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# Nutritional and Phytochemical Profiling of Underutilized Wild Edible Plants and Their Potential Contribution to Nutritional Security in Rural Communities

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## ABSTRACT

*Underutilized wild edible plants (WEPs) are accessible sources of macro- and micronutrients and bioactive phytochemicals for rural and tribal communities. This study documented and characterized 10 traditionally consumed WEPs of Gond, Govari, Mana, Pradhan and Halba communities in Bhandara district, Maharashtra. Species were selected through semi-structured interviews and free-listing with 96 key informants. Edible parts were evaluated for proximate composition, energy, minerals, ascorbic acid, phytochemicals, and antioxidant activity (DPPH and FRAP). Protein ranged from 6.8–28.4 g/100 g dry weight, fibre from 6.4–24.6 g/100 g and energy from 241.6–656.4 kcal/100 g. Maximum iron (52.6 mg/100 g) was recorded in Alternanthera sessilis, calcium (1120 mg/100 g) in Amaranthus spinosus, and ascorbic acid (142.4 mg/100 g) in Bauhinia variegata flower buds. Total phenolics ranged from 4.2–38.6 mg GAE/g and showed a strong correlation with FRAP ($r = 0.912$, $p < 0.01$). Senna tora exhibited the highest DPPH activity ($IC_{50}$ = 28.4 µg/mL). Overall, the studied WEPs demonstrated substantial nutritional and phytochemical potential and may contribute to dietary diversification and nutritional security in rural communities when appropriately processed and consumed.*

**Keywords:** *Wild edible plants; Proximate composition; Phytochemical screening; Antioxidant activity; Nutritional security.*

## 1 Introduction

Despite the considerable advances made in the production of staples, the prevalence of chronic micronutrient deficiencies, known as hidden hunger, remains a problem among the rural populations of South Asia. The reduction in the global dietary diversity is believed to play an important role in this situation. Though there are several thousand plant species that can be eaten by people, only a fraction of them are grown commercially, whereas a few cereals contribute most of the energy consumed globally [1]. A dependence on the limited number of staple crops may ensure a proper intake of energy but does not guarantee the consumption of sufficient amount of minerals, dietary fibre and phytochemicals.

The wild edible plants (WEPs) are an additional source of food diversity that has long been established historically. WEPs are the plants that have not been grown or domesticated, but rather have been gathered from natural or semi-natural environments and eaten as food [2]. They are mostly low in cost and are easily available and can be a good source of vitamins, minerals, proteins, carbohydrates, dietary fiber, unsaturated fatty acids, and phenolic compounds [3]. Most of the WEPs have been naturally adapted to local environmental and edaphic conditions and thus can be sources of food in seasonally and environmentally stressful situations. It is due to this reason that neglected and underutilized plant species have started getting increasing focus in recent times as an addition to diverse food systems because of their contribution to food and agrobiodiversity [4,5,6].

The utilization of WEPs is highly relevant for rural and tribal societies in India, especially those living in areas rich in forest cover. Various wild green leaves, tubers, roots and fruits among others, are collected and eaten by the communities as complementary food sources, and in certain cases, become very significant during lean seasons within the agricultural calendar. The availability of these plants locally and their low cost of acquisition enable families to obtain other nutrient sources when commercial vegetables and fruits are not available.

In spite of the significance of WEPs for human nutrition, much is yet to be discovered about their nutritional value and chemical composition. Current research often pays attention to the ethnobotanical study and usage of WEPs while there were not many studies that took into account the nutritional and chemical composition of these foods. Therefore, the recent reviews pointed out the need to study the composition of phytochemicals that include phenols, flavonoids, alkaloids, and antioxidants and other health-promoting compounds [7,8].

Underutilized wild edible plants represent an important but often overlooked source of nutritional and health-promoting phytochemicals, particularly for rural and forest-dependent communities. Previous investigations on Indian plant species have demonstrated considerable phytochemical diversity and the presence of biologically active constituents with potential therapeutic significance, including antioxidant and antibacterial activities [9,10,11].

The utilization of wild plant resources is also closely associated with indigenous traditional knowledge, which provides valuable information on the selection, preparation, and consumption of locally available plant species [12]. More recent phytochemical profiling studies using chromatographic approaches have further confirmed the presence of diverse bioactive compounds in lesser-known plant taxa, highlighting their potential for nutritional and health-related applications [13]. Collectively, these findings support the need for systematic nutritional and phytochemical evaluation of underutilized wild edible plants as potential dietary resources and as locally accessible components of strategies aimed at strengthening nutritional security in rural communities

The experimental research has shown that there is great variation in the nutritional and bioactive composition of wild edibles. The nutritional studies of wild edibles from the North Eastern Hill region of India have revealed significant amounts of phenols and antioxidant activity of these plants along with their positive nutritional composition [14]. In a similar way, some Ethiopian wild edible plants have been found to possess protein levels of 13.1-33.63 g/100 g and gross energy levels of 213.05-414.80 kcal/100 g [15]. Some wild vegetables found in Khyber Pakhtunkhwa, Pakistan, have been shown to contain large amounts of carbohydrates and energy levels with carbohydrate levels going as high as 71.99% and energy levels of 349.02 kcal/100 g [16]. In comparative research studies, it has been revealed that in some species which have cultivated counterparts, the wild variants may possess higher levels of certain nutrients than their cultivated counterparts.

The current study is thus an attempt to combine ethnobotanical evaluation with nutritional and phytochemical profiling of certain underutilized wild edible plants that have proven to be nutritionally valuable in the region of Bhandara district. The objectives of this research include the taxonomic identification of the chosen wild edible plants and their edible parts; evaluation of their proximate composition, mineral and ascorbic acid content; characterization of the phytochemical composition and in vitro antioxidant activity; and calculation of the contribution of these plants to the recommended nutrient intake according to Indian Recommended Dietary Allowances. In addition, quantitative information regarding the contribution of these less known edible plants to nutrient recommendations has yet to be determined.

