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AQAR REPORT 2023-24

3.2.1 Number of papers published per teacher in the Journals notified on UGC website during the year 2023-24

Sl. No.	Title of paper	Name of the author/s	Department of the teacher	Name of journal	Year of publication	ISSN number	Link to the recognition in UGC enlistment of the Journal
1	Unconventional but valuable phytoresources: exploring the nutritional benefits of 18 wild edible Asteraceae from West Bengal, India.	**SathiSaha**, SaradinduSaha, SumanKalyan Mandal, ChowdhuryHabiburRahaman	Botany	Genetic Resources and Crop Evolution	14 June, 2023	E ISSN 1573-5109	https://doi.org/10.1007/s10722-023-01621-9
2	Fading but still existing: some new observations on Santals' Ethnoveterinary medicinal practices from the Purba and PaschimBardhaman districts of West Bengal (India)	**SathiSaha**, SumanKalyan Mandal	Botany	Ethnobotany Research and Applications	24 July, 2023	ISSN 1547-3465	http://dx.doi.org/10.32859/era.26.16.1-16
3	The importance of wild edible plant and macrofungi diversity to attain food security for the tribes of eastern India—a quantitative study	SumanKalyan Mandal, **SathiSaha,** and SaradinduSaha	Botany	Frontiers in Sustainable Food Systems	28 August, 2023	ISSN 2571-581X (Online)	https://doi.org/10.3389/fsufs.2023.1198187
4	Assessment of cytotoxic and genotoxic effects of Colletotrichumgloeosporioides and C. capsici toxins on tobacco BY-2 cells	**SaikatSahoo**, Sovan Mishra &MaumitaBandyopadhyay	Botany	The Nucleus	13 March, 2024	ISSN 0029-5698	https://doi.org/10.1007/s13237-024-00467-5
5	Assessment of Science PCK: A Review	Dr.Sudhindra Roy	Education	Education India: A Quarterly Refereed Journal	04 November,2023	ISSN 2278-2435	https://www.educationindiajournal.org/

				Of Dialogues On Education			
6	Understanding the Bengali Homeland Narrative: A Saga of Loss and Evasive Social Justice	Dr.SumitHowladar	Political Science	International Education and Research Journal	Jul-23	2454-9916	DOI: 10.21276/2454-9916
7	Impact of Intellectual Capital on Financial Performance in Indian Banking Sector	ShyamalGarai	Commerce	IPE Journal of Management	January-June 2024	2249-9040	https://ugccare.unipune.ac.in/Apps1/User/WebA/SearchList
8	Recent developments of nanocatalysts for Stille coupling reaction	Sasadhar Majhi and **Shyamal Kr. Jash**	Department of Chemistry	Synthetic Communications	2023	0039-7911 (print); 1532-2432 (web)	https://www.tandfonline.com/doi/full/10.1080/00397911.2023.2269585
9	A Brief Sketch of Strategies and Planning for Plant Metabolic Pathway Moderation	DR. HENA PAUL	DEPARTMENT OF CHEMISTRY	SCIENCE AND CULTURE	2023	0036-8156	DOI: https://doi.org/10.36094/sc.v89.2023.A_Brief_Sketch_of_Strategies_and_Planning.Paul.427
10	Exploration of Recent Progress of Plant Synthetic Biology for Plant Natural Products	Lalan Chandra Mandal	Chemistry	Science and Culture	2023	0036-8156	DOI: https://doi.org/10.36094/sc.v89.2023.Exploration_of_Recent_Progress_of_Plant_Synthetic.Mandal.432
11	Effect of channel morphological changes on wetland transformation,	DR. SURAJIT LET	GEOGRAPHY	Science of the Total Environment 942 (2024) 173802, June 2024, pp.1-17.	2024	0048-9697 (print); 1879-1026 (web)	https://department.kccollege.ac.in/assets/img/uploads/article_body_image/SL_1_ELSEVEIR.pdf
12							journal homepage: www.elsevier.com/locate/scitotenv, [https://doi.org/10.1016/j.scitotenv.2024.173802].
13	Singular Bautin	apan Saha,	**MATHEM**	Nonlinear	**2024**		**https://link.sp**

	bifurcation analysis of a slow–fast predator–prey system	Pranali Roy Chowdhury , Pallav Jyoti Pal, Malay Banerjee	**ATICS**	Dynamics			**ringer.com/article/10.1007/s11071-024-09387-0**
14	Unveiling the dynamics of canard cycles and global behaviour in a singularly perturbed predator–prey system with Allee effect in predator	Tapan Saha, Pallav Jyoti Pal	MATHEMATICS	Computational and Applied Mathematics	2024		https://link.springer.com/article/10.1007/s40314-024-02603-y
15	Allee effect and hunting-induced bifurcation inquisition and pattern formation in a modified Leslie–Gower interacting species system	Pallav Jyoti Pal, Gourav Mandal, Lakshmi Narayan Guin, Tapan Saha	MATHEMATICS	Chaos, Solitons & Fractals	2024		https://www.sciencedirect.com/science/article/pii/S0960077924003369
16	Arbitrary L-statre solution of shifted DENG-FAN potential by interpolating wavelet collocation method	**Dr. Manoj Kumar Saha**	**Physics**	**Science and culture 89**	**2023**	**0036-8156**	https://portal.issn.org/resource/ISSN/0036-8156#
17	A Quest For Female Identity In The Poetry Of Anne Bradstreet	Mahananda Barman	English	*Humanities and Social Sciences Studies*	2024	2319-829X	https://ugccare.unipune.ac.in/Apps1/User/WebA/ViewDetails?JournalId=101001991&flag=Search
18	Identifying key drivers of extinction for Chitala populations: data-driven insights from an intraguild predation model using a Bayesian framework	Joyita Mukherjee	Zoology	Environmental and Ecological Statistics	2024	13528505, 15733009	https://link.springer.com/article/10.1007/s10651-024-00631-9

Total No. of Papers Published:18

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NOTES ON NEGLECTED & UNDERUTILIZED CROPS

Unconventional but valuable phytoresources: exploring the nutritional benefits of 18 wild edible *Asteraceae* from West Bengal, India

Sathi Saha · Saradindu Saha · Suman Kalyan Mandal · Chowdhury Habibur Rahaman

Received: 12 February 2023 / Accepted: 27 May 2023

Abstract Wild plants are the largest source of genetic diversity for crop breeding. Since ancient times, people have used wild edibles for sustenance, and these foods are frequently the focus of efficient coping mechanisms for malnutrition. Many tribal communities in West Bengal, India, are malnourished. Incorporating wild green leafy vegetables (WGLVs) into daily cuisine may be a better food-based strategy for alleviating their hidden hunger. *Asteraceae* members have traditionally been used as wild edibles and medicines in India. The current study sought to ascertain the acceptability, nutritional potential, and health benefits of 18 WGLVs of *Asteraceae*. Mineral nutrients, vitamins, proximate contents, antioxidant activity, total phenolic and flavonoid contents, and in vitro toxicity of the selected WGLVs have been assessed. Altogether 36 types of different food and medicinal preparations have been recorded. Ten taxa have been found rich in nutritional compositions like soluble and insoluble carbohydrates, crude protein, crude fat, and dietary minerals (Na, K, Ca, Mg, Fe, Mn, Zn, and Cu). *Cotula anthemoides* L., *Emilia sonchifolia* (L.) DC., *Sonchus arvensis* L., and *Sphaeranthus indicus* L. are some examples of underutilized edible herbs that contain significant amounts of vitamins, health-beneficial phytochemicals, and antioxidants. All of the investigated WGLVs have a wide range of nutritional potentialities and can be used for human consumption as alternative and functional food items, which may potentially alleviate hidden hunger and provide food security.

