}	45.89 ± 0.23^{b}	5.33 ± 0.17^{b}	
	3	48.72 ± 0.18^{a}	47.05 ± 0.44^{a}	4.12 ± 0.18^{c}	
26–50	1	41.84 ± 0.13^{b}	38.44 ± 0.32^{c}	19.41 ± 0.29^{a}	
	2	45.66 ± 0.26^{a}	35.55 ± 0.40^{b}	18.73 ± 0.17^{b}	
	3	46.59 ± 0.44^{a}	37.94 ± 0.73^{a}	14.96 ± 0.56^{c}	
51–100	1	34.70 ± 0.32^{c}	36.46 ± 0.17^{c}	19.56 ± 0.30^{a}	9.12 ± 0.10^{a}
	2	36.00 ± 0.81^{b}	38.70 ± 0.27^{b}	18.57 ± 0.26^{a}	6.53 ± 0.32^{b}
	3	39.37 ± 0.53^{a}	42.54 ± 0.13^{a}	18.07 ± 0.62^{b}	
>100	1	28.51 ± 0.12^{c}	31.70 ± 0.13^{c}	18.47 ± 0.10^{c}	20.77 ± 0.15^{a}
	2	31.74 ± 0.17^{b}	33.53 ± 0.24^{b}	20.77 ± 0.23^{b}	13.68 ± 0.31^{b}
	3	35.81 ± 0.20^{a}	38.45 ± 0.82^{a}	25.69 ± 0.47^{a}	

Mean values within each column for a particular GBH group followed by different letters differ significantly at $p < .05$.

completed in 18 months, and 51 cm and above girth class regeneration was completed in 24 months. Bark regeneration was faster in younger trees compared to older trees.

Table 5 depicts the influence of harvesting seasons on bark regen- eration with respect to GBH in *Arjuna*. Bark regeneration showed significant variation in different harvesting seasons. Faster bark regeneration was observed when the bark was harvested in the month of March fol- lowed by December and slowest in June. Bark regeneration was completed.

Table 5: Seasonal variation in bark regeneration of *Terminalia arjuna*.

GBH group (cm)	Harvesting season	Bark regeneration percentage			
		6 months	12 month	18 months	24 months
10–25	March	43.52 ± 0.27^{a}	35.62 ± 0.22^{b}	20.75 ± 0.31^{c}	
	June	31.27 ± 0.12^{d}	38.52 ± 0.26^{a}	29.35 ± 0.09^{a}	
	September	35.52 ± 0.11^{c}	36.41 ± 0.19^{b}	27.50 ± 0.07^{b}	
	December	40.42 ± 0.40^{b}	36.52 ± 0.52^{b}	23.04 ± 0.10^{c}	
26–50	March	45.63 ± 0.37^{a}	35.42 ± 0.13^{b}	18.52 ± 0.16^{b}	
	June	30.41 ± 0.14^{b}	37.20 ± 0.41^{a}	31.85 ± 0.43^{a}	
	September	31.02 ± 0.10^{b}	38.42 ± 0.17^{a}	30.24 ± 0.31^{a}	
	December	42.57 ± 0.16^{ab}	34.85 ± 0.41^{b}	22.14 ± 0.27^{b}	
51–100	March	41.78 ± 0.12^{a}	37.52 ± 0.08^{a}	20.41 ± 0.34^{b}	
	June	28.72 ± 0.18^{d}	34.96 ± 0.25^{b}	24.85 ± 0.10^{a}	11.46 ± 0.24^{ab}
	September	31.20 ± 0.78^{c}	29.51 ± 0.64^{c}	23.59 ± 0.09^{a}	15.41 ± 0.08^{a}
	December	37.20 ± 0.18^{b}	30.10 ± 0.72^{c}	22.68 ± 0.62^{a}	9.45 ± 0.24^{b}
>100	March	30.24 ± 0.24^{a}	29.52 ± 0.32^{b}	28.75 ± 0.64^{a}	11.42 ± 0.36^{c}
	June	22.56 ± 0.49^{b}	32.86 ± 0.38^{a}	24.85 ± 0.61^{c}	19.52 ± 0.52^{a}
	September	25.42 ± 0.84^{b}	31.85 ± 0.08^{a}	24.82 ± 0.31^{c}	17.79 ± 0.25^{ab}
	December	28.57 ± 0.51^{a}	25.61 ± 0.19^{c}	26.12 ± 0.27^{b}	18.96 ± 0.13^{a}

Mean values within each column for a particular GBH group followed by different letters differ significantly at $p < .05$.

within 18 months in smaller GBH groups (10–25 and 26–50 cm) while it was completed in 24 months in larger GBH groups (51 cm and above).