## 1 Materials and Methods

### 1.1 Description of the study area

The research was carried out in Bhandara district of Vidarbha region of the state of Maharashtra in India. The district is situated in the eastern part of Maharashtra with co-ordinates 21.09 degrees N latitude and 79.42 degrees E longitude, bound in the east by Gondia district, in the south by Chandrapur district, in the west by Nagpur district and to the north is Madhya Pradesh state. The district is well known as the Lake District of Maharashtra and has forests of about 1343.77 sq. km of southern tropical dry deciduous forests spread over ten forest ranges and is based on an agro-industrial forest economy [17]. Sampling was done after dividing the population into seven tehsils of the district to include the various habitats used for collecting wild food, that include reserved/protected forests, forest periphery, tank/wetlands peripheries, agricultural bunds, fallow lands and roadsides.

### 1.2 Ethnobotanical documentation and species selection

Field surveys were conducted between June 2024 and August 2026 in all major seasons in an attempt to capture the differences due to seasons in the availability of food plants. Information on the use of wild edible plants was gathered by semi-structured interviews and free listing of 96 key informants purposefully selected from elderly members, traditional herbal healers, forest department workers and people with knowledge of Ayurvedic medicine among the communities of Gond, Govari, Mana, Pradhan and Halba, using a standard quantitative ethnobotanical approach. Prior verbal informed consent was taken from each informant before the interview.

Selection of species for laboratory testing was done on the basis of three factors: higher citation frequency by respondents, the non-availability or lack of published analytical studies for that taxon in India, and being currently absent from commercial market and cultivation, i.e., being underutilized. RFC and UV were determined for each taxon according to formulas and the 10 highest ranking underutilized taxa were selected for further analysis.

### 1.3 Collection, identification and preparation of plant material

Mature healthy specimens that were free from disease were selected at their natural location, and GPS coordinates were noted at each collection site. Identification of the specimens was done by regional and state floras [18,19,20]. The nomenclature was checked with Plants of the World Online (POWO) and World Flora Online. The voucher specimens were poisoned, mounted, and deposited in the herbarium of the Department of Botany, Janata Mahavidyalaya, Chandrapur with accession numbers JMC-WEP-101 to JMC-WEP-110.

Analysis of only those parts of the plants that were habitually used as food sources by the local community was undertaken. The edible plant samples were then washed in running tap water and then distilled water to wash off the impurities. A split sample of the sample was made. The first sample was kept in its fresh form for moisture, ascorbic acid, and cyanogenic content analyses. The second sample was air dried in the shade for seven days, dried in an oven at 45 degrees centigrade to constant weight, then milled through a 60-mesh sieve and stored in air tight amber colored bottles at 4 degrees centigrade.

### 1.4 Proximate composition and energy value

Determination of the proximate composition was done according to the Official Methods of Analysis of AOAC International (AOAC, 2019). Moisture content was determined using oven-drying method at 105 degrees C to constant weight (Method 925.10); total ash using incineration at 550 degrees C for 5 hours in a muffle furnace (Method 923.03); crude fat using Soxhlet extraction with petroleum ether (Method 920.39); crude fibre by digestion successively with 1.25% sulphuric acid and 1.25% sodium hydroxide (Method 962.09); and crude protein by micro-Kjeldahl method using 6.25 conversion factor for nitrogen to protein ratio (Method 984.13). The available carbohydrate was computed as (100 – [moisture + ash + crude fat + crude fibre + crude protein]). Gross energy was estimated using Atwater factors: [(9 x crude fat) + (4 x crude protein) + (4 x available carbohydrate)].

### 1.5 Mineral and ascorbic acid analysis

In order to determine minerals, 0.5 g of the dried and powdered sample was digested in a di-acid solution containing concentrated nitric acid and perchloric acid (9:4, v/v) in a hot plate until a clear solution was obtained, and the solution was diluted to 50 ml with distilled water. Calcium, magnesium, iron, zinc, copper and manganese were measured using atomic absorption spectroscopy while sodium and potassium were measured using flame photometry, and phosphorus was measured colorimetrically using the vanadomolybdophosphoric acid method (AOAC, 2019). The calibration was done using multi-element standard, and blank and reference material were processed for quality control. Ascorbic acid content was determined using the 2,6 dichlorophenolindophenol titration method and expressed as mg/100g fresh weight.

### 1.6 Preparation of extracts and qualitative phytochemical screening

Powdered extractable material (10 g) was successively extracted with methanol (80%, v/v) via cold maceration for 48 hours with occasional shaking, filtration through Whatman No. 1 filter paper, and evaporation to dryness in a rotary evaporator at 40 degrees C. The extracts were kept in dark-colored vials at 4 degrees C prior to use. Qualitative analysis of alkaloids (Mayer, Wagner and Dragendorff tests), flavonoids (alkaline and lead acetate tests), phenols (ferric chloride test), tannins (gelatin test), saponins (foam and hemolysis tests), steroids and triterpenoids (Liebermann-Burchard and Salkowski tests), glycosides (Keller-Killiani test), and reducing sugars (Fehling and Benedict tests) was done based on standard protocols [21]. Reaction outcomes were assessed semi-quantitatively ranging from absent to strongly positive.

### 1.7 Quantitative phytochemical estimation

The total amount of phenolics was quantified using the Folin-Ciocalteau colorimetric assay with measurements taken at 765 nm. The data were expressed in mg gallic acid equivalent per g dry weight. The total flavonoids were quantified using the aluminium chloride colorimetric assay at 415 nm and the data were expressed in mg quercetin equivalent per g dry weight. Condensed tannins were quantified using the vanillin hydrochloric acid colorimetric assay and the data expressed in mg catechin equivalent per g. The total amount of alkaloids and the total amount of saponins were quantified gravimetrically. Spectrophotometric analysis was done using the reagent blank with a UV-visible spectrophotometer. Calibration curves were prepared with r squared of ≥ 0.99.

