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Good Field Collection Practices and Quality Evaluation of Medicinal Plants: Prospective Approach to Augment Utilization and Economic Benefits

A.K. Pandey and Rameshwar Das
Institute of Forest Productivity, Lalgutwa, 835303, Ranchi, India

Corresponding Author: A.K. Pandey, Institute of Forest Productivity, Lalgutwa, 835303, Ranchi, India

ABSTRACT

Medicinal plants play an important role in disease management and livelihoods of people worldwide. In recent years, the growing demand for medicinal plants has accelerated overexploitation of valuable resources by unscientific and destructive manner without considering sustainability and quality issues. As a consequence, the quality of both raw material and finished products has become important concern for herbal/pharmaceutical/nutraceutical/cosmeceutical industries and the public alike. Moreover, medicinal plant collectors are not getting remunerative value for their produce because of poor quality (due to wrong identification, immature collection, poor processing, inadequate storage, adulteration etc.). Good collection/harvesting practices of some important medicinal plants i.e., Aonla (*Phyllanthus emblica*), Baividang (*Embelia tsjeriam-cottam*), Baheda (*Terminalia bellerica*), Gudmar (*Gymnema sylvestre*), Sarpagandha (*Rauvolfia serpentina*) and Kalmegh (*Andrographis paniculata*) have been standardized for tropical climate of central India. The quality (active ingredients) of above plants was also evaluated. It is evident from our study that the medicinal plants harvested at right time of maturity following Good Field Collection Practices (GFCPs) possess better quality in terms of active ingredients concentration. Adoption of GFCPs and quality evaluation of medicinal plants will have positive impact on resource conservation, socio-economic status of community, quality of produce, economic returns and marketing. To achieve these, R and D institutions may act as nodal centers for quality evaluation and dissemination of GFCPs to the collector/growers of medicinal plants to augment utilization and get premium price of their produce.

Key words: Harvesting practices, livelihood, medicinal plants, quality produce, active ingredients

INTRODUCTION

Globally, millions of people dwelling in forests depend on non Timber Forest Products (NTFPs) for subsistence, income and livelihood security (Vedeld *et al*., 2004). In India, over 50 million people are directly dependent on NTFPs and about 500 million are indirectly dependent on NTFPs for their sustenance (Tewari, 1998). More than 80% of the forest dwellers are dependent on NTFPs for their basic needs which contribute roughly one-third of their incomes (Government of India, 2007). In the state of Madhya Pradesh (India) about 40-63% of total rural income comes from the collection and sale of NTFPs (Tewari and Campbell, 1996) and in Orissa it is 15-30% and the relative contribution is highest amongst the poorest households (Mahapatra and Shackleton, 2011). The

NTFPs play an important role in both the local and national economies (Appasamy, 1993; Shiva and Mathur, 1995; Hegde *et al*., 1996; Sekhar *et al*., 1996). The annual consolidated trade was estimated at US $ 111 million (Rs. 5,250 million) in respect of the 'nationalized' and 'non-nationalized' NTFPs in the state of Chhattisgarh for the year 2006-07 (Chhattisgarh State MFP Market Survey Report, 2006).

Interest in traditional systems of medicine and herbal medicines has increased substantially in both developed and developing countries over the past two decades. According to the Secretariat of the Convention on Biological Diversity, global sales of herbal products totaled an estimated US $ 60,000 million in the year 2000. As a consequence, the safety and quality of herbal medicines as well as traditional medicine therapies have become increasingly important concerns for health authorities and the public alike (WHO, 2002).

In India, medicinal plants harvested from the forests have been the main source of raw material used in the manufacture of herbal products. Almost 90% of the raw materials of medicinal plants used by the manufacturing units are sourced from natural forests, often with little regard to environmental and social considerations, resulting in harvest much in excess of sustainable limits. Harvesting of NTFPs also provides vital seasonal sources of cash income for poor forest dwellers. Increasing commercial demand of NTFPs has promoted over exploitation, resulting in reduced yields and lesser regeneration leading to resource depletion in many regions (Sheldon *et al*., 1997; Ticktin, 2004; Gaoue and Ticktin, 2007), although examples of sustainable harvest can also be found (Emanuel *et al*., 2005; Gaoue and Ticktin, 2008). Unsustainable harvesting not only threatens the survival of the plant species but also the people that depend on them in different ways, such as reduced yields per unit effort, increased travel or harvesting distances and reduced incomes. Thus, the promotion of sound and sustainable harvesting practices is vital for many NTFPs, especially those with large and widespread commercial demand. Management and governance interventions to promote sustainability strongly depend upon the plant part harvested (Ticktin and Shackleton, 2011). For example, harvesting of leaves is less detrimental to the individual and population than harvesting of roots or entire plant. The effects of fruit harvesting on population stability are harder to ascertain because of the long-term nature required to detect population trends. This usually requires a modeling approach to determine threshold harvesting levels (Bernal, 1998; Emanuel *et al*., 2005). Sustainable Harvesting can be defined as "Collection/harvest of resources in such a way that it does not lead to long term decline of resources, there by maintaining its potential to meet the needs and aspirations of future generations".

The main objectives of sustainable harvesting are:

- Encourage and support the sustainable collection/harvesting of medicinal plants in ways that respect the environment and support the conservation of medicinal plants
- Contribute to the quality assurance of raw materials used as the source for products (herbal, nutraceuticals and cosmeceuticals) which will in turn improve the quality, safety and efficacy of finished products
- Formulate the national and regional GFCP guidelines and monographs for medicinal plants and related Standard Operating Procedures (SOP)

Good field collection practices need to be followed for getting quality raw material. These practices ensure better quality of the produce vis a vis maintaining population of wild medicinal plants.

Collection practices should ensure the long-term survival of wild populations and their associated habitats. The population density of the target species at the collection site(s) should be determined and species that are rare or scarce should not be collected. To encourage the regeneration of medicinal plant species, collection of the oldest and youngest individuals of the population should be avoided. Management plans should refer to the species and the plant parts (roots, leaves, fruits, bark etc.) to be collected and should specify collection levels and collection practices. Medicinal plant materials should be collected during the appropriate season or time to ensure the best possible quality of both source materials and finished products as well as sustainability of species. It is well known that the concentration of biologically active constituents varies with the stage of plant growth and development. The best time for collection (quality peak season time^{-1} of day) should be determined according to the quality and concentration of biologically active constituents rather than the total vegetative yield of the targeted medicinal plant parts. After collection, the plant materials may be subjected to appropriate preliminary processing, including elimination of undesirable materials and contaminants, washing (to remove excess soil), sorting and cutting. The collected medicinal plant materials should be protected from insects, rodents, birds and other pests and from livestock and domestic animals.