The data obtained on chemical analysis of *T. Arjuna* bark of different girth classes is presented in Table 6. Maximum tannins con- tent (4.01±0.17%) was found in 51–100 cm GBH group, followed by 3.96

0.31% in 101 cm and above GBH groups and lowest (1.32±0.03%) in GBH group 26 cm–50 cm. The maximum mucilage content (3.84±0.06%) was found in 10–25cm GBH group followed by 3.75±0.14% in the 26–50 cm GBH group, while minimum levels (1.12±0.07%) were recorded for the 101 cm and above GBH group. Younger trees showed higher amount of mucilage in their bark as compared to older trees. Tannins and mucilage con- tent were found at highest levels when the bark was harvested in the month of March and lowest levels when the bark harvesting was done in the month of June from local area of Manipur.

The data on impact of harvesting tool on bark regeneration of *T. arjuna* is depicted in Table 7. The data on bark regeneration revealed that wound healing was faster when harvesting was done with the help of a sharp tool, concluding within 18–24 months in comparison to harvesting done with a traditional tool (axe), which took 24–30 months for complete regeneration.

Figures 5 and 6 represent the comparison of increment in GBH of *T. arjuna* trees. The data revealed that there is an increase.

Table 6: Tannins and Mucilage Content in *Terminalia arjuna*.

GBH group (cm)	Harvesting months	Tannin %	Mucilage %
10–25	March	3.94 ± 0.08^{a}	3.84 ± 0.06^{a}
	June	1.56 ± 0.03^{b}	2.23 ± 0.12^{a}
	September	2.86 ± 0.05^{ab}	2.59 ± 0.08^{a}
	December	3.24 ± 0.10^{a}	3.45 ± 0.02^{a}
26–50	March	3.32 ± 0.13^{a}	3.75 ± 0.14^{a}
	June	1.32 ± 0.03^{b}	1.39 ± 0.07^{ab}
	September	2.23 ± 0.09^{ab}	2.46 ± 0.02^{ab}
	December	2.96 ± 0.05^{ab}	3.35 ± 0.08^{a}
51–100	March	4.01 ± 0.17^{a}	3.37 ± 0.07^{a}
	June	2.22 ± 0.13^{ab}	1.96 ± 0.08^{ab}
	September	3.21 ± 0.02^{a}	2.74 ± 0.10^{ab}
	December	3.85 ± 0.06^{a}	3.01 ± 0.05^{a}
>100	March	3.96 ± 0.31^{a}	3.22 ± 0.02^{a}
	June	1.35 ± 0.03^{ab}	1.12 ± 0.07^{ab}
	September	2.12 ± 0.08^{a}	1.56 ± 0.03^{ab}
	December	2.76 ± 0.23^{a}	2.85 ± 0.04^{a}

Mean values within each column for a particular GBH group followed by different letters differ significantly at $p < .05$.

Table 7: Impact of Harvesting Tool on Bark Regeneration.

		Bark regeneration				
Species	Tool	6 months	12 months	18 months	24 months	30 months
T. arjuna	Sharp tool	45.29 ± 0.47	33.41 ± 0.57	15.31 ± 0.31	6.25 ± 0.09	
	Traditional tool (axe)	30.89 ± 0.18	25.53 ± 0.21	11.17 ± 0.24	15.49 ± 0.14	17.49 ± 0.17

in the girth of trees even after harvesting was done which suggests that bark harvesting does not have any negative impact on overall growth of trees. Higher incremental growth was observed in younger and middle aged trees.

DISCUSSION

The results revealed that bark regeneration was faster in younger and middle aged trees which corroborates with the findings of Delvaux, Sinsin, and Van Damme (2010) in which they reported that trees of *Pseudocedrela kotschyi* had similar responses to bark harvesting—i.e., medium sized trees (21–30 cm diameter at breast height [DBH]) had a faster bark recovery than the other studied DBH classes.