### 1.8 In vitro antioxidant activity

The radical scavenging capability was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) test, based on the procedure outlined by Brand-Williams et al. (1995), with the absorption reading taken at 517 nm within 30 min of dark incubation period; percent inhibition was calculated and the IC50 value was obtained from the graph. The ferric reducing antioxidant power (FRAP) of the sample was measured using the method described by Benzie and Strain (1996) and expressed as micromoles of Fe(II) equivalent per gram dry weight. Ascorbic acid and butylated hydroxytoluene were used as positive controls. Since antioxidant capability depends on the method of evaluation, two methods were adopted to cross-validate the data obtained.

### 1.9 Assessment of contribution to nutritional security

Each species' nutrient contribution was assessed based on the amount of nutrients per 100 grams of edible portion in relation to the Recommended Dietary Allowance (RDA) for a moderately active adult female Indian individual. This calculation utilized reference values by the Indian Council of Medical Research and National Institute of Nutrition (ICMR-NIN, 2020). In compliance with international food label recommendations, a portion providing 15% or greater of the RDA was considered to be a good source while that providing 30% or greater was a rich source of a particular nutrient. The findings were compared to those of cultivated vegetable species commonly consumed in India as listed in the Indian Food Composition Tables [22].

### 1.10 Statistical analysis

All tests were conducted in triplicate and the data were expressed as the mean ± SD. The data was first checked for normal distribution (Shapiro-Wilk test) and equality of variance (Levene test) before performing further analysis. The differences among the species were determined through One-Way Analysis of Variance followed by Duncan Multiple Range Test at $p < 0.05$. Correlation coefficient was calculated in order to investigate the association between the total phenolic, total flavonoid content and antioxidant potential. Principal Component Analysis and Hierarchical Cluster Analysis were used on the standardised nutrition and phytochemical matrix to classify similar nutrition structure of the plant species. The analyses were conducted through SPSS 26.0 and R 4.3.2.

## 2 Results and discussion

### 2.1 Diversity and ethnobotanical status of the documented species

There were 10 underutilized wild edible plant species belonging to 10 genera and 7 families that are widely consumed by rural and tribal inhabitants of Bhandara district (Fig. 1). The Amaranthaceae family has been found to have the highest representation in terms of number of species (3 species; 30.0%) followed by Fabaceae family (2 species; 20.0%) while the remaining families of Portulacaceae, Boraginaceae, Sapotaceae, Anacardiaceae and Moraceae have only one species each. Among the life forms, tree species are found to be highest (5 species; 50.0%) followed by herbs (4 species; 40.0%) and an undershrub (10.0%). Among the feeding types, maximum number of species is observed to eat leaves and tend shoots (5 species; 50.0%) followed by fruits (3 species; 30.0%) and there is only one flower eating and kernel eating species each. Relative frequency of citation varies between 0.34 to 0.92 with the *Amaranthus spinosus* (0.92), *Senna tora* (0.88) and *Madhuca longifolia* (0.86) being the highest. Preponderance of the Amaranthaceae family in the present study is consistent with earlier studies conducted in the Vidarbha region and adjoining tribal lands of central India [23]. Interestingly, the three Amaranthaceae species are seasonal ephemerals that grow on field bunds.

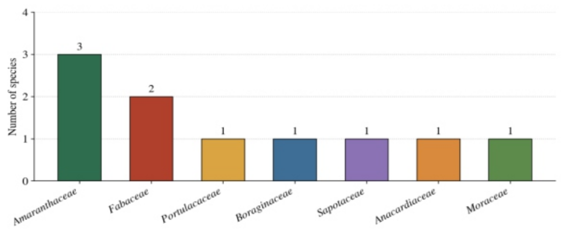


*Figure 1. Family-wise distribution of the 10 underutilized wild edible plant species documented from Bhandara district, Maharashtra*

*Table 1: Underutilized wild edible plant species of Bhandara district selected for nutritional and phytochemical analysis*

| S. No. | Botanical name | Family | Vernacular name | Habit | Part used | Season | RFC |
|---|---|---|---|---|---|---|---|
| 1 | *Amaranthus spinosus* L. | Amaranthaceae | Kate math | Herb | Leaves | Jul-Oct | 0.92 |
| 2 | *Celosia argentea* L. | Amaranthaceae | Kurdu | Herb | Tender shoots | Jul-Sep | 0.81 |
| 3 | *Alternanthera sessilis* (L.) R.Br. | Amaranthaceae | Kanchari | Herb | Leaves | Aug-Dec | 0.69 |
| 4 | *Portulaca oleracea* L. | Portulacaceae | Ghol | Herb | Whole plant | Jun-Oct | 0.63 |
| 5 | *Senna tora* (L.) Roxb. | Fabaceae | Takla | Undershrub | Young leaves | Jul-Sep | 0.88 |
| 6 | *Bauhinia variegata* L. | Fabaceae | Kanchan | Tree | Flower buds | Feb-Apr | 0.71 |
| 7 | *Cordia dichotoma* G.Forst. | Boraginaceae | Bhokar | Tree | Ripe fruit | Apr-Jun | 0.52 |
| 8 | *Madhuca longifolia* (J.Konig) | Sapotaceae | Moha | Tree | Corolla | Mar-May | 0.86 |
| 9 | *Buchanania cochinchinensis* (Lour.) | Anacardiaceae | Char | Tree | Kernel | Apr-Jun | 0.48 |
| 10 | *Ficus racemosa* L. | Moraceae | Umbar | Tree | Ripe fruit | Mar-Jun | 0.34 |