The quality of raw plant materials and finished products depends on factors which are classified as intrinsic (genetic) or extrinsic (environment, field collection practices, cultivation, harvest, post-harvest processing, transport and storage). Thus, the produce needs to be certified before selling to the pharmaceutical industries. National Medicinal Plants Board, Government of India has launched a Voluntary Certification Scheme for Medicinal Plants (VCSMP). The scheme covers certification of medicinal plants both for Good Agricultural Practices (GAP) and Good Field Collection Practices (GFCP) in the wild. Lack of appropriate knowledge about the natural resources being used and variation in harvesting and post harvest practices are major contributory factors for poor quality of medicinal produce. Quality assurance measures are needed to overcome these problems and ensure a steady, affordable and sustainable supply of medicinal plant materials of good quality. Moreover, quality evaluation and sustainable harvesting of medicinal plants will augment their utilization and ensure higher economic returns to the collectors/growers.

In the backdrop, a study was conducted, at Tropical Forest Research Institute, Jabalpur, to develop species specific sustainable harvesting practices for some important medicinal plants, *Andrographis paniculata* (Kalmegh), *Embelia tsjeriam-cottam* (Baividang), *Gymnema sylvestre* (Gudmar), *Phyllanthus emblica* (Aonla), *Rauvolfia serpentina* (Sarpagandha) and *Terminalia bellerica* (Baheda). Quality evaluation was also done to find the best time to harvest the produce having maximum concentration of active ingredients. Table 1 represents the plant part used and major active ingredient of the selected species.

Table 1: Major active ingredients of studied species

Medicinal plants	Family	Part used	Major constituents
Andrographis paniculata (Kalmegh)	Acanthaceae	Leaves and entire plant	Andrographolide
Embelia tsjeriam-cottam (Baividang)	Myrsinaceae	Fruits	Embelin
Gymnema sylvestre (Gudmar)	Asclepiadaceae	Leaves	Gymnemic acid
Phyllanthus emblica (Aonla)	Euphorbiaceae	Fruits	Ascorbic acid and gallic acid
Rauvolfia serpentina (Sarpagandha)	Apocynaceae	Roots	Total alkaloid and reserpine
Terminalia bellerica (Baheda)	Combretaceae	Fruits	Tannins and gallic acid

Present harvesting practices: Till now most of the collection is coming from wild and the species are becoming vulnerable/endangered. Moreover, removal of immature fruits/roots results in a low quality produce because the active ingredients for the medicinal properties accumulate on maturation.

In *Phyllanthus emblica* and *Terminalia bellerica*, currently immature fruits are harvested by lopping and pollarding of branches and even in some cases felling the trees. The cutting of branches makes the harvest of fruits easier than picking individual fruits from the tree. Often the largest branches are cut, as fruits at the tips of these branches are the most inaccessible to harvest. In *Embelia tsjeriam-cottam*, generally, harvesters target immature fruits (green) in October and November by cutting or breaking fruit-bearing branches (as the fruits are small in size). They bring branches to their home, where they pluck fruits. These harvesting methods do not leave any mature seeds in the forest, thereby affecting natural regeneration. In *Gymnema sylvestre*, leaves are collected from the forest area. Normally collectors harvest the leaves by cutting the main stem of climber and pulling down to the ground. In *Andrographis paniculata*, often whole plant is uprooted from the forest. Harvesters harvest immature plant and do not leave mature plants for regeneration. In *R. serpentina*, roots are the useful part used for the manufacture of drug. Often, whole plant is uprooted between 6-12 months for its roots before maturity which results in lesser concentration of active ingredients. Moreover, uprooting of entire *R. serpentina* plant for roots has affected the population considerably. The plant has already entered into critically endangered category. Due to these prevailing harvesting practices, the availability of above species has decreased in the forests.

MATERIALS AND METHODS

The study was conducted in Chhattisgarh, India. Surveys were conducted to select study areas. However, prior to initiation of study, essential information viz., taxonomy, distribution, phenology, reproductive biology and ethnobotany of the studied species were acquired. The geographical distribution and population density of the targeted species in study area was also gathered.

Aonla (*Phyllanthus emblica*): Aonla growing areas were selected in September 2007 in Dhamtari and Sarguja districts of the Chhattisgarh. The experiments were laid out in different sites viz., Dugli-Jabarra, Dhamtari, Chanderi Dharpur, East Sarguja and Kudergarh, South Surguja forest divisions to standardize sustainable harvesting practices in Peoples Protected Areas (PPAs) and multiple use natural forests (Non PPAs). Linear transects were used to sample the initial population (trees, saplings and seedlings) of Aonla. At each site 50×50 m plots (0.25 ha) were randomly laid out with three replications in the PPAs as well as in adjoining multiple use natural forest areas (Non PPAs). These transects were used to study the impact of fruit harvesting on sustainability. Aonla fruits were collected at different stages of maturity from selected locations to study the impact of harvesting time on quality and quantity of produce.

Baheda (*Terminalia bellerica*): Baheda growing areas were selected in Dhamtari, Sarguja and Raigarh forest divisions of Chhattisgarh. Surveys were conducted to select populations of varying density of *T. bellerica*. At the four sites (South Singhpur, Dhamtari has both PPA and Open forests) three replicate plots of 200×100 m (2 ha) were randomly selected and within each plot, eight subplots of 50×50 m (0.25 ha) were delineated. Subplots were first surveyed to quantify the initial Baheda population (including seedlings, saplings and trees) in 2006.

Baividang (*Embelia tsjeriam-cottam*): Surveys were conducted to select populations of varying density of *E. tsjeriam-cottam*. At the four sites (Jabarra, Dhamtari has both PPA and Open forests) three replicate plots of 40×20 m (0.08 ha) were randomly selected to sample the initial population of Baividang. Within each plot eight subplots of 10×10 m (0.01 ha) were delineated in which two harvesting methods and four harvesting treatments were assigned. Subplots were first surveyed to quantify the initial Baividang population (including seedlings, saplings and shrubs) in 2005.

The subplots were resurveyed annually in December 2007, 2008 and 2009. Annual recruitment and mortality were calculated following the methods of Hall *et al*. (1998) and Phillips (1998):

$$\text{Annual recruitment (\% per year)} = \frac{\ln[(\text{No.} - \text{Nd} + \text{Nt})}{(\text{No.} - \text{Nd})}]\, t \times 100$$

Where,
N_t is newly recruited trees in t years
No. is initial number of trees
Nd is number of dead trees in t years
t is time

To investigate the effect of harvesting methods and intensities on the density of *P. emblica*, *T. bellerica* and *E. tsjeriam-cottam* experiments were laid out randomly in each plot. Two harvesting methods were considered, namely the traditional method of branch cutting and non-destructive harvesting of fruits. In non-destructive method, the mature fruits were harvested by vigorously shaking the fruited branches with the help of bamboo pole and collecting the fallen fruits in case of Aonla and Baheda and by hand plucking in case of Baividang. To avoid any microbial contamination, polythene sheet was placed above ground before harvesting the fruits. To find out sustainable harvesting limit, four different harvesting intensities (on the basis of percent harvest) i.e., H_1 (60% harvest), H_2 (70% harvest), H_3 (80% harvest) and H_4 (90% harvest) were selected. At the different sites, the plots were located in forests that have similar kind of management practices for fruit harvesting, protection, grazing, etc. Additionally, periodic regeneration surveys were used to quantify the initial density of seedlings and saplings in the populations being exploited. Transects were sampled once a year.