Keywords Traditional knowledge · Wild edible · *Asteraceae* · WGLVs · Nutritional analysis · Crop genetic resource

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Introduction

Food is the foremost basic need of all human beings, but its insufficiency and inadequate consumption push approximately two billion people towards undernourished conditions (FAO 2009). It is one of the biggest concerns and threats to humanity in the twenty-first century. In course of transformation of human society,

their food habits are mostly confined to a monotonous cereal-rich meal which causes chronic micronutrient deficiency (Saunders and Smith 2010). Micronutrient deficiencies, also known as 'Hidden Hunger' affect the overall physical and mental health of a population and are considered vital among the top 10 risk factors contributing to the global burden of chronic health issues (GBD 2020). The risk of micromineral deficiency of Ca, Fe, and Zn is significantly high among Indians of all ages (Venkatesh et al. 2021; Awasthi et al. 2022). Currently, 50% of the total micronutrient-deficient population of the world belongs to India (Ritchie et al. 2018). It is a threat to the public health of a nation, and it becomes a challenge to humans in achieving the sustainable development goals (SDGs) in several developing countries (Ghosh-Jerath et al. 2020). Several scientists have recommended food-based strategies to get the best possible nutritional requirements to beat nutritional deficiencies and related health problems (Tontisirin et al. 2002; Bamji et al. 2021). Incorporating wild edibles into daily diets has been advocated as the most sustainable and effective way to evade malnutrition (Chadha and Oluoch 2003). Wild edible plants are those plant species that grow in wild or semi-wild conditions and are not domesticated, cultivated, or taken as food conventionally (Tardío et al. 2006). The contribution of wild edible plants as human food is as old as human civilization (Flyman and Afolayan 2006). On the other hand, wild plants remain the largest source of genetic diversity for breeding crops.

Ethnic people who are close to nature and forests have been enjoying the advantage of directly accessing numerous unconventional and wild food items to satisfy their hunger (Abbasi et al. 2013; Ahmad and Pieroni 2016; Güneş et al. 2018; Çakılcıoğlu 2020; Garekae and Shackleton 2020; Opazo-Navarrete et al. 2021). Many wild edibles contribute a lot to meet the food crisis during emergency periods of famine, war, pandemic, or prolonged natural disasters (Reyes-García et al. 2015; Zhang et al. 2016; Bhushi 2021). Research has revealed that wild-growing green leafy vegetables (WGLVs) are packed with essential nutrients, rich in dietary fiber, low in fat content, high in folate, ascorbic acid, and several other vitamins that offer a disease-free and healthier life (Duguma 2020; Mishra et al. 2021). Wild greens are also marked as the storehouse of a wide range of beneficial phytochemicals such as carotenes, xanthophylls, anthocyanins, simple phenols, flavonoids, and many polyphenols. The delightful nutritional profile of such WGLVs has an effective contribution in diminishing the risk of many acute health issues (Åhlberg 2021).

A perusal of the literature revealed that a large portion of the tribal community including *Santals* living in the laterite region of West Bengal (India) uses wild edibles in their daily diet (Bandyopadhyay and Mukherjee 2009; Roy et al. 2015) but still suffer from malnutrition mainly due to lack of optimum diet intake and other socio-cultural limitations (Bisai 2014; Stiller et al. 2020; Chandra et al. 2021). On the other hand, with ongoing anthropogenic activity in the forest, shifting cultivation, reliance on the limited number of high-yielding cultivars, climate change, and changes in the socio-economic conditions of the ethnic people, the traditional societies are silently losing their food heritage along with the related phytoresources (Luczaj et al. 2012; Downs et al. 2020; Ghosh-Jerath et al. 2021). Wild vegetables contribute a lot to the food security of multiple ethnic communities in India, but only limited research has been carried out in documenting wild edibles from the laterite region of West Bengal (Banerjee et al. 2013; Dey and Mukherjee 2015; Bouri and Ganguly 2016) or studying their nutritional profile (Chaudhury et al. 2018).

Many research articles and review papers on wild edible plants with immense beneficial attributes have been published so far focusing on specific plant families like *Solanaceae*, *Leguminosae*, *Lamiaceae*, *Asteraceae*, and many more (Samuels 2015; Satovic 2016; Garcia-Oliveira et al. 2021). The family *Asteraceae* is one of the most diverse and largest families among flowering plants and it is contributing to almost every sector of economic utilization of plant wealth including food and medicine (Koc et al. 2015; Michel et al. 2020; Rolnik and Olas 2021). It has been found that the edible leaves, flowers, and roots of many wild *Asteraceae* are good sources of essential mineral nutrients and vitamins (García-Herrera et al. 2014). Herbs like *Crepis vesicaria* L., *Sonchus oleraceus* L. and *S. asper* (L.) Hill are very popular in the Mediterranean diet and these herbs are a very good source of dietary fiber, vitamin A, and thiamine (Panfili et al. 2020). There are 121 species of the *Asteraceae* used as food, spices, pickles, and recreational tea in Turkey (Şenkardeş et al. 2019). Nowadays, many traditionally used plants of the family *Asteraceae* are being considered as potential candidates for their exploitation in

the pharmaceutical as well as functional food industries all over the world (Garcia-Oliveira et al. 2021; Rolnik and Olas 2021). In India, about 1,403 plant species distributed in 184 families are recognized as edible ones, among which *Asteraceae* includes the second-highest number of edible species (Ray et al. 2020). Many of these edible members of *Asteraceae* still need a thorough investigation on their wide acceptability as food and nutritional items. A perusal of literature published from West Bengal indicates that there is a potential lack of scientific information about the nutritional prospects of the locally available wild edible greens of the family *Asteraceae*.

In this context, the present study aims to fulfill the following goals:

- To document the traditional knowledge on 18 wild-growing leafy vegetables of the *Asteraceae* family used by the tribal people of West Bengal, India.
- To assess their nutrient and proximate content.
- To understand their potentialities for managing the persistent hidden hunger among the local tribes.