*RFC = relative frequency of citation (n = 96 informants). Voucher specimens are deposited in the herbarium of the Department of Botany, Janata Mahavidyalaya, Chandrapur (accession nos. JMC-WEP-101 to JMC-WEP-110).*

## 2.2 Proximate composition and energy value

Table 2 shows the values of the proximate analysis of the edible parts of the plants under study, while Figure 2 provides their graphical representation. Moisture contents ranged from 5.8 g/100 g to 89.4 g/100 g for *Buchanania cochinchine*nsis kernels and *Portulaca oleracea*, respectively. Such wide fluctuations of the water content in the plants indicate the primary difference between succulent green leafy vegetables and oilseeds. The contents of crude protein in the plants on a dry matter basis ranged from 6.8 to 28.4 g/100 g, crude fat – from 1.9 to 58.7 g/100 g, crude fibre - from 6.4 to 24.6 g/100 g, total ash - from 4.2 to 22.4 g/100 g, and available carbohydrate contents - from 12.7 to 68.3 g/100 g, the gross energy content ranged from 241.6 to 656.4 kcal/100 g. Statistically significant differences ($p < 0.05$) between the species were found for all proximate characteristics.

*Amaranthus spinosus* was found to have the highest protein content (28.4 g per 100 g), followed by *Celosia argentea* (26.1) and *Senna tora* (25.6). These data lie in the range between 13.1 and 33.63 g per 100 g of protein for wild edible plants from the northeast part of Ethiopia [23] and are similar to those obtained in studies on wild vegetables from North Eastern Hill Region of India. Importantly, all Amaranthaceae were above the protein content usually found in spinach and palak cultivated [25] and are therefore nutritionally important in a diet where protein intake from animal products is limited by costs.

The high levels of crude fibre in *Ficus racemosa* (24.6 g/100 g) and *Cordia dichotoma* (19.8 g/100 g) can be considered equally important taking into account the proven role of dietary fibre in glycaemic regulation, lipid metabolism, and gut health, and the low dietary fibre intake in rural diets based on cereals.

The high ash content of *Portulaca oleracea* (22.4 g/100 g) and *Alternanthera sessilis* (19.1 g/100 g) means a significant proportion of minerals, a fact that is confirmed by the elemental analysis presented below. The energy value of the leafy plants (241.6 to 312.8 kcal/100 g) falls into the range of 213.05 to 414.80 kcal/100 g described by [26], which means that they are used mainly as sources of micronutrients but not as alternatives to cereals regarding energy supply. However, *Buchanania cochinchinensis* stands out as an exception because of its kernel containing 58.7% of crude fat and 656.4 kcal/100 g, which surpasses the maximum value of 349.02 kcal/100 g described by [27] for wild vegetables of Khyber Pakhtunkhwa and, therefore, is a source of energy-dense food.

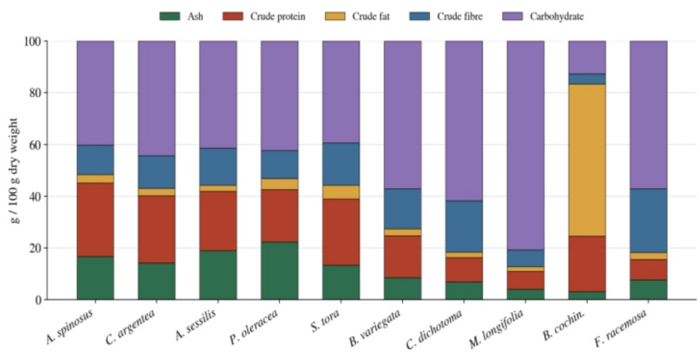


***Figure 2. Stacked proximate composition (g/100 g dry weight) of the edible parts of the studied species, illustrating the contrast between the protein- and ash-rich leafy taxa and the lipid-dominated kernel of Buchanania cochinchinensis***

*Table 2: Proximate composition (g/100 g dry weight) and gross energy value (kcal/100 g) of the edible parts of underutilized wild edible plants of Bhandara district*

| Species | Moisture (FW) | Ash | Crude protein | Crude fat | Crude fibre | Carbohydrate | Energy |
|---|---|---|---|---|---|---|---|
| *A. spinosus* | 84.6 ± 1.2 | 16.8 ± 0.4 | 28.4 ± 0.6 | 3.2 ± 0.2 | 11.4 ± 0.3 | 40.2 ± 0.9 | 303.2 ± 4.1 |
| *C. argentea* | 86.2 ± 1.4 | 14.2 ± 0.3 | 26.1 ± 0.5 | 2.8 ± 0.1 | 12.6 ± 0.4 | 44.3 ± 0.8 | 306.8 ± 3.6 |
| *A. sessilis* | 87.1 ± 1.3 | 19.1 ± 0.5 | 22.9 ± 0.5 | 2.4 ± 0.1 | 14.2 ± 0.4 | 41.4 ± 0.8 | 278.8 ± 3.4 |
| *P. oleracea* | 89.4 ± 1.6 | 22.4 ± 0.6 | 20.3 ± 0.4 | 4.1 ± 0.2 | 10.9 ± 0.3 | 42.3 ± 0.9 | 287.3 ± 4.2 |
| *S. tora* | 80.3 ± 1.0 | 13.4 ± 0.3 | 25.6 ± 0.6 | 5.4 ± 0.3 | 16.2 ± 0.4 | 39.4 ± 0.8 | 308.6 ± 4.6 |
| *B. variegata* | 78.4 ± 1.1 | 8.6 ± 0.2 | 16.2 ± 0.4 | 2.7 ± 0.1 | 15.4 ± 0.4 | 57.1 ± 1.0 | 317.5 ± 3.8 |
| *C. dichotoma* | 72.6 ± 1.3 | 6.9 ± 0.2 | 9.4 ± 0.3 | 2.2 ± 0.1 | 19.8 ± 0.5 | 61.7 ± 1.1 | 304.2 ± 3.5 |
| *M. longifolia* | 74.8 ± 1.5 | 4.2 ± 0.1 | 6.8 ± 0.2 | 1.9 ± 0.1 | 6.4 ± 0.2 | 80.7 ± 1.2 | 367.1 ± 3.2 |
| *B. cochinchinensis* | 5.8 ± 0.3 | 3.1 ± 0.1 | 21.6 ± 0.5 | 58.7 ± 1.1 | 3.9 ± 0.2 | 12.7 ± 0.6 | 656.4 ± 8.4 |
| *F. racemosa* | 68.9 ± 1.4 | 7.8 ± 0.2 | 7.9 ± 0.2 | 2.6 ± 0.1 | 24.6 ± 0.6 | 57.1 ± 1.0 | 283.4 ± 3.1 |