Gurmar (*Gymnema sylvestre*): The study was conducted at Non Wood Forest Produce (NWFP) Nursery of the Tropical Forest Research Institute, Jabalpur. The plants were grown under open conditions at 0.5×0.5 m spacing and the study was conducted for 3 years after planting. The leaves were harvested twice in a year in the months of October (First harvest) and June (Second harvest). Only 60% mature leaves were harvested by hand plucking. Regular observations were taken plant growth. Total yield from the harvest was also calculated by determining the fresh and dry weight of the leaves.

Kalmegh (*Andrographis paniculata*): The experiments were conducted at Non Wood Forest Produce Nursery, Tropical Forest Research Institute, Jabalpur. Kalmegh seeds were sown in nursery and seedlings were planted in field at 45×45 cm spacing in first week of July. The crop was grown as per cultivation practices developed by Pandey and Mandal (2008). Two harvesting

methods, destructive (uprooting) and non-destructive (cutting), were compared in the study. The herb was cut at 08-12 cm above the ground level at the time of initiation of flowering. Total three cuttings were obtained from a single crop. Different harvest intensities (60, 70, 80 and 90%) were also tried to determine the optimum harvesting limits. Regular observations were recorded on number of branches tillers^{-1}, herbage yield (fresh and dry) from the experimental field.

Sarpgandha (*Rauvolfia serpentina*): The crop was cultivated by planting seedlings at 45×45 cm spacing as per existing agronomical practices (Pandey *et al*., 2001). The roots were harvested at different harvesting time i.e., 6, 12 and 18 months after planting. The crop was irrigated 8-10 days prior to uprooting and the above ground foliage was cut and the roots were uprooted. The roots were cleaned, washed and dried in shade. Care was taken not to damage outer bark of roots while uprooting as it contains maximum amount of alkaloid. Fresh and dry root biomass was taken to obtain yield. The experiments were carried out to optimize harvesting methods. Two harvesting methods, traditional and non destructive (leaving behind a small part of root) were experimented in the field.

Chemical analysis: To find out optimum harvesting time with regard to fruit quality, fruits of Aonla were harvested at monthly intervals from September to January. The ascorbic acid content in the fruits was estimated by titrimetric method of Aberg (1958) and gallic acid by High Performance Liquid Chromatography (HPLC) method (Charpentier and Cowles, 1981). Fruits of Baheda were collected monthly during the fruiting season (September-January) from the experimental plots and analyzed for their tannin and gallic acid content by Spectrophotometer and HPLC, respectively (Schanderi, 1970; Charpentier and Cowles, 1981). Fruits of Baividang were collected monthly during the fruiting season from the experimental plots and analyzed for their embelin content by HPLC method of Choudhury *et al*. (2007) with some modifications. Leaf samples of Gudmar for gymnemic acid estimation were collected in such a way that the sample contained both tender and mature leaves. Gymnemic acid concentration in the leaves was estimated by HPLC method of Toshihiro *et al*. (1994). Andrographolide content in Kalmegh was analyzed by the method of Pandey and Mandal (2010). Sarpagandha roots were harvested after 6, 12 and 18 months of planting and total alkaloid content in the roots was estimated by the method given by Ahmad *et al*. (2002).

Statistical analysis: The data pertaining to annual regeneration and recruitment rates with respect to harvesting methods and intensities and data on effect of harvesting month on the quality of Aonla, Baheda and Baividang fruits were subjected to Analysis of Variance (ANOVA) using SPSS (Statistical Package for the Social Sciences, Version 14.0) at $p<0.05$ level of significance. However, data on biomass yield of Kalmegh was statistically analyzed by one way ANOVA using SX software.

RESULTS AND DISCUSSION

Aonla: Table 2 represents the effect of harvesting time on quality of Aonla fruits. It has been observed that there was significant increase both in fresh weight and ascorbic acid content from September to January.

The fresh weight showed gradual increase from 14.75 to 22.25 g and ascorbic acid content also gradually increased from 198.24-675.50 mg 100 g^{-1}. The tannin content was higher in the fruit samples harvested in October (6.68%) than samples harvested in January (4.75%). Gallic acid

Table 2: Effect of harvesting time on quality of *Phyllanthus emblica* fruits

Harvesting time	Fresh weight (gm)	Ascorbic acid (mg 100 g^{-1})	Tannin (%)	Gallic acid (mg 100 g^{-1})
September	14.75±0.82^{a}	198.24±1.63^{a}	5.25± 1.02^{a}	25.48±1.55^{a}
October	15.50±3.27^{a}	360.15±8.16^{b}	6.68±2.45^{a}	43.45±1.63^{b}
November	19.85±1.63^{b}	402.25±1.47^{c}	5.65±2.45^{a}	128.35±4.08^{c}
December	20.45±0.98^{bc}	595.45±8.23^{d}	5.25±0.82^{a}	125.25±4.08^{d}
January	22.25±.51^{d}	675.50± 8.25^{e}	4.75±0.61^{a}	75.65±1.76^{e}

a, b, c: Mean values within each column followed by different letter differ significantly and the values with same letter are not significantly different at $p<0.05$

Table 3: Regeneration and annual recruitment status of *Phyllanthus emblica*

			Regeneration of plants (%)		Annual recruitment of plants (%)	
Site	Harvesting level (%)	Initial No. of plants in 2006	2007	2008	2007	2008
Non PPA, Jabarra, Dugali,	H_1 (60)	20.8	4.67±0.46^{a}	4.39±1.98^{a}	2.28±0.14 ^{a}	1.69±0.57^{a}
Dhamtari	H_2 (70)	19.2	7.17±2.23^{b}	8.66±1.04^{b}	3.55±1.04^{b}	2.75±0.18^{b}
	H_3 (80)	17.2	2.64±0.97^{c}	10.31±2.21^{c}	1.29±0.56^{c}	3.80±0.93^{c}
	H_4 (90)	17.8	1.57±1.73^{c}	5.42±1.26^{ab}	1.22±0.61^{d}	1.75±0.53^{d}
PPA Jabarra, Dugali,	H_1 (60)	33.66	11.66±0.78^{a}	13.97±3.34^{a}	5.47±0.16^{a}	13.97±3.32^{a}
Dhamtari	H_2 (70)	31.33	15.94±2.25^{a}	11.07±1.28^{b}	7.25±1.09^{b}	11.17±1.34^{ab}
	H_3 (80)	36	11.08±1.19^{a}	9.46±0.15^{bc}	4.32±0.97^{ab}	9.47±0.14^{b}
	H_4 (90)	41	12.38±0.27^{b}	2.49±4.78^{c}	5.74±0.03^{ab}	2.49±4.79^{c}
PPA Changari, Dharpur,	H_1 (60)	22	44.67±6.74^{a}	12.17±1.01^{a}	36.78±5.38^{a}	5.66±0.45^{a}
East Sarguja	H_2 (70)	14	46.65±8.13^{a}	17.38±4.68^{b}	37.45±5.85^{a}	7.94±2.07^{b}
	H_3 (80)	22.5	25.53±6.79^{b}	7.19±2.52^{c}	22.16±4.95^{b}	3.45±1.11^{c}
	H_4 (90)	17.5	23.72±8.07^{b}	6.26±3.17^{c}	20.27±6.28^{b}	3.02±1.41^{c}
PPA Kudurgarh, South	H_1 (60)	18	43.78±11.85^{a}	20.19±3.71^{a}	35.82±9.24^{a}	8.88±1.40^{a}
Sarguja	H_2 (70)	17.75	19.8±5.11^{ab}	17.06±1.49^{a}	17.94±3.40^{b}	8.09±0.85^{a}
	H_3 (80)	17.75	23.45±2.53^{bc}	12.81±1.51^{b}	18.51±2.99^{b}	5.98±0.64^{b}
	H_4 (90)	13.5	21.05±4.22^{c}	9.71±3.69^{c}	18.74±2.84^{b}	4.61±1.61^{b}