Materials and methods

Study area

For the present study, we focused mainly on the district Birbhum, the land of varied topography, dry deciduous *Saal* forest, and diverse tribal groups residing in remote villages as well as urban and semi-urban areas of this district. The study area is located between 23°32′30″ and 24°35′00″ North latitudes and 87°5′25″ and 88°1′40″ East longitudes, and occupies an area of 4545 sq km (Fig. 1). In Birbhum, 15,927 hectares of land is covered by forest; out of which 2849 hectares of land is under the reserved forest areas, 6242 hectares is protected forest areas and 6835 hectares of land is unclassified state forest land. Some of the main forests in the district are Ballavpur forest, Gonpur forest, Chaupahari forest, Chorchor forest, the forest of Chinpai, and Bhandibon. All these natural forests are rich in various medicinal and edible species of diverse plant groups which are gathered mainly by the tribal people for partial fulfillment of their daily diet and primary healthcare needs (Mandal and Rahaman 2014).

We had purposefully selected 11 Blocks of Birbhum district in West Bengal, India where approximately 80% of the district's tribal population resides to date. 'Block' represents one of many administrative units under a Subdivision of a district usually consisting of several villages. The blocks included in our research were Rampurhat-I, Mohammad Bazar, Rajnagar, Suri-I, Suri-II, Sainthia, Labpur, Nanoor, Bolpur-Sriniketan, Illambazar, and Dubrajpur.

Collection of data and selection of participants

Field surveys were conducted from March 2015 to February 2017 based on in-depth semi-structured interviews and focus group discussions. We have randomly selected 10 localities from each of the investigated blocks. A multistage sampling method was applied to select the key participants. At first, 528 inhabitants of the target area were asked a 'Wh' question about whether they use wild greens as vegetables and for medicinal purposes or not. Among them, 273 inhabitants had responded positively with 'YES'. Then flowering twigs of locally available 25 *Asteraceae* herbs were exhibited to those 273 respondents. Finally, 150 participants were able to recognize 18 species as leafy vegetables. These participants' age ranged from 10 to 87 years. Altogether 87 women, 34 men, 21 girls, and eight boys from 132 households scattered in remote rural areas, semi-urban and urban settlements were included as key-participants. Among the participants, 14 were traditional healers having versatile knowledge of plants and well-recognized in their respective localities for their healing skills. The data on the local name of the plant species, its traditional uses, occurrence, season of availability, frequency of use in a week, and side effects, if any, were recorded after taking Free and Prior Informed Consent (FPIC) from each of the participants. At the time of the field survey, we had strictly followed the best field practice as proposed earlier by the scientists (Heinrich and Verpoorte 2014; Heinrich et al. 2018), and the Code of Ethics recommended by the International Society of Ethnobiology (ISE 2006). The collected data were compared with the relevant literature on ethnobotany and economic botany (Paria 2005; Khare 2008; Jain 2012; Jain and Jain 2016; Mandal and Rahaman 2022).

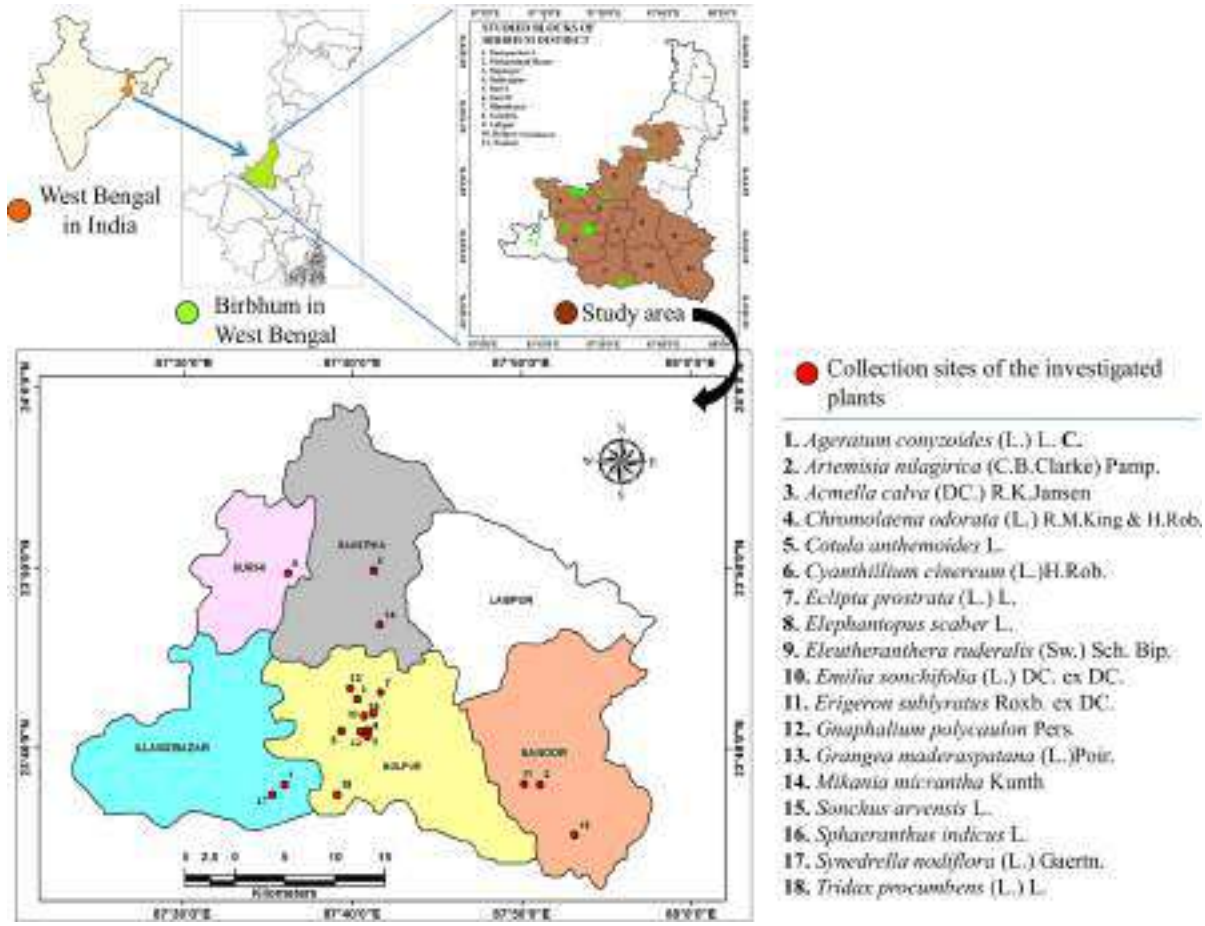

Fig. 1 Study area showing GPS coordinates of the collection sites for the selected 18 wild green leafy vegetables (WGLVs) of the family *Asteraceae*