*Values are means of three replicates ± standard deviation, expressed on a dry weight basis except moisture (fresh weight). Means within a column differ significantly at p < 0.05 (Duncan's multiple range test).*

## 2.3 Mineral and ascorbic acid content

Concentrations of minerals found in the selected plants are shown in Table 3 while rank order of the two important nutrition minerals is shown in Figure 3. The most abundant mineral among the macro-elements is potassium, ranging between 486 and 4360 mg per 100 g, while calcium ranges between 196 and 1120 mg per 100 g. Magnesium ranges between 94 and 618 mg per 100 g, and phosphorus ranges between 118 and 542 mg per 100 g.

Among the trace minerals, iron ranges between 3.6 and 52.6 mg per 100 g, zinc between 1.4 and 5.9 mg per 100 g, manganese between 0.8 and 14.2 mg per 100 g, and copper between 0.3 and 2.1 mg per 100 g. Ascorbic acid levels in the edible fresh portions of the plants range from 8.6 and 142.4 mg per 100 g, where *Bauhinia variegata* flower buds

The levels of iron (52.6, 38.7 and 24.8 mg per 100g of dry weight) in *Alternanthera sessilis*, *Amaranthus spinosus* and *Celosia argentea*, respectively, should not be overlooked in the context of iron-deficiency anaemia in women of reproductive age and adolescents, which is a serious public health concern in the area. A high level of mineral content in wild plants compared to domesticated species has been documented before and explained by the fact that wild plants have deeper roots, lack yield-dependent dilution, and maintain their mineral uptake physiology unchanged [28]. The richest sources of calcium were *Amaranthus spinosus* and *Alternanthera sessilis*, containing 1120 and 968 mg per 100 g, respectively.

Moreover, the favourable ratio between potassium and sodium, which was 14.6:1 to 38.2:1 for the leafy plants studied, is important for preventing hypertension. Nevertheless, it should be pointed out that the total concentration of minerals is not an adequate measure of nutritional quality because of phytates, oxalates and tannins present in the same plant matrix that chelate divalent cations and decrease their bioavailability.

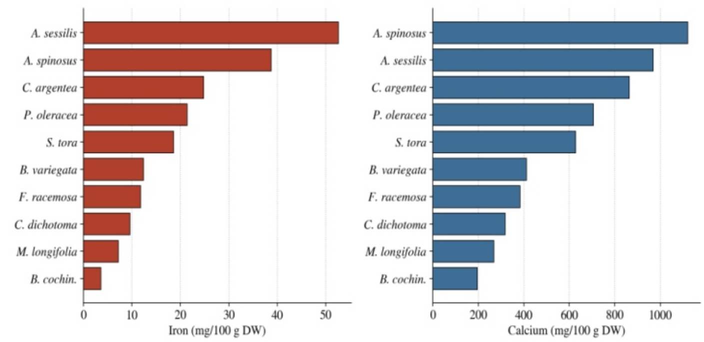


*Figure 3. Rank-ordered iron (left) and calcium (right) concentrations in the edible parts of the studied species, expressed on a dry weight basis*

*Table 3: Mineral composition (mg/100 g dry weight) and ascorbic acid content (mg/100 g fresh weight) of underutilized wild edible plants of Bhandara district*

| Species | K | Ca | Mg | P | Fe | Zn | Mn | Ascorbic acid |
|---|---|---|---|---|---|---|---|---|
| *A. spinosus* | 3840 | 1120 | 618 | 426 | 38.7 | 5.9 | 14.2 | 118.6 |
| *C. argentea* | 3260 | 864 | 512 | 398 | 24.8 | 4.6 | 9.4 | 96.2 |
| *A. sessilis* | 4360 | 968 | 574 | 412 | 52.6 | 5.2 | 12.8 | 68.4 |
| *P. oleracea* | 4120 | 706 | 596 | 542 | 21.4 | 3.8 | 6.2 | 76.8 |
| *S. tora* | 2640 | 628 | 398 | 318 | 18.6 | 4.4 | 7.9 | 62.4 |
| *B. variegata* | 1860 | 412 | 246 | 224 | 12.4 | 2.8 | 3.4 | 142.4 |
| *C. dichotoma* | 1240 | 318 | 184 | 168 | 9.6 | 2.1 | 2.6 | 34.6 |
| *M. longifolia* | 986 | 268 | 142 | 146 | 7.2 | 1.9 | 1.8 | 12.8 |
| *B. cochinchinensis* | 486 | 196 | 94 | 118 | 3.6 | 1.4 | 0.8 | 8.6 |
| *F. racemosa* | 1420 | 384 | 216 | 192 | 11.8 | 2.4 | 3.1 | 28.4 |

*Values are means of three replicates; standard deviations were below 4% of the mean in all cases and are omitted for clarity. Recovery of the certified reference material ranged from 94.6 to 103.2%.*

**2.4 Qualitative and quantitative phytochemical profile**

Results from preliminary qualitative screening of the secondary metabolites showed an abundant and taxonomically diverse profile (Table 4; Figure 4). All 10 species tested positive for phenolics and flavonoids, nine of the 10 for saponins, five for alkaloids, eight for tannins, and eight for steroids/triterpenoids. Among the alkaloids, there was abundant expression in *Senna tora* and *Ficus racemosa* while none was present in any of the three Amaranthaceae family members.