a, b, c: Mean values within each column followed by different letter differ significantly and the values with same letter are not significantly different at $p<0.05$

content was highest (128.35 mg 100 g^{-1}) in the samples collected in the month of November. The results suggested that Aonla fruits attained maturity in the month of December-January which may be the optimum harvesting time for this crop under tropical climatic conditions of Chhatisgarh.

The data pertaining to annual regeneration and recruitment of Aonla after harvesting the fruits as per treatments are presented in Table 3. The annual regeneration and rate of recruitment varied among sites. Intensity of harvesting played significant role in regeneration and recruitment of Aonla. Statistically, H_2 treatment i.e., 70% harvesting intensity was found to be the best treatment as determined by Duncan's Multiple Range Test (DMRT) however, it is statistically at par with H_1 (60% harvesting intensity) treatment.

Over harvesting is a major cause for poor regeneration of Aonla in the state. The areas with higher harvest intensity showed poor regeneration. Murali and Hegde (1997) reported deficient natural regeneration under the trees which were over harvested for fruits. They suggested that regulated fruit harvest should be done leaving some fruits on the tree for regeneration. The high permissible sustainable harvest (70%) of the Aonla fruits as found in the present study suggests that the population can be maintained without any decline as a result of fruit harvest.

Emanuel *et al.* (2005) reported that 92% fruits of *Sclerocarya birrea* could be harvested without impacting the current population in the South African lowveld. The current harvesting levels of the fruits seem to have negative impact on population of Aonla. Our findings are in accordance with the findings of Avocevou-Ayisso *et al.* (2009). Sinha and Bawa (2002) also found that populations of *P. emblica* and *P. indofischeri* are sensitive to destructive harvesting (due to lopping of branches) than fruit harvest. They found that such harvesting technique reduce fruit production in the following year for these species. Cutting of primary branches to harvest fruits has deleterious effect on fruit productivity in subsequent years. Murali and Hegde (1997) and Setty *et al.* (2008) suggested regulated harvesting to ensure perpetual regeneration of *P. emblica* in the moist evergreen and moist deciduous forests of South India.

Baheda: Table 4 depicts the regeneration and annual recruitment rates of Baheda. The annual regeneration and recruitment rates varied significantly in open forest and PPA at South Singhpur, Dhamtari site. Recruitment was low in the unprotected forest (open forest) with only 1.2% increase in initial density of plants during the study period, compared to 3.6% increment in the protected forest. The harvesting treatments significantly influenced regeneration and recruitment rates. The interaction of treatment with year on regeneration and recruitment was not significant.

Population density of baheda was significantly higher in PPA sites than in open forest site. Several workers (Lykke, 1998; Tesfaye *et al.*, 2002; Wadt *et al.*, 2005; Peres *et al.*, 2003); had suggested that there are many biotic and abiotic factors that affect the population structure. At experimental sites, we also observed a difference in regeneration and recruitment at regions proximal to the settlements (perhaps due to an increased level of harvesting and other human mediated disturbances), in PPA the effects seem to be subdued. Furthermore, the observed regeneration and recruitment rates were high in low intensity harvesting sites but very low in high intensity harvesting sites. The results revealed that when sites are destructively over-harvested they tend to have fewer individuals in different age-classes. Many workers (Shackleton *et al.*, 2005; Ticktin, 2004) opined that heavy harvesting of fruits/seeds could have long-term detrimental effects on recruitment of new individuals and can bring changes in population structure and dynamics of plants being harvested due to limited regeneration and recruitment. However, Harper (1997) suggested that to correctly measure the recruitment rate, the study should be conducted over a series of years to eliminate the effect of episodic regeneration. Furthermore, there is some evidence that fruit yield is highly variable from year to year (Shackleton, 2002) and hence it is realistic to expect some fluctuations in recruitment of concerned species.

The concentration of tannin and gallic acid increased during the fruiting season (September-January) at each site. The concentration of tannin was maximum (14.04±0.35%) in the month of December at Harishankarpur, Kudergarh, South Sarguja (PPA) when the fruits were mature and minimum (8.21±0.31) in the month of September at South Singhpur, Dhamtari (open forest) when the fruits were immature. Gallic acid concentration was maximum (24.15±0.87) in the month of December at South Singhpur, Dhamtari (PPA) whereas it was found minimum (15.08±0.19) in September at South Singhpur, Dhamtari (open forest) (Table 5).

The best time of collection should be according to maturity of fruits as the concentration of biologically active constituents varies with the stage of plant growth and development. The tannin