Selection and collection of plant samples

Here in the present study, we had selected 18 WGLVs which were identified as edible ones during the interview process. All those species from the *Asteraceae* family are *Acmella calva* (DC.) R.K.Jansen, *Ageratum conyzoides* (L.)L., *Artemisia nilagirica* (C.B.Clarke) Pamp., *Chromolaena odorata* (L.) R.M.King & H.Rob., *Cotula anthemoides* L., *Cyanthillium cinereum* (L.) H.Rob., *Eclipta prostrata* (L.)L., *Elephantopus scaber* L., *Eleutheranthera ruderalis* (Sw.) Sch.Bip., *Emilia sonchifolia* (L.) DC. ex DC., *Erigeron sublyratus* Roxb. ex DC., *Gnaphalium polycaulon* Pers., *Grangea maderaspatana* (L.)Poir., *Mikania micrantha* Kunth, *Sonchus arvensis* L., *Sphaeranthus indicus* L., *Synedrella nodiflora* (L.)Gaertn., and *Tridax procumbens* (L.)L. Selected WGLVs have both medicinal and food values and were investigated for estimating their nutritional potential and range of contribution toward food security of the local tribes. The selected leafy greens were collected from different wild and semi-wild populations of the Birbhum district, West Bengal (India) following the standard collection method set by the National Medicinal Plants Board of India (NMPB 2015).

Identification of plant samples and nomenclature update

For identification of the collected herbs, consultation of different floras and expert opinion were considered (Guha Bakshi 1984; Sanyal 1994; Ranjan et al. 2016). Sample specimens were collected and preserved as herbarium specimens following conventional techniques (Jain and Rao 1977) and kept

in the Departmental Herbarium, Department of Botany, Visva-Bharati University, Santiniketan, India for future reference.

The scientific names used for the selected species had been updated following the standard websites like 'Plants of the World Online' (https://powo.science.kew.org/).

Preparation of plant samples

Preparation of plant samples were made with some modification of the procedure stated by (Hussain et al. 2009). The fresh WGLVs were carefully washed with running tap water, then distilled water, and lastly with deionized water to remove various soil and airborne contaminants. To evaporate the surface water, plant samples were scattered on the blotting paper and cautiously soaked in the adhered water to make the sample dry with the help of blotting paper. After that, they were immediately placed in the desiccators to control the loss of moisture. The plant samples were then chopped into tiny pieces and oven dried at 55° C. Fully dried materials were crushed into a fine powder and preserved in an airtight container at 4° C for further analysis.

Preparation of plant extract

Plant powder (10 g) of each of the investigated taxa was extracted with 100 mL of ethanol in a ratio of 1:10 in a 250 mL conical flask and kept in a mechanical shaker in continuous agitation for 36 h (28 ± 2 °C temperature maintained). The whole process was repeated thrice for single extraction. The slurry substance thus obtained was filtered with Whatman's (No.1) filter paper. The filtrate was concentrated by evaporation at room temperature (28 ± 2 °C). The ultimate yield was stored at -20 °C and dissolved in dimethylsulfoxide (DMSO) to make the stock before use.

Proximate and mineral content analysis

The crude protein content was determined by Micro-Kjeldahl method (Gupta 2006). Crude fat content was estimated following the method described by (Chopra and Kanwar 1991). The crude fibre was estimated by the acid-alkaline digestion method (Chopra and Kanwar 1980). The ash content was estimated following the method described in the AOAC guidelines (AOAC 2006). To determine soluble and insoluble carbohydrate contents, Anthrone method was followed (Mc.Cready et al. 1950). Here, the percentage of nitrogen-free extract calculated mathematically by the sum of the percentages of crude protein, crude fat, crude fiber, and total ash on a dry matter basis was subtracted from 100. Minerals were analyzed using the standard method (Kilgour 1986).

Detection of heavy metals

The presence of heavy metals (Pb, Cr, Hg, Cd, and As) in the plant sample was detected through acid digestion and atomic absorption spectrophotometric method (Annan et al. 2013).

Estimation of water-soluble vitamins

Following the guidelines of AOAC (AOAC 1995), the thiamine and riboflavin contents were determined fluorometrically using a Horiba Fluoromax-plus spectrofluorometer. The amount of vitamin C was measured by titration method observing the pink color appeared and sustained for at least 15 s due to the reduction of 2,6-dichlorophenol-indophenol dye (AOAC 1995).

Estimation of important phytochemical groups

Total phenolic content

It was estimated by standard methods using Folin–Ciocalteu reagent and absorbance was measured at 650 nm against a blank using Shimadzu UV-1800 double-beam spectrophotometer. A standard calibration curve was prepared using ten different concentrations of Gallic acid (Malick and Sing 1980).

Total flavonoid content

Here the aluminium chloride method was followed (Zhishen et al. 1999). Absorbance was taken at 415 nm against the suitable blank using Shimadzu UV-1800 double-beam spectrophotometer. A standard calibration curve was prepared using ten different concentrations of Catechin.

DPPH radical scavenging activity

DPPH radical scavenging activity was determined following the standard method (Thipong et al. 2006). The standard curve was prepared with standard i.e. ascorbic acid. Results were expressed in % of scavenging activity. Radical scavenging activity was determined by the following formula-

$$\text{Radical scavenging activity } (\%) = (A_0 - A_t/A_0) \times 100,$$

where A_0 is the absorbance value of control and A_t is the absorbance value of test samples.

Percent inhibition of DPPH radical versus concentration of plant extract was plotted in a curve and finally, the concentration of sample required for 50% inhibition was determined and represented as IC_{50} value for each of the test samples. Based on the value of IC_{50}, the eighteen investigated taxa have been categorized into four groups following the proposal of Blois (1958).

In vitro cell cytotoxicity assay

Cell toxicity assay was performed against the HepG2 and THP-1 like cancer cell lines (procured from National Centre for Cell Science, Pune, India) using the MTT assay following the standard protocol depicted by Mosmann (1983). Doxorubicin, a well-known effective anticancerous drug was applied to the cells as a positive control.

Statistical analysis

Data were presented as mean ± SD. One way analysis of variance (ANOVA) was carried out to compare the values between different plant species. After the ANOVA analysis, Duncan's multiple range tests (DMRT) were used to separate the means according to significance. All of the analyses were carried out using Microsoft Excel 2008 and SigmaPlot 15.0 software. Three replicates were carried out for all the parameters.

The detailed methodology has been provided in Supplementary File 1.