Quantitative assessment of phenolic and flavonoid content revealed 4.2–38.6 mg of GAE per gram dry weight of total phenolic content and 1.8–19.4 mg of QE per gram dry weight of total flavonoid content, with the maximum concentration in the case of both observed in the plant *Senna tora*, while *Ficus racemosa* had 31.2 mg of GAE per gram and *Bauhinia variegata* had 26.8 mg of GAE per gram. Contents of condensed tannins, alkaloids, and saponins varied from 0.9 to 14.2, 0.4 to 3.8, and 1.2 to 8.6 mg per gram respectively. All these results provide quantified evidence to the general observation that wild edible plants are high in antioxidant compounds such as phenolics, flavonoids, vitamin C, and carotenoids and the presence of bioactive compounds might help in preventing any oxidative stress-induced diseases like cardiovascular and neurodegenerative disorders [29]. Phenolic concentrations in *Senna tora* and *Ficus racemosa* plants have been found to be comparable to those found in wild vegetables of northeastern India [30].

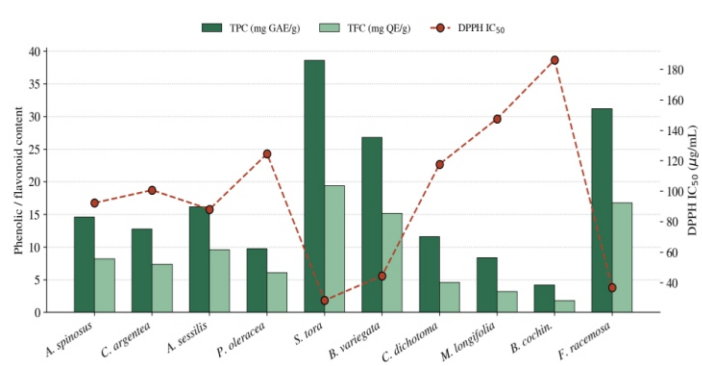


*Figure 4. Total phenolic and total flavonoid contents (bars, left axis) plotted against DPPH radical-scavenging IC50 values (dashed line, right axis). Lower IC50 denotes stronger antioxidant activity*

**Table 4: Qualitative phytochemical screening and quantitative estimation of major secondary metabolite classes in underutilized wild edible plants of Bhandara district**

| Species | Alk. | Flav. | Phen. | Tann. | Sap. | TPC (mg GAE/g) | TFC (mg QE/g) |
|---|---|---|---|---|---|---|---|
| *A. spinosus* | - | ++ | ++ | + | + | 14.6 ± 0.4 | 8.2 ± 0.3 |
| *C. argentea* | - | ++ | ++ | + | ++ | 12.8 ± 0.3 | 7.4 ± 0.2 |
| *A. sessilis* | - | ++ | ++ | ++ | + | 16.2 ± 0.5 | 9.6 ± 0.3 |
| *P. oleracea* | + | ++ | ++ | - | + | 9.8 ± 0.3 | 6.1 ± 0.2 |
| *S. tora* | +++ | +++ | +++ | +++ | ++ | 38.6 ± 0.9 | 19.4 ± 0.5 |
| *B. variegata* | ++ | +++ | +++ | ++ | +++ | 26.8 ± 0.7 | 15.2 ± 0.4 |
| *C. dichotoma* | + | + | ++ | ++ | ++ | 11.6 ± 0.3 | 4.6 ± 0.2 |
| *M. longifolia* | - | + | + | + | +++ | 8.4 ± 0.2 | 3.2 ± 0.1 |
| *B. cochinchinensis* | - | + | + | - | - | 4.2 ± 0.2 | 1.8 ± 0.1 |
| *F. racemosa* | ++ | +++ | +++ | +++ | ++ | 31.2 ± 0.8 | 16.8 ± 0.4 |

*+++ strongly present; ++ moderately present; + present in traces; - absent. TPC = total phenolic content (gallic acid equivalents); TFC = total flavonoid content (quercetin equivalents).*

## 2.5 Antioxidant capacity and its relationship with phenolic constituents

The antioxidant capacity using the DPPH assay provided IC50 values of between 28.4 and 186.2 micrograms per mL, with the lowest IC50 value, hence highest activity, found for *Senna tora* (28.4), followed by *Ficus racemosa* (36.8) and *Bauhinia variegata* (44.6), while the least active species was *Buchanania cochinchinensis* (186.2). The IC50 for the positive control, Ascorbic acid, was 9.6 micrograms per mL. The FRAP assay results were of the range 42.6 to 318.4 micromoles Fe(II) equivalents per g dry weight, with *Senna tora* being the highest in activity (318.4).

Pearson correlation analysis revealed a significant positive correlation between total phenolics content and FRAP value ($r = 0.912$, $p < 0.01$) and between total flavonoids content and DPPH radical scavenging activity ($r = 0.847$, $p < 0.01$); this implies that the phenolics are major contributors to the antioxidant ability of these matrices (Figure 5). The residual variance of around 17-28% reflects the additional contribution of ascorbic acid, carotenoids, and other non-phenolic reductants to the antioxidant property of the tested leaves; this is explained by the case of *Bauhinia variegata* which ranks higher than what could be expected based on its phenolic content, and had the highest concentration of ascorbic acid in this study. This disparity is expected in the light of the well-known dependency of antioxidant capacity measurements on methods of measurement and emphasizes the need for complementary tests. PCA of the standardized nutritional and phytochemical matrix explains 78.4% of total variance in the first two principal components where the leafy taxa belonging to the Amaranthaceae family characterized by minerals and proteins content (PC1) were differentiated from the phenolic-rich *Senna tora* and *Ficus racemosa* cluster (PC2) with *Buchanania cochinchinensis* being an outlier with dominant lipids.