Table 4: Regeneration and annual recruitment status of *Terminalia bellerica*

Location	Harvesting method	Harvesting intensity (%)	Initial No. of plants in 2006	Regeneration (%)		Recruitment (%)	
				2007	2008	2008	2009
South Singhpur,	Traditional	60	10.3±0.09	0.54±0.04^{b}	0.71±0.40^{b}	0.56±0.05^{b}	0.56±0.07^{b}
Dhamtari (Open forest)		70	09.5±0.11	0.94±0.30^{a}	1.01±0.16^{a}	0.75±0.15^{a}	0.98±0.11^{a}
		80	08.8±0.02	0.75±0.06^{b}	0.61±0.27^{b}	0.46±0.03^{b}	0.60±0.08^{b}
		90	10.7±0.11	0.64±0.09^{b}	0.45±0.04^{b}	0.40±0.02^{b}	0.41±0.06^{b}
	Non-destructive	60	13.0±0.13	0.98±0.12^{b}	0.57±0.04^{b}	0.85±0.05^{b}	0.94±0.17^{b}
		70	10.5±0.13	1.17±0.14^{a}	1.61±0.17^{a}	1.94±0.08^{a}	1.86±0.14^{a}
		80	09.7±0.10	0.85±0.11^{b}	0.54±0.13^{b}	0.53±0.18^{b}	0.88±0.11^{b}
		90	10.5±0.11	0.71±0.09^{c}	0.43±0.05^{c}	0.50±0.02^{b}	0.65±0.09^{b}
South Singhpur,	Traditional	60	12.3±0.12	1.19±0.04^{a}	1.01±0.02^{a}	1.16±0.05^{a}	0.24±0.02^{a}
Dhamtari (PPA)		70	16.5±0.29	1.75±0.06^{a}	0.94±0.01^{ab}	1.46±0.03^{a}	0.64±0.03^{a}
		80	19.8±0.16	1.44±0.30^{a}	0.91±0.02^{ab}	1.19±0.05^{a}	0.12±0.01^{a}
		90	14.7±0.14	1.14±0.09^{a}	0.62±0.04^{a}	0.68±0.02^{a}	0.21±0.02^{a}
	Non-destructive	60	20.0±0.15	3.37±0.32^{b}	1.73±0.21^{a}	3.64±0.77^{ab}	0.80±0.17^{a}
		70	12.5±0.21	4.67±0.94^{a}	1.85±0.03^{a}	4.15±1.42^{a}	0.87±0.02^{a}
		80	15.4±0.15	3.09±0.11^{b}	1.11±0.08^{b}	2.18±0.76^{b}	0.53±0.06^{b}
		90	20.5±0.15	3.00±0.41^{b}	1.04±0.05^{b}	2.74±0.19^{ab}	0.80±0.07^{a}
Hariharpur Kudurgarh,	Traditional	60	15.6±0.21	0.75±0.04^{b}	0.38±0.01^{a}	0.65±0.01^{a}	0.11±0.02^{a}
South Sarguja (PPA)		70	24.4±0.17	1.99±0.01^{a}	0.78±0.01^{a}	0.93±0.03^{a}	0.17±0.01^{a}
		80	19.8±0.17	0.71±0.02^{b}	0.69±0.05^{a}	0.64±0.01^{a}	0.09±0.01^{a}
		90	25.7±0.24	0.61±0.03^{b}	0.45±0.02^{a}	0.60±0.02^{a}	0.09±0.01^{a}
	Non-destructive	60	27.7±0.28	1.96±0.02^{ab}	1.10±0.02^{ab}	1.79±0.15^{b}	0.47±0.28^{ab}
		70	28.3±0.29	2.29±0.56^{b}	1.38±0.16^{a}	2.78±0.16^{a}	0.62±0.09^{ab}
		80	26.4±0.18	1.79±0.86^{ab}	1.12±0.03^{a}	1.53±0.36^{b}	0.55±0.08^{a}
		90	17.2±0.23	1.50±0.02^{a}	1.14±0.09^{a}	1.72±0.21^{b}	0.55±0.35^{a}
Mohanpur, Raigarh (PPA)	Traditional	60	17.9±0.13	0.85±0.04^{b}	0.38±0.09^{a}	1.47±0.02^{a}	0.77±0.17^{b}
		70	25.4±0.17	1.39±0.05^{a}	0.83±0.02^{a}	1.57±0.02^{a}	1.60±0.24^{a}
		80	16.9±0.27	0.75±0.03^{b}	0.34±0.23^{a}	0.69±0.04^{b}	0.57±0.26^{b}
		90	27.7±0.29	0.53±0.02^{b}	0.23±0.03^{a}	0.56±0.02^{b}	0.61±0.21^{b}
	Non-destructive	60	17.5±0.22	2.32±0.16^{b}	0.90±0.34^{b}	2.18±0.14^{b}	2.01±0.05^{a}
		70	21.3±0.34	3.41±0.03^{a}	2.81±0.67^{a}	3.30±0.25^{a}	2.29±0.13^{a}
		80	24.6±0.27	2.01±0.02^{b}	0.88±0.35^{b}	1.88±0.80^{b}	1.23±0.03^{a}
		90	24.4±0.21	1.67±0.25^{b}	1.50±0.20^{b}	1.58±0.42^{b}	1.59±0.09^{a}

Mean values within each column followed by different letter differ significantly at $p<0.05$

and gallic acid content were observed maximum in the month of December when the fruits were mature and minimum in the month of September when the fruits were immature. Cirak *et al.* (2007) studied variation of bioactive secondary metabolites in *Hypericum origanifolium* during its phenological cycle and reported increase in the concentration of secondary metabolites on fruit maturation. Mhamdi *et al.* (2010) reported increase in the concentration of total phenolic acids with the ripening of Borage seeds (*Borago officinalis* L.). Similarly, variation in gallic acid content was observed in our study. Thus it can be interpreted that harvesting time influences the quality of produce. Baheda fruits should be harvested after maturity when they change their colour from green to dark brown. We conclude that fruit should be harvested during December to mid January to ensure quality of both source materials and finished products.

Table 5: Tannins and gallic acid content in *Terminalia bellerica* fruits harvested at different months of the fruiting season

Location	Harvesting time	Tannins (%)	Gallic acid mg 100 g^{-1}
South Singhpur, Dhamtari (Open forest)	September	08.21±0.31^{b}	15.08±0.19^{bc}
	October	09.65±0.25^{b}	17.29±0.15^{b}
	November	10.69±0.17^{ab}	19.35±0.89^{ab}
	December	11.17±0.31^{a}	21.28±0.67^{a}
	January	10.85±0.21^{ab}	20.27±0.24^{a}
South Singhpur, Dhamtari (PPA)	September	09.54±0.28^{ab}	17.67±0.52^{c}
	October	10.33±0.45^{ab}	19.14±0.55^{bc}
	November	10.07±0.77^{ab}	21.29±2.16^{b}
	December	12.45±0.41^{a}	24.15±0.87^{a}
	January	11.68±0.39^{a}	23.94±0.29^{a}
Hariharpur Kudurgarh, South Sarguja (PPA)	September	08.62±0.15^{b}	15.28±0.34^{c}
	October	09.95±0.81^{b}	17.68±0.93^{c}
	November	11.18±0.44^{ab}	20.50±0.75^{b}
	December	14.04±0.35^{a}	23.04±0.35^{a}
	January	12.69±0.56^{ab}	21.57±0.62^{b}
Mohanpur, Raigarh (PPA)	September	08.27±0.50^{bc}	17.05±0.46^{b}
	October	10.08±0.55^{b}	18.94±0.85^{b}
	November	11.35±0.52^{ab}	19.85±0.33^{b}
	December	13.22±0.91^{a}	23.98±0.92^{a}
	January	12.68±0.37^{a}	22.59±0.37^{a}

Mean values within each column followed by different letter differ significantly at $p<0.05$

Baividang: Hand picking resulted in the highest regeneration as compared to traditional methods. The annual regeneration and recruitment rates varied significantly in open forest and PPA at Jabarra, Dhamtari site. Recruitment was low in the unprotected forest (open forest) (Table 6). Statistically, hand plucking 70% fruits was found to be best treatment as determined by Duncan Multiple Range Test (DMRT).