Results and discussion

Ethnogastronomy of wild food plants and acceptability among the local tribes

A total of 921 citations (ethnic food–202; medicinal uses–719) were made by the 150 participants for 36 types of different culinary and medicinal uses attached with the 18 WGLVs of the family *Asteraceae*. The updated scientific name of the investigated WGLVs, voucher specimen numbers, their common and local names, traditional local uses, number of citations, and a comparative account of various uses mentioned in the relevant previous literature have been presented in Table 1.

Mainly the leaves, sometimes the tender shoots were used as leafy vegetables and consumed in the form of raw, boiled, braised alone, or mixed with other food items. Among the studied taxa, 7 WGLVs were cited very frequently i.e., ≥ 10. The plant *Emilia sonchifolia* (L.) DC. was identified as the most popular one with 53 citations followed by *Gnaphalium polycaulon* Pers. (20), *Cyanthillium cinereum* (L.) H.Rob. (19), *Eclipta prostrata* L. (18), *Grangea maderaspatana* (L.) Poir. (15), *Elephantopus scaber* L. (11), and *Erigeron sublyratus* Roxb. ex DC. (10). High preference for these WGLVs lies in their palatability. Furthermore uses of tender shoots of *Artemisia nilagirica* (C.B.Clarke) Pamp., nonflowering shoots of *Acmella calva* (DC.) R.K.Jansen, and leaves of *Synedrella nodiflora* (L.) Gaertn. as leafy vegetables and leaf juice of *Mikania micrantha* Kunth as thickening agent were found new to the existing ethnogastronomic database of the state West Bengal. In the locality herbs like *Eleutheranthera ruderalis* (Sw.) Sch.Bip. which grows abundantly in the monsoon was sometimes used as an alternative to one of the most frequently cited WGLVs like *C. cinereum*. The plant *Sonchus arvensis* L. was slightly bitter but its bitterness was preferred by the local tribes as a means of medicinal food. It was also evident from previous studies that the preference for bitter vegetables among consumers is very much attached to its medicinal properties (Olivier and van Wyk 2013; Cavallo et al. 2019; Yanagisawa and Misaka 2021). Furthermore, leaves of *Grangea maderaspatana* (L.) Poir., *Cotula anthemoides* L., and *Chromolaena odorata* (L.) R.M.King & H.Rob. were used to add extra aroma to the ethnic dishes. On the contrary, uses of

Table 1 Enumeration of the recorded wild green leafy vegetables (WGLVs) of the *Asteraceae* family

Scientific Name of the investigated taxa, voucher specimen number and GPS coordinates of the collection site	Common English name, local and tribal name[a]	Traditional uses and Nos. of citations in each uses[b]	Occurance and season of collection	Referred traditional uses
Ageratum conyzoides L. SS-21 23°38′0.6″ N & 87°36′0.4″ E	Goatweed; *Uchunti* (Beng.), *Heren-ba-ara* (Sant.)	EF (07), EM (17), EVM (13)	Abundant Winter	Wild edible: Fresh leaves are cooked and taken with boiled rice (Dansi et al. 2008; Saikia and Kumar 2020) Ethnomedicine: Leaf is used to treat wounds, burns, boils, skin disease, leprosy, eye problem, headache, pneumonia, dyspepsia; the entire plant is used in colic, colds, fever, acute stomach pain, diarrhea, spasms, rheumatism, and as tonic. (Paria 2005; Jain 2012; Jain and Jain 2016) Ethnoveterinary medicine: Fresh leaves are used to heal wound and as expectorant (Gaur et al. 2010)
Artemisia nilagirica (C.B.Clarke) Pamp. SS-07 23°38′1.5″ N & 87°51′5.0″ E	Indian wormwood; *Nagdona* (Beng.), *Lagdona* (Sant.)	EF (03), EM (19)	Uncommon Autumn	Wild edible: Tender shoots are used as vegetable[c] Ethnomedicine: Used in skin diseases, wound, cuts, scabies, inflammations, fever, arthritis, asthma, cough, headache, nose bleeding, and nervous disorder (Namsa et al. 2011; Jain 2012; Arya et al. 2020)
Chromolaena odorata (L.) R.M.King & H.Rob. SS-19 23°41′1.5″ N & 87°40′56.7″ E	Devil Weed; *Kaslimosla, Ropani* (Beng.), *Desmara kher* (Sant.)	EF (06), EM (08)	Abundant Winter	Wild edible: Tender leaves are cooked with pulses and taken with boiled rice (Paṭiri and Borah 2007); mature leaves are used as flavoring agent in seasonal mixed-veg soup (Achigan-Dako et al. 2010) Ethnomedicine: Used in cuts, wounds, hemorrhage, colds, influenza, fever, diabetes, bronchitis (Jain and Jain 2016; Debbarma et al. 2017)

Table 1 (continued)

Scientific Name of the investigated taxa, voucher specimen number and GPS coordinates of the collection site	Common English name, local and tribal name[a]	Traditional uses and Nos. of citations in each uses[b]	Occurance and season of collection	Referred traditional uses
Cotula anthemoides L. SS-11 23°40′59.7″ N & 87°39′20.6″ E	Button-weed; *Horin-singa* (Beng.), *Tendi-barango* (Sant.)	EF (08), EM (03)	Uncommon Late Monsoon	Wild edible: Freshly collected leaves are made per-boiled and taken with boiled potato (Welcome and Van Wyk 2019) Ethnomedicine: Used to treat rheumatism, eye disease, head and chest pain, colds, eyewash, fever, fractured bones and as blood purifier (Lone et al. 2015; Jan et al. 2021)
Cyanthillium cinereum (L.) H.Rob. SS-17 23°49′51.8″ N & 87°41′14.5″ E	Purple Fleabane; *Sahadevi* (Beng.), *Birkusuri* (Sant.)	EF (19), EM (31), EVM (17)	Abundant Winter	Wild edible: Fresh twigs are collected along with the twigs of *Portulaca oleracea* L. and juvenile *Brassica nigra* (L.) K.Koch. All three green vegetables are then cooked together and served with rice (Jadhav et al. 2015; Golait et al. 2021) Ethnomedicine: Leaves are used in cuts, eczema, jaundice, hepatitis, insomnia, night urination among infants, infected sores, mastitis, sprains, carbuncle, scorpion bite, snake bites and obstruction in urination; used in acute hemorrhoids, neurasthenia, humid herpes, stomach ache (Jain 2012; Santhosh Kumar et al. 2019) Ethnoveterinay medicine: Whole plant is used to increase the appetite of cattle (Yadav et al. 2014)

Table 1 (continued)