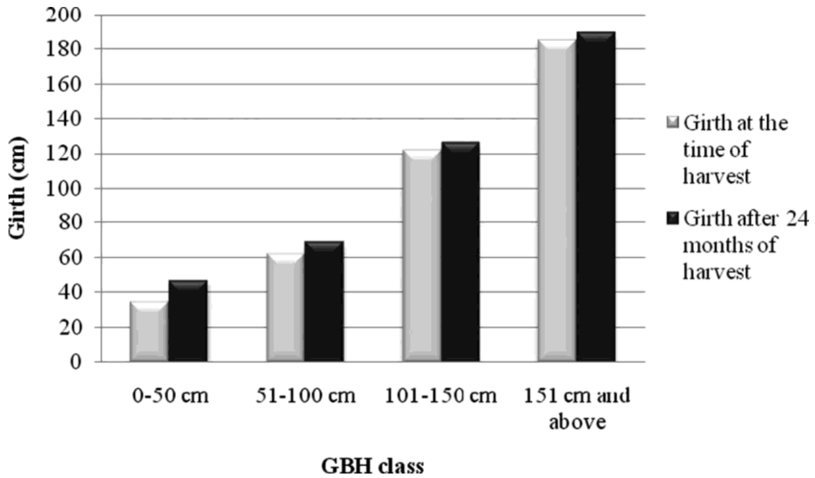

Figure 5: Increase in girth at breast height (GBH) before and after harvesting in *Terminaliaarjuna* trees.

Strip harvesting (Method 3) showed faster bark regeneration in all the GBH groups in both the species because in this method only a small por- tion of bark was removed, resulting in a smaller wound. Moreover, bark regeneration was also faster during the initial 6 months due to plant wound closure mechanisms that occur during the first few months after wounding (Schmitt & Liese, 1993; Oven & Torelli, 1994). In trees of higher girth classesand large blazes, the size of the wound is greater, resulting in more exposed surface area, which increases recovery time. In the first 6 months after har- vest, mostly edge growth was observed during bark regeneration. Thereafter, both edge and sheet growth were observed in accordance with the find- ings of Delvaux, Sinsin, Darchambeau, and Van Damme (2009), where they reported edge and sheet bark regrowth in some medicinal trees species of Benin, West Africa. This could be explained by a higher hormonal activity stimulated by stress in order to restore water conductivity and thus to close the wound as soon as possible (Mohr & Schopfer, 1995).

During bark harvesting, inner bark was left for regeneration as it main- tains humidity and promotes the regeneration process. Several experiments have shown that the humidity of the exposed surface is the most impor-tant factor for successful regeneration (Zimmermann & Brown, 1971; Neely, 1988; Stobbe, Schmitt, Eckstein, & Dujesiefken, 2002; Juan et al., 2006). Bark regrowth varies with site differences, season, and microclimate. In both *T. arjuna*, better bark regeneration was observed in moist sites as compared to drier sites. Cunningham (2001) also reported that bark regrowth varied with site differences, season, and microclimate.

The effect of harvesting season on bark regeneration was more or less similar in both the species. When the bark was harvested in the month of March, the bark regeneration was faster. However, the bark regeneration wasslower when the bark was harvested in the month of June. Similar interpre- tations can also be made on the basis of quality of the bark with respect to their phytoconstituents; the bark harvested in the month of March has higher concentration of constituents as compared to the bark harvested in the month of June. Therefore, the ideal time for bark harvesting to get qual- ity produce is from February to March for *T. arjuna*. The concentration of chemical constituents also varied in original and regenerated bark. Lipetz (1970) and Wu and Hao (1993) also reported significant change in the amount of tannins in regenerated bark of higher plants phytochemical extract 2023.

This study has revealed that the technique of bark harvesting also plays an important role in the regeneration of bark. Bark regeneration was faster when harvesting was done with the help of an indigenously designed sharp tool in comparison to harvesting done by using a conventional axe.

CONCLUSIONS

Arjuna and Maida bark can be obtained on a sustainable basis if the bark is harvested through non-destructive harvesting techniques and sufficient time is allowed between two successive harvests for the plant to regenerate new bark. Bark should be harvested longitudinally from trunk and branches. In younger trees having GBH less than 60 cm, bark should be extractedby removing 5- to 8-cm wide strips on the main trunk of the tree. For sustainable harvest, bark can be harvested by making a blaze one fourth ofthe circumference of the tree trunk. Only outer and middle bark should be removed leaving the inner bark for regeneration. Sustainable bark harvesting can be done after every 24 months in *T. arjuna* and 18 months in *L. glutinosa* by extracting opposite quarters of the trunk bark rather than girdling the trees. Sustainable bark harvesting techniques should be practiced in order to conserve and sustainably utilize these forest resources.

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