Plants from which fruits were harvested by cutting or breaking branches on average yielded 60-66% less fruits than the plants harvested by hand picking of fruits. We also observed variation in fruit production during the study period. High fruit production was observed in the year 2005; good fruiting in 2007 and 2008. However, fruiting was not observed in 2006. We only recorded fruit production in our experimental sites. However, the variation in fruit production in different years was the general trend observed in the state.

Population density of baividang was significantly higher in PPA sites than in the single open forest site. In the present study, the populations of baividang in the open forest and PPA site experiences more or less similar conditions (light tolerane, habitat type and climate) except the management. The results revealed that when sites are over-harvested they tend to have fewer individuals in different age-classes. The variation in regeneration and recruitment rates at various sites with regard to harvesting methods and intensities could be resulting from over-harvesting of fruits. At experimental sites, we also observed a difference in regeneration and recruitment at regions proximal to the settlements; in PPA the effects seem to be subdued. Furthermore, the observed regeneration and recruitment rates were high in low intensity harvesting sites but very low in high intensity harvesting sites.

Table 6: Regeneration and annual recruitment status of *Embelia tsjeriam-cottam*

Location	Harvesting method	Harvesting intensity (%)	Initial No. of plants in 2005	Regeneration (%)		Recruitment (%)	
				2006	2007	2007	2008
Jabarra, Dhamtari	Traditional	60	14.3±0.09	0.97±0.04^{b}	1.01±0.40^{b}	0.76±0.05^{b}	0.56±0.07^{b}
(Open forest)		70	16.5±0.11	1.44±0.30^{a}	2.21±0.16^{a}	1.19±0.15^{a}	1.86±0.11^{a}
		80	11.8±0.02	0.75±0.06^{b}	1.41±0.27^{b}	0.46±0.03^{b}	0.66±0.08^{b}
		90	14.7±0.11	0.64±0.09^{b}	0.52±0.04^{b}	0.50±0.02^{b}	0.41±0.06^{b}
	Hand plucking	60	15.0±0.13	1.57±0.12^{b}	1.47±0.04^{b}	1.14±0.05^{b}	1.34±0.17^{b}
		70	13.5±0.13	2.24±0.14^{a}	2.71±0.17^{a}	2.94±0.08^{a}	2.86±0.14^{a}
		80	17.7±0.10	1.12±0.11^{b}	1.09±0.13^{b}	1.13±0.18^{b}	1.08±0.11^{b}
		90	18.5±0.11	0.84±0.09^{c}	0.75±0.05^{c}	0.60±0.02^{c}	0.65±0.09^{c}
Jabarra, Dhamtari	Traditional	60	50.6±0.20	2.05±0.04^{b}	2.81±0.08^{b}	2.65±0.05^{b}	2.87±0.02^{ab}
(PPA)		70	43.4±0.14	4.71±0.22^{a}	4.29±0.05^{a}	3.54±0.01^{a}	3.99±0.05^{a}
		80	54.8±0.05	2.61±0.03^{b}	2.45±0.12^{b}	2.00±0.15^{b}	1.43±0.02^{b}
		90	65.7±0.29	1.99±0.01^{c}	2.41±0.05^{b}	1.96±0.03^{c}	1.20±0.01^{b}
	Hand plucking	60	57.7±0.21	3.14±0.05^{b}	3.19±0.09^{b}	3.72±0.04^{b}	3.21±0.08^{b}
		70	48.3±0.26	5.75±0.03^{a}	5.20±0.04^{a}	5.56±0.06^{a}	5.61±0.07^{a}
		80	56.5±0.03	2.49±0.04^{c}	2.17±0.08^{c}	1.78±0.06^{c}	1.22±0.10^{c}
		90	62.2±0.22	2.25±0.14^{c}	2.10±0.03^{c}	1.08±0.01^{c}	0.92±0.04^{c}
Keochi, Marvahi	Traditional	60	31.9±0.05	2.09±0.11^{b}	1.83±0.02^{b}	3.58±0.07^{b}	2.89±0.13^{b}
(PPA)		70	45.4±0.15	4.75±0.04^{a}	2.38±0.09^{a}	4.47±0.02^{a}	4.14±0.05^{a}
		80	34.9±0.04	1.65±0.03^{c}	1.23±0.23^{b}	1.62±0.09^{c}	2.78±0.03^{b}
		90	37.7±0.28	1.33±0.05^{c}	1.07±0.03^{b}	1.30±0.05^{c}	2.77±0.09^{b}
	Hand plucking	60	35.5±0.29	3.37±0.08^{b}	4.11±0.04^{ab}	3.12±0.02^{ab}	4.12±0.01^{ab}
		70	41.3±0.02	5.43±0.09^{a}	5.91±0.02^{a}	4.44±0.08^{a}	5.51±0.02^{a}
		80	38.6±0.25	2.45±0.03^{c}	3.23±0.08^{b}	3.50±0.02^{ab}	3.24±0.04^{b}
		90	30.4±0.12	2.14±0.05^{c}	3.10±0.02^{b}	2.11±0.05^{b}	3.35±0.06^{b}
Ataria, Bilaspur	Traditional	60	32.5±0.24	1.58±0.14^{b}	1.71±0.10^{b}	0.86±0.05^{b}	0.76±0.07^{b}
(PPA)		70	35.9±0.04	2.98±0.08^{a}	2.51±0.06^{a}	1.29±0.05^{a}	1.87±0.01^{a}
		80	45.5±0.19	0.95±0.03^{b}	1.21±0.07^{b}	0.86±0.03^{b}	0.78±0.04^{b}
		90	33.5±0.17	0.84±0.02^{b}	0.89±0.03^{c}	0.58±0.02^{b}	0.81±0.01^{b}
	Hand plucking	60	31.4±0.18	3.88±0.02^{b}	3.46±0.05^{b}	2.72±0.01^{b}	1.65±0.01^{b}
		70	36.4±0.34	6.69±0.04^{a}	5.23±0.03^{a}	5.51±0.07^{a}	5.28±0.05^{a}
		80	41.2±0.14	3.12±0.03^{b}	3.85±0.04^{b}	2.85±0.06^{b}	2.86±0.09^{ab}
		90	14.3±0.09	3.24±0.01^{b}	3.43±0.07^{b}	2.58±0.04^{b}	1.08±0.08^{b}

Mean values within each column followed by different letter differ significantly at $p<0.05$

The concentration of embelin increased during the fruiting season at each site, being maximum in December when the fruits were mature and was at a minimum in September when the fruits were immature (Table 7). The highest concentration was found during December 2008 at PPA site of Jabarra, Dhamtari forest division as determined by Duncan's Multiple Range Test (DMRT).