Scientific Name of the investigated taxa, voucher specimen number and GPS coordinates of the collection site	Common English name, local and tribal name[a]	Traditional uses and Nos. of citations in each uses[b]	Occurance and season of collection	Referred traditional uses
Eclipta prostrata L. SS-05 23°43′6.4″ N & 87°41′41.5″ E	False Daisy; *Bhringaraj, Kesuti* (Beng.), *Lau-kesari* (Sant.)	EF (18), EM (113), EVM (29)	Abundant Winter	Wild edible: Leaves are cooked with pulses and consumed with rice (Sivakumar and Murugesan 2005; Kumari and Solanki 2019; Singh and Rani 2019) Ethnomedicine: Leaves used in expulsion of worms, infections and burning sensation in urinary tract, insect bites, eye infections, piles and other skin diseases. It is used to rejuvenate teeth, bones, kidney and liver function, memory, sight, and hearing, post-delivery uterine pain, and helps to prevent repeated miscarriage and abortion (Pal and Jain 1998; Timalsina and Devkota 2021; Ishtiaq et al. 2021) Ethnoveterinary medicine: Leaves are used to treat wound, pus in the ear, and rhinorrhoea (Saha et al. 2014; Verma 2014; Mandal and Rahaman 2022)
Elephantopus scaber L. SS-14 23°40′57.3″ N & 87°40′29.8″ E	Elephant's Foot; *Hasti-pada* (Beng.), *Mejurjhuti* (Sant.)	EF (11), EM (66), EVM (15)	Abundant Autumn	Wild edible: Moderately mature leaves are used as vegetables (Padhan and Panda 2015; Saikia and Kumar 2020) Ethnomedicine: Leaves used in pains, piles, hair fall, inflammations, eczema and bronchitis; used as diuretic, laxative, analgesic, febrifuge, cardiac and brain tonic, stomach pain, diarrhea (Hiradeve and Rangari 2014; Xavier et al. 2014) Ethnoveterinary medicine: Used in worm infested wounds, diarrhea, dysentery (Bhatt et al. 2019; Sikarwar and Tiwari 2020)

Table 1 (continued)

Scientific Name of the investigated taxa, voucher specimen number and GPS coordinates of the collection site	Common English name, local and tribal name[a]	Traditional uses and Nos. of citations in each uses[b]	Occurance and season of collection	Referred traditional uses
Eleutheranthera ruderalis (Sw.) Sch.Bip. SS-09 23°49′42.9″ N & 87°36′13.0″ E	Ogiera	EF (04), EM (15)	Abundant Monsoon	Wild edible: Nonflowering twigs are used as a substitute for *C. cinereum* (L.) H.Rob[c] Ethnomedicine: Leaves are used as laxative; used in rheumatism, piles, cuts and wounds. Whole plant is used to promote longevity, as galactagogue, in high blood pressure (Lawal et al. 2022)
Emilia sonchifolia (L.) DC. SS-25 23°41′56.6″ N & 87°41′12.8″ E	Purple Sow Thistle; *Sachimodi* (Beng.),*Kulai-lutur-ara* (Sant.)	EF (53), EM (42), EVM (02)	Abundant Winter	Wild edible: Tender shoots are cooked alone or sometimes with other seasonal vegetables (Narayanan et al. 2011; Murtem and Chaudhry 2016; Mallick et al. 2020; Saikia and Kumar 2020) Ethnomedicine: Whole plant is used as astringent, antipyretic, antiasthmatic, ophthalmic, febrifuge; useful in cuts, wounds, bowel complaint and respiratory troubles. Leaf juice is used in eye inflammation, cataract, night blindness, wound, and sore of ears (Chaudhury et al. 2018; Santhosh et al. 2020) Ethnoveterinary medicine: Leaf is used to treat spider poison in cattle (Prasad and Shyma 2013)
Erigeron sublyratus Roxb. ex DC. SS-29 23°38′4.0″ N & 87°50′7.8″ E	Daisy fleabane	EF (10), EM (04)	Rare Late Summer	Wild edible: Shoots of juvenile plant is collected, crushed and mixed with leaf paste of *Paederia foetida* L. and paste of lentil. Crunchy vegetable fritters are made with this mixture and taken as snacks or with rice (Bisht 2017) Ethnomedicine: Leaf used in abdominal pain, diarrhea, and night blindness (Bisht 2017; Faruque et al. 2019)

Table 1 (continued)

Scientific Name of the investigated taxa, voucher specimen number and GPS coordinates of the collection site	Common English name, local and tribal name[a]	Traditional uses and Nos. of citations in each uses[b]	Occurance and season of collection	Referred traditional uses
Gnaphalium polycaulon Pers. SS-32 23°40′43.6″ N & 87°40′54.6″ E	Western cudweed; *Bara-kamra* (Beng.), *Bara-kamri-ara* (Sant.)	EF (20), EM (37), EVM (06)	Abundant Winter	Wild edible: Leaves are used as a flavouring agent in several cooked items (Reddy et al. 2007; Taram et al. 2018, 2019) Ethnomedicine: Used as galatogogue; used to treat pulmonary trouble and burn wound (Pal and Jain 1998; Uniyal and Shiva 2005) Ethnoveterinary medicine: Used in ephemeral fever, and for holes on palate of livestock (Pal and Jain 1998; Reddy et al. 2006)
Grangea maderaspatana (L.) Poir. SS-13 23°43′21.2″ N & 87°39′53.2″ E	Madras Worm-wood; *Namuti* (Beng.); *Panijhari, Agni-kumari* (Sant.)	EF (15), EM (51), EVM (14)	Abundant Winter	Wild edible: Boiled leaves are mixed with smashed potato and taken with rice (Mallick et al. 2020) Ethnomedicine: Leaf used as antispasmodic, antiseptic, stomachic, deobstruent, anodyne, a tonic, appetizer, anti-convulsant, laxative; used in hysteria, obstructed menses, and in earache. Flower used in headache (Pal and Jain 1998; Jain and Jain 2016; Singh and Beg 2015) Ethnoveterinary medicine: Whole plant is used to increase milk production and to cure stomach disorder (Jain 1999)

Table 1 (continued)