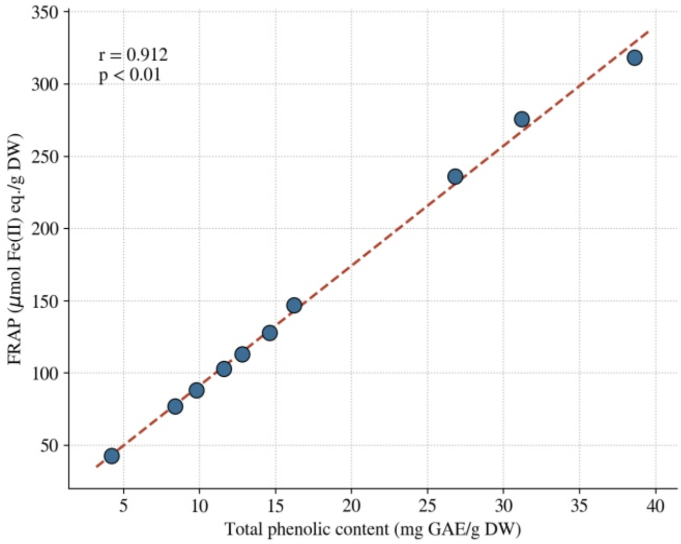


*Figure 5. Relationship between total phenolic content and ferric reducing antioxidant power across the 10 species examined. The dashed line represents the least-squares linear fit*

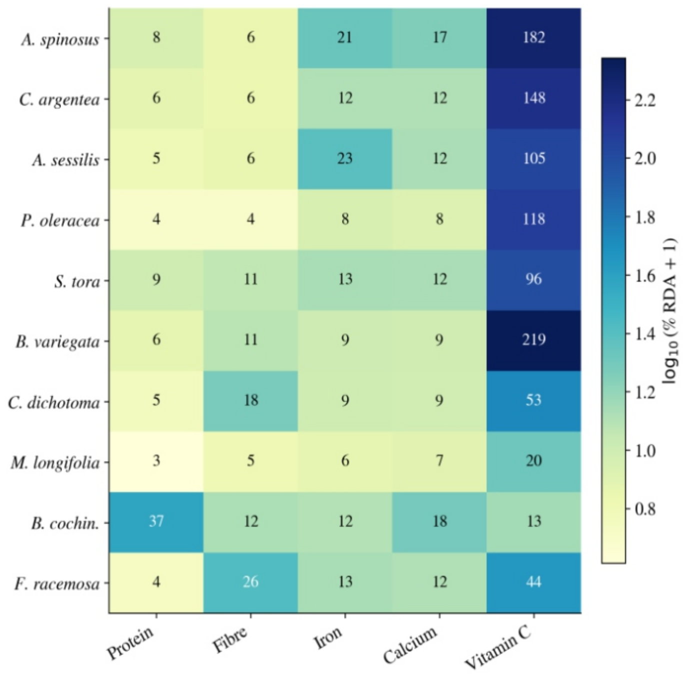


*Figure 6. Heat map of the contribution of a 100 g fresh edible portion to the ICMR-NIN Recommended Dietary Allowance for an adult Indian woman with moderate physical activity. Cell values are % RDA; shading follows a log10 scale to accommodate the wide range of vitamin C values*

## 2.6 Contribution to recommended dietary allowances and implications for nutritional security

Table 5 represents the nutrient composition of a 100 g fresh edible portion of each plant as a percentage of the ICMR-NIN Recommended Dietary Allowance of an adult Indian woman having a moderate level of physical activity (ICMR-NIN, 2020); the same is represented by a heat map in Figure 6. In accordance with these data, 6 species of plants were considered as rich sources of iron, 4 as rich sources of calcium, 5 as sources of proteins, 7 as rich sources of ascorbic acid, while 5 species provided more than 20% of the recommended daily allowance of dietary fiber from a single portion. 23.4% of the daily iron requirement was fulfilled by a 100 g portion of *Alternanthera sessilis*, and a similar quantity of *Bauhinia variegata* flower buds fulfilled 219% of the ascorbic acid requirement.

*Table 5: Contribution of a 100 g fresh edible portion of selected underutilized wild edible plants to the ICMR-NIN Recommended Dietary Allowance (% RDA) for an adult Indian woman with moderate physical activity*

| Species | % RDA Protein | % RDA Fibre | % RDA Iron | % RDA Calcium | % RDA Vitamin C |
|---|---|---|---|---|---|
| *A. spinosus* | 7.9 | 5.9 | 20.6 | 17.2 | 182.5 |
| *C. argentea* | 6.5 | 5.8 | 11.8 | 11.9 | 148.0 |
| *A. sessilis* | 5.3 | 6.1 | 23.4 | 12.5 | 105.2 |
| *P. oleracea* | 3.9 | 3.9 | 7.8 | 7.5 | 118.2 |
| *S. tora* | 9.1 | 10.6 | 12.6 | 12.4 | 96.0 |
| *B. variegata* | 6.3 | 11.1 | 9.2 | 8.9 | 219.1 |
| *C. dichotoma* | 4.6 | 18.1 | 9.1 | 8.7 | 53.2 |
| *M. longifolia* | 3.1 | 5.4 | 6.3 | 6.8 | 19.7 |
| *B. cochinchinensis* | 36.6 | 12.2 | 11.7 | 18.5 | 13.2 |
| *F. racemosa* | 4.4 | 25.5 | 12.6 | 11.9 | 43.7 |