Significant variation in annual fruit production was observed during the study period. Variation in fruit production has also been found in other forest species (Janick and Moore, 1975; Shackleton, 2002) and in fruits of tree species (Kozlowski and Pallardy, 1997). The best time of collection should be according to maturity of fruits as the concentration of biologically active constituents varies with

Table 7: Embelin content in *Embelia tsjeriam-cottam* fruits harvested at different months of the fruiting season

		Embelin content (%)		
		Harvesting years		
Location	Harvesting month	2005	2007	2008
Jabarra, Dhamtari (Open forest)	September	1.01±0.01^{c}	1.28±0.02^{b}	1.45±0.02^{c}
	October	1.74±0.01^{c}	1.84±0.01^{b}	1.95±0.02^{c}
	November	2.51±0.01^{b}	2.67±0.02^{b}	2.75±0.01^{b}
	December	3.58±0.02^{a}	3.86±0.03^{a}	3.99±0.02^{a}
Jabarra, Dhamtari (PPA)	September	1.02±0.01^{c}	1.23±0.01^{c}	1.28±0.01^{c}
	October	2.36±0.03^{b}	2.89±0.03^{c}	3.12±0.02^{b}
	November	3.45±0.02^{ab}	3.75±0.04^{b}	3.86±0.02^{b}
	December	4.56±0.05^{a}	5.12±0.04^{a}	5.63±0.03^{a}
Keochi, Marvahi (PPA)	September	1.03±0.01^{c}	1.13±0.01^{b}	1.65±0.01^{b}
	October	2.03±0.01^{c}	2.09±0.02^{b}	2.68±0.02^{b}
	November	3.02±0.02^{b}	3.54±0.02^{ab}	3.89±0.05^{ab}
	December	4.15±0.02^{a}	4.19±0.03^{a}	4.98±0.03^{a}
Ataria, Bilaspur (PPA)	September	1.01±0.03^{d}	1.12±0.02^{c}	1.45±0.02^{c}
	October	2.05±0.02^{c}	2.63±0.02^{c}	2.74±0.03^{bc}
	November	3.05±0.01^{b}	3.16±0.02^{b}	3.48±0.02^{b}
	December	4.85±0.03^{a}	4.89±0.03^{a}	4.99±0.01^{a}

Mean values within each column followed by different letter differ significantly at $p<0.05$

the stage of plant growth and development. Thus it can be interpreted that harvesting time influences the quality of produce. Baividang fruits should be harvested after maturity when they change their colour from green to pink or red. There was not any significant difference in the embelin content between the fruits harvested in November and December. We conclude that fruit should be harvested during mid-November to mid-December to ensure quality of both source materials and finished products.

Good field collection practices to be followed for Aonla, Baheda and Baividang:

- 70-80% fruits should be harvested and 20-30% of mature fruits should be left for regeneration
- Fruits should be hand-plucked (Baividang) or harvested with the help of bamboo pole (Aonla and Baheda)

Fruits should be harvested at right time of maturity:

- Aonla (December-January)
- Baheda (December-January)
- Baividang (December)

Gurmar: Gymnemic acid being secondary metabolite is often influenced by the environmental and seasonal factors. The data on non-destructive harvesting method of Gudmar was recorded and tabulated in Table 8. During first harvest, in the month of October, 751.66 leaves were harvested and 231.00 young leaves were left for maturity. In second harvesting, 667.33 leaves were harvested and 192.00 leaves were left. In this way, a total of 1446.00 leaves were harvested in a

Table 8: Non-destructive harvesting of *Gymnema selvestre* (Gudmar) leaves

First harvesting				Second harvesting				
Total No. of leaves	No. of leaves harvested	No. of leaves left	Gymnemic acid (%)	Total No. of leaves	No. of leaves harvested	No. of leaves left	Gymnemic acid (%)	Total No. of leaves harvested in year
961.66	751.66	231.00	1.58	859.33	667.33	192.00	1.60	1446.00

Table 9: Influence of harvesting techniques on biomass yield and andrographolide content of Kalmegh

	No. of branches tillers^{-1}		Herbage biomass		
Harvesting techniques	Main crop	Ratoon crop	Fresh weight (g)	Dry weight (g)	Andrographolide content (%)
Destructive	09	-	58.50	17.80	1.87
Non-destructive	08	19	170.79	51.56	1.98
SE±			3.783	1.006	-
CD at 5%			48.07	12.79	NS

year. On an average 200-500 g dried leaves per plant can be obtained from a 4-year-old plant yielding about 4,000-6,000 kg of dried leaves ha^{-1}. The crop can be cultivated for 10-15 years under good management. Immature leaves harvested posses lesser concentration of gymnemic acid (0.69%) than mature leaves.

Good field collection practices to be followed for Gurmar:

- Leaves are ready for harvest after two years of planting
- Harvesting of the leaves should be done twice in the year
- Leaves should be selectively hand plucked
- First harvest-at the start of flowering, i.e., during June
- Second harvest-September-October
- Leaves should be shade dried by spreading thinly on clear ground for 7-8 days to obtain quality produce
- Certain percentage of leaves (40%) should be left on plant to ensure normal physiological processes of the plant
- The branches should not be chopped to facilitate the collection of otherwise inaccessible leaves

Kalmegh: The data pertaining to influence of harvesting technique on biomass yield and andrographolide content are presented in Table 9. Fresh and dry weights were found maximum when Kalmegh was harvested following non-destructive methods (170.79 g and 51.56 g, respectively) and minimum in destructive harvesting practices (58.50 g and 17.80 g, respectively). Based on cumulative yields of total biomass, crop harvested non-destructively yielded more than those of the destructive harvesting method. Fresh and dry foliage yield was found affected by harvesting techniques. In second crop (ratoon), number of branches/tillers was more than the initial crop. The total herbage yield was more in second crop (ratoon). Andrographolide content varied from 1.87 to 1.98% in Kalmegh harvested by different methods. On experimenting different harvest intensities, 80% harvest resulted in more regeneration in the next season.

Raina *et al.* (2007) conducted a study and also reported variation of andrographolide content in dry leaves from 1.14 to 2.60% amongst their collections. The maximum andrographolide

(1.98%) was found in the crop harvested by non-destructive methods. However, minimum andrographolide content (1.87%) was found in the crop harvested by destructive methods. There was no significant difference found in androgrpholide content among first and ratoon crop. Cut method (sustainable harvesting) is superior to destructive harvesting method since it improves natural regeneration of the herb. This harvesting practice can be used for sustainable development of Kalmegh. Sustainable harvesting technique will be very useful in the forest areas where the Kalmegh was available earlier but due to destructive harvesting the population has decreased. By non-destructive harvesting technique root stock of Kalmegh can be preserved in the forest areas.