Scientific Name of the investigated taxa, voucher specimen number and GPS coordinates of the collection site	Common English name, local and tribal name[a]	Traditional uses and Nos. of citations in each uses[b]	Occurance and season of collection	Referred traditional uses
Mikania micrantha Kunth SS-31 23°46′51.6″ N & 87°41′37.8″ E	Climbing hemp weed; *Banchhalata, Taralata* (Beng.), *German lor* (Sant.)	EF (03), EM (03), EVM (02)	Abundant Summer	Wild edible: Leaves are used as vegetables. Sometimes leaf juice is used in cooking to amplify thickness of different vegetable soupe[c] Ethnomedicine: Used to treat wound, diarrhoea, dysentery, stomach ache, fever, jaundice, rheumatic pain, colds, respiratory diseases, scorpion stings, body sprain, diabetes, snake bites, itches, gout, and flatulence. Leaves used as good haemostatic agent. (Laldingliani et al. 2022) Ethnoveterinary medicine: It is used to treat diarrhoea of veterinary animals and to repeal body lice of poultry birds (Saha et al. 2014)
Sonchus arvensis L. SS-22 23°35′13.4″ N & 87°53′6.2″ E	Field Sow Thistle; *Dudhi* (Beng.), *Dudhi-ara* (Sant.)	EF (09), EM (08)	Uncommon Autumn	Wild edible: The plant is slightly bitter in taste but its flavor is preferred by the local tribes.Leaves are used as flavoring agent in several traditional dishes and sometimes used alone as a leafy vegetable (Seal 2011) Ethnomedicine: Used in chronic fevers, coughs, jaundice, asthma, swelling, scorpion bite, skin disease (Sharif et al. 2022)
Sphaeranthus indicus L. SS-28 23°41′47.4″ N & 87°40′41.5″ E	East Indian globe thistle; *Bhuin-Kadam* (Beng.), *Belaunja* (Sant.)	EF (07), EM (47), EVM (02)	Abundant Pre-Winter	Wild edible: Juvenile plants are used as a substitute for *Cotula anthemoides* L.[c] Ethnomedicine: Plant is used to treat cough, chest congestion, epilepsy, and jaundice. Leaf used as nervine tonic and as a sniffing material like narcotic (Galani et al. 2010) Ethnoveterinary medicine: Plant is used to heal the wound of cattle (Mandal and Rahaman 2022)

Table 1 (continued)

Scientific Name of the investigated taxa, voucher specimen number and GPS coordinates of the collection site	Common English name, local and tribal name[a]	Traditional uses and Nos. of citations in each uses[b]	Occurance and season of collection	Referred traditional uses
Acmella calva (DC.) R.K.Jansen (Syn.- *Spilanthes calva* DC.) SS-18 23°42′44.1″ N & 87°40′16.5″ E	Spot flower; *Ushni shak* (Beng.) *Masang-ara* (Sant.)	EF (04), EM (41), EVM (07)	Abundant Winter	Wild edible: Nonflowering shoots are boiled with pulses and taken with rice[c] Ethnomedicine: Herb used in dysentery, toothache, scabies and psoriasis; used to cure paralysis of tongue. Leaf used in skin diseases; paste applied to cut to stop bleeding; used as diuretic (Peiris et al. 2001; Tiwari et al. 2011) Ethnoveterinary medicine: Flowering twig used in cold and cough, tongue sore of cattle (Jagadeeswary et al. 2014)
Synedrella nodiflora (L.) Gaertn. SS-10 23°37′28.0″ N & 87°35′16.9″ E	Node-weed; *Sonraj* (Beng.), *Daryna-ara* (Sant.)	EF (04), EM (21)	Abundant Monsoon	Wild edible: Leaves are collected along with the shoots of *Boerhavia diffusa* L., cooked and consumed as leafy vegetables[c] Ethnomedicine: It is used in itch, eczema, scabies, any type of skin disorders, swellings, body ache; helps to stop bleeding (Hossan et al. 2009; Santhosh Kumar et al. 2019; Singh et al. 2020)
Tridax procumbens L. SS-36 23°37′28.0″ N & 87°39′5.6″ E	Mexican daisy; *Tridhara ful* (Beng.), *Handiful* (Sant.)	EF (06), EM (55), EVM (26)	Abundant Winter	Wild edible: Nonflowering twigs are collected along with the shoots of *Trianthema portulacastrum* L.and *Rothia indica* (L.) Druce; fried with garlic and consumed with rice (Prajapati et al. 2008; Sharma et al. 2013) Ethnomedicine: Leaf used as hair tonic for infant, and in injury (Manoranjotham and Kamaraj 2016; Sikarwar and Tiwari 2020) Ethnoveterinary medicine: Leaf juice is used to treat maggot infested wounds (Mishra 2013)

[a]Local and tribal names of the investigated taxa (Beng.- Bengali; Sant.- Santali)

[b]Traditional uses (EF- Ethnic food; EM- Ethnomedicine; EVM- Ethnoveterinary medicine)

[c]Reported first time from the state of West Bengal

six WGLVs like *Artemisia nilagirica* (C.B.Clarke) Pamp., *Eleutheranthera ruderalis* (Sw.) Sch.Bip., *Mikania micrantha* Kunth, *Sphaeranthus indicus* L., *Acmella calva* (DC.) R.K. Jansen, and *Synedrella nodiflora* (L.) Gaertn. which have slightly pungent taste and unsoothing aroma were cited infrequently by the informants resulting in a total of 25 citations. It might be an indication of their unacceptability due to poor taste, or decreasing traditional food-medicinal knowledge associated with those plants in the society.

All the recorded plants are indigenously utilized as culinary items and their associated traditional knowledge is still persisting sporadically in the localities studied. We were informed by the elderly participants that there is a trend of ignorance regarding the uses of WGLVs among the tribal communities of the studied area, due to the influence of modern consumeristic culture. Consequently, this valuable food plant knowledge is gradually waning from society. Another probable cause may be the rapid loss of biodiversity, which leads to the disappearance of important plant genetic resources. Here it is found that *Cotula anthemoides* L. and *Erigeron sublyratus* Roxb. ex DC. became very rare in the studied area. Furthermore, on the one hand, the poor economic condition of the local tribes becomes a barrier between the maintenance of health and the sufficiency of commercially available costly vegetables. On the other hand, there is marked negligence and also ignorance toward utilizing the locally available nutritious WGLVs. This bimodal effect may be a strong reason for persistent hidden hunger and the prevalence of anemia among the local tribes.

Composition of proximate content of WGLVs and their nutritional benefits

Among the proximate components, the moisture content is very much related to physical properties like texture, taste, and freshness of food; and is responsible for its shelf-life. Whereas nutritional input of carbohydrate, protein, fat, and dietary fiber have a direct impact on health. The study on proximate content of the 18 investigated WGLVs under the family *Asteraceae* had revealed that 10 out of 18 WGLVs are rich in nutritional compositions like soluble and insoluble carbohydrates, crude protein, and crude fat (Table 2). Insoluble carbohydrate content was found highest in *Elephantopus scaber* L. (50.01%) and in the case of *Emilia sonchifolia* (L.) DC. ex DC., soluble carbohydrate content (10.78%) was observed at maximum. In general Indian diets comprise high carbohydrate staple which acts as the main source of energy and helps to fuel our body. As per recommended dietary allowance (RDA), 300 gm of carbohydrates can be consumed ideally by an Indian adult every day (RDA 2020). In a healthy diet plan, half of an eating dish should fill with fruits and vegetables which are excellent sources of slowly digestable carbohydrates that help lowering down the risk of diabetes (Mudgil and Barak 2013). In this dietary plan, herbs like *Elephantopus scaber* L., *Mikania micrantha* Kunth, *Gnaphalium polycaulon* Pers., and *Eleutheranthera ruderalis* (Sw.) Sch.Bip. can contribute a lot as they are identified as major sources of insoluble carbohydrates.