*RDA values used: protein 55.5 g, dietary fibre 30 g, iron 29 mg, calcium 1000 mg, vitamin C 65 mg (ICMR-NIN, 2020). Classification: >=15% RDA = source; >=30% RDA = rich source.*

## 3. Conclusion

The current study is the first attempt towards the integration of nutrition, phytochemistry and antioxidant characterization of the neglected wild edible plants consumed by the rural and tribal communities of Bhandara district, Maharashtra. The 10 selected species exhibited a high concentration of crude protein (up to 28.4 g per 100 g), dietary fiber (up to 24.6 g per 100 g), iron (up to 52.6 mg per 100 g), calcium (up to 1120 mg per 100 g) and ascorbic acid (up to 142.4 mg per 100 g), along with rich in phenolics which contribute to the in vitro antioxidant activity. Some of the species such as *Amaranthus spinosus, Alternanthera sessilis, Senna tora* and *Bauhinia variegata* showed equal or better nutritional attributes than their traditional cultivated counterparts and yet are not available in markets nor cultivated. These results demonstrate that these neglected plants constitute a scientifically validated and locally available economic resource that can be used to enhance dietary diversity and overcome deficiencies of micronutrients in rural central India. The development and promotion of these plants should take place along three avenues: information about processing procedures necessary for safe consumption of each species; recording of the associated traditional knowledge so that it is not forgotten; and the domestication of the high-performing plants so that an increase in their popularity does not lead to exploitation of the remaining wild populations. Further research should include determination of the bio accessibility and bioavailability of these compounds in vitro and in vivo; determination of the individual phenolic and flavonoid compounds by HPLC and LC-MS; and determination of the variability in nutrient and phytochemical content according to season and habitat.

## Appendix: Field documentation of voucher specimens

Representative field photographs documenting in situ collection of the voucher specimens are presented in Plate 1. Each photograph was captured on-site at the time of collection using GPS-enabled camera software, which geotagged the image with the location name, geographic coordinates and timestamp, corroborating the collection localities and seasons reported in Table 1.

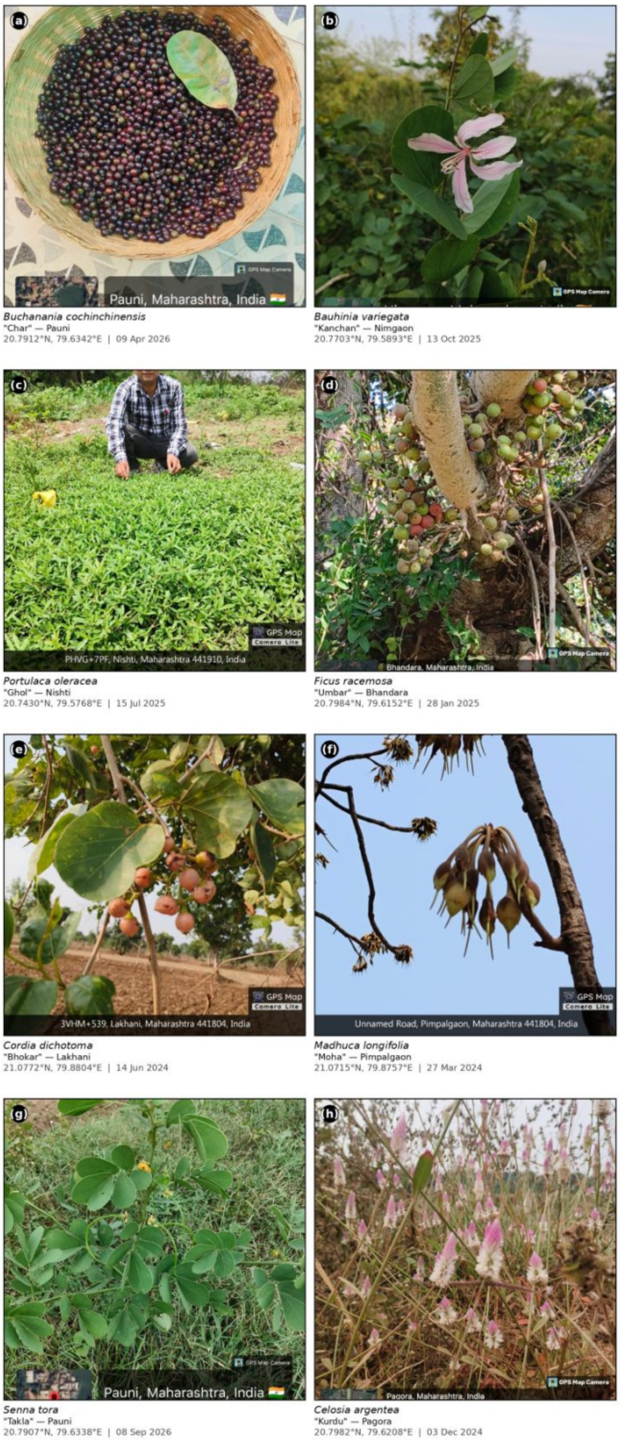


***Plate 1. Field photographs documenting in situ collection of voucher specimens: (a) Buchanania cochinchinensis, Pauni; (b) Bauhinia variegata, Nimgaon; (c) Portulaca oleracea, Nishti; (d) Ficus racemosa, Bhandara; (e) Cordia dichotoma, Lakhani; (f) Madhuca longifolia, Pimpalgaon; (g) Senna tora, Pauni; (h) Celosia argentea, Pagora. Coordinates, dates and locations are geotagged on each photograph.***

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