Good field collection practices to be followed for Kalmegh:

- Harvesting should be done after 110 days of planting i.e., just before flowering
- Whole plant should be uprooted or cut 15 cm above ground level
- Adequate population (10-20%) should be left for regeneration
- Crop should be dried in shade

Sarpagandha: Sarpagandha roots were harvested at 3 different stages of maturity. Chemical analysis showed that there was a significant difference in the root yield and alkaloid content in the roots harvested after 6, 12 and 18 months of planting (Table 10). The roots harvested after 18 months of planting possesses higher alkaloid content (1.97%) compared to roots harvested after 12 months (0.69%) and 6 months (0.41%) after planting. Sobte *et al.* (1951) reported that the yield of roots and alkaloid content increases with the age of the plant.

Our findings are similar with the findings of earlier workers. Previously it was reported that Sarpagandha roots contained not less than 1% total alkaloids (WHO, 1996). In our study Sarpagandha roots contain alkaloid more than 1%. Different harvesting stages/time influenced the root yield and alkaloid content of Sarpagandha (Chatterjee *et al.*, 1956). Study revealed that harvesting of plant after 18 months would yield in better quality produce. Adoption of non destructive harvesting method resulted in the formation of new plants in next season.

Good field collection practices to be followed for Sarpagandha:

- The crop should be harvested after 18 months of planting i.e., in the month of December when the plant sheds its leaves
- Above ground foliage should be cut and the roots must be uprooted
- Irrigation should be provided 8-10 days prior to uprooting
- The roots should be cleaned, washed and dried in shade. Care should be taken not to damage outer bark of roots while uprooting as it contains maximum amount of alkaloid

Table 10: Root biomass and alkaloid content of *Rauvolfia serpentina* roots

	Harvesting time of *R. serpentina* roots								
	6 months			12 months			18 months		
Harvesting method	Fresh weight (g)	Dry weight (g)	Total alkaloid (%)	Fresh weight (g)	Dry weight (g)	Total alkaloid (%)	Fresh weight (g)	Dry weight (g)	Total alkaloid (%)
Destructive	15.86	4.89	0.38	35.68	10.43	0.70	59.32	23.66	1.95
Non-Destructive	20.33	7.67	0.41	41.46	13.52	0.69	58.73	25.23	1.97

Table 11: Variation in concentration of active ingredient before and after maturation

	Collection time		Active ingredients (%)	
NTFP species	Immature collection	Mature collection	Immature collection	Mature collection
Andrographis paniculata (Kalmegh)	September	110 DAP (just before of flowering) in the month Oct-Nov	Andrographolide 0.35%	Andrographolide 2.35%
Embelia tsjeriam-cottam (Baividang)	September	December	Embelin 1.25%	Embelin 1.90%
Gymnemma sylvestre (Gudmar)	Immature leaves	1st harvest-June; 2nd harvest-October	Gymnemic acid 0.69%	Gymnemic acid 1.58%
Phyllanthus emblica (Aonla)	September	December-January	Ascorbic acid, (198.24 mg 100 g^{-1}) Gallic acid (25.48 mg100 g^{-1})	Ascorbic acid (675.50 mg 100 g^{-1}), Gallic acid (125.65 mg 100 g^{-1})
Rauvolfia serpentina (Sarpagandha)	12 months	18 months (Dec)	Alkaloid 0.59%	Alkaloid 1.71%
Terminalia bellerica (Baheda)	September	December-January	Gallic acid (16.27 mg 100 g^{-1}), Tannin% (8.66)	Gallic acid (43.11 mg 100 g^{-1}), Tannin% (12.72)

Table 11 shows the difference in the concentration of active ingredients collected before and after maturation. It shows that the plant part harvested at immature stage contains lesser concentration of active ingredient as compared to mature plant part.

CONCLUSION

Increased demand of herbal products has accelerated over exploitation of valuable medicinal plants by unscientific and destructive manner. As the overexploitation and present harvesting approaches are compromising the long term utilization of resources, the ecological and quality assessments of harvesting from wild populations are necessary to evaluate the sustainability of harvest and quality of produce. If resources are managed sustainably by adopting sustainable harvesting practices they can fulfill the raw material demand of pharmaceutical industry and also provide opportunities for rural people to engage in income generating activities. Harvesting time, variety, site and duration of harvest plays major role on quality and productivity of produce. Sustainable harvesting will result in resource conservation, quality produce, drug safety and efficacy, quality produce and higher economic returns.

For sustainable harvesting of *P. emblica* (Aonla), fruits should be harvested after maturity and ideally 20% fruits should be left for regeneration. If it is difficult to leave 20% fruits on every tree/shrub, leave at least 10% fruiting trees/shrub for regeneration purpose. Non-destructive harvesting of mature fruits helps in maintaining the population because only mature fruits will produce viable seeds and during harvest some fruits will fall and germinate in due course of time. In *T. belerica* (Baheda) and *E. tsjeriam-cottam* (Baividang), non-destructive harvesting of 70% fruits was the best for maintaining sustainability. The study revealed that hand plucking was best for maintaining sustainability in all the above species. For proper dispersal and to maintain sustainability, mature seeds should be dispersed in the forest area. These practices may be helpful for the sustainable management of these important medicinal plants. *G. sylvestre* (Gurmar), leaves should be selectively harvested after 2 years of plantation

by hand plucking twice in the year (June and October). In *Andrographis paniculata* (Kalmegh), results showed a significant difference in the yield of the herb in relation to harvesting techniques. Cut method (non-destructive method) was found to be superior and has an edge over the uprooting (destructive harvesting method) since it improves natural regeneration of the herb. In *R. serpentina* (Sarpagandha) highest root yield and alkaloid content can be obtained from the crop harvested after 18 months of planting in the month of December. By sustainable harvesting technique the above species can be preserved in the forest areas. Extractions of medicinal plants, if done on sustainable basis can provide sustainable supply of raw material and conservation of valuable medicinal plants resources. Drying medicinal plant material directly on bare ground should be avoided. If a concrete/cement surface is used, medicinal plant materials should be laid on a tarpaulin or other appropriate cloth/sheeting. Insects, rodents, birds and other pests, livestock and domestic animals should be kept away from drying sites. Fresh medicinal plant materials should be spread out in thin layers and stirred or turned frequently. We conclude that all the species studied can be sustainably harvested from the forests by following prescribed harvesting approaches. These methods are also useful in providing quality raw material to the pharmaceutical industry on sustainable basis.

Sustainable harvesting practices have a potential to enhance the ecological knowledge bases of harvesting communities and narrows the disparities between the livelihood gains and ecological cost leading to a greater livelihood security to poor forest dependent communities. Promotion of non destructive harvesting practices had shown prominent impact on conservation and quality of NTFP species in the study area. Involvement of local people in management of NTFP resources had increased sustainable fruit, mainly through adoption of scientifically developed non destructive harvesting techniques, harvesting of produce at right time of maturity and thereby decreased tree/plant damage during harvest. Adoption of non destructive harvesting practices had resulted in reduced incidences of destructive harvesting such as lopping, pollarding, cutting of branches, felling of trees, immature fruit collection, from younger trees etc. This has resulted in conservation of NTFP resources vis a vis generating employment opportunities, production of quality raw material and enhanced earnings on sustainable basis.

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