Protein is a vital macronutrient which is needed to grow new cells, renew old tissues and develop muscles. The recommended dietary allowance of protein is 45.7 g and 54 g/day for Indian adult men and women respectively (RDA 2020). To fulfill this daily need for protein one has to depend mainly on animal sources and pulses. But apart from the pulses, there are many protein-rich vegetables like broccoli, cabbage, cauliflower, parsley, mustard green, etc. In the investigated WGLVs crude protein content varied from 2.04 g to 2.81 g/100 g which is quite higher than the protein content present in some popular commercially available leafy vegetables like lettuce or parsely (Singh and Singh 2015). For example, crude protein content was estimated maximum (2.81 g/100 g) in *Synedrella nodiflora* (L.) Gaertn.

Crude fat content was estimated highest (6.04 g/100 g) in *Eleutheranthera ruderalis* (Sw.) Sch. Bip. But out of 18 WGLVs two plant species namely *Tridax procumbens* L., and *Chromolaena odorata* (L.) R.M.King & H.Rob possessed very low crude fat content (varies from 1.18 g to 1.26 g/100 g) and were identified as potent candidates for low-calorie diets (Randhawa et al. 2015). Such alternative food items can be effectively beneficial for the rural as well as the health-conscious urban population struggling with weight management.

Dietary fibre is mostly made up of non-digestible complex carbohydrates which delay and check the ready absorption of simple carbohydrates, and fats and in turn maximize the bulk of stools (Dhingra et al. 2012). Foods rich in dietary fibre are considered much healthier as it exerts beneficiary effects on

gut motility, gut microbiota, chronic inflammation, cardiovascular disease, colorectal carcinoma, mental health, and many more (Barber et al. 2020). For an adult in India, RDA for dietary fibre is 40gm/day in men and 30gm/day in case of women. Plants like *Grangea maderaspatana* (L.) Poir. (34.07 g/100 g) and *Mikania micrantha* Kunth (33.38 g/100 g) have the capability to provide this much dietary fibre individually everyday if consumed. The fibre content of these two plants was found almost equal to the total dietary fibre content (32 g/100 g) of *Basella sp.* (Kumar et al. 2015) and attractively higher than the most commonly used and locally available leafy green vegetables like Moringa leaf—0.9 g/100 g (Gopalakrishnan et al. 2016), Spinach -2.5 g/100 g and Amaranth -4 g/100 g (Singh and Singh 2015).

Composition of mineral nutrients in WGLVs- a weapon to fight against hidden hunger

Among the wide range of essential minerals, we quantified eight dietary minerals (Na, K, Ca, Mg, Fe, Mn, Zn and Cu) in the selected WGLVs. From the mineral content analysis (Table 3) it had been found that total Ca content varied from 390 to 1870.03 mg/100gm. The highest Ca content (1870.03 mg/100 g) was observed in *Sonchus arvensis* L. Total Mg content ranged from 110.37 to 370.43 mg/100 g and it was found highest (370.43 mg/100 g) in *Artemisia nilagirica* (C.B.Clarke) Pamp. The range of total Fe content was found here between 4.4 and 63.02 mg/100 g and the maximum amount of Fe (63.02 mg/100 g) was estimated in *Grangea maderaspatana* (L.)Poir. Total Mn content varied from 4.36 to 55.73 mg/100 g and it was found highest (55.73 mg/100 g) in *Eclipta prostrata* (L.) L. The total Cu content varied from 2.06 to 41.2 mg/100 g and it was found its maximum (41.2 mg/100 g) in *Artemisia nilagirica* (C. B. Clarke) Pamp. Total Zn content ranged from 03.03 to 8.87 mg/100 g and it was found highest (8.87 mg/100 g) in *Elephantopus scaber* L.

Sodium (Na) and Potassium (K) play important roles as vital electrolytes that help to maintain optimum volumes of our blood and other body fluids. Deficiency or imbalance of these two essential macro-elements can manifest several health risks associated with cardio-vascular and cerebro-vascular systems (Anand et al. 2020; Kogure et al. 2021). Among the analyzed WGLVs, two edible greens *Cotula anthemoides* L. (619.97 mg/100 g), and *Grangea maderaspatana* (L.) Poir. (650.43 mg/100 g) were found to have total Na content astonishingly higher than commonly marketed vegetables like Amaranth, cauliflower, cabbage, broccoli, and lettuce (Singh and Singh 2015). To date, Sodium is not a nutrient of concern in our daily diet rather a recent report explored that Na intake by an Indian in the form of salt is around 11 g /day, double the WHO's recommended value of 5 g /day (Johnson et al. 2019).

Eight WGLVs can be considered rich source of K (value ranges from 3320 to 4420 mg/100 g) are *Sonchus arvensis* L., *Cotula anthemoides* L., *Tridax procumbens* L., *Gnaphalium polycaulon* Pers., *Eleutheranthera ruderalis* (Sw.) Sch.Bip., *Chromolaena odorata* (L.) R.M.King & H.Rob., *Ageratum conyzoides* L., and *Artemisia nilagirica* (C.B.Clarke) Pamp. They have higher Potassium content than those of the food plants rich in K, such as Spinach or Parsley with the content value ranging between 600 and 1000 mg/100gm (Souci et al. 2008).

In the present study, the highest Ca content (1870.03 mg/100 g) was observed in *Sonchus arvensis* L., a leafy vegetable used locally as a substitute for costly spinach. The same species of *Sonchus* collected from Meghalaya state exhibited the Ca content of 2295 mg/100 g which is higher than the Ca content estimated in the present study (Seal 2011). Some other plants which were rich in Ca content are *Ageratum conyzoides* L., *Eclipta prostrata* L., *Tridax procumbens* L., *Emilia sonchifolia* (L.) DC., and *Eleutheranthera ruderalis* (Sw.) Sch.Bip. All these wild greens can compensate for the need for daily dietary Ca intake of Indian adults (600 mg/day) and pregnant and lactating mothers (1200 mg/day) (RDA 2020).

Magnesium (Mg) is one of the most abundant nutrients required in the body and mainly functions as a cofactor for approximately 300 enzymatic reactions (Alawi et al. 2018). Among the analyzed WGLVs, six plants were found rich in Mg content are *Ageratum conyzoides* L., *Artemisia nilagirica* (C.B.Clarke) Pamp., *Eleutheranthera ruderalis* (Sw.) Sch.Bip., *Gnaphalium polycaulon* Pers., *Sonchus arvensis* L., and *Tridax procumbens* L. Mg content of these plants range from 330.47 to 370.43 mg/100 gm. which can contribute a lot to fight against Mg deficiency.

Iron (Fe) is the most vital trace element that the human body requires in very small amounts (RDA

for men- 19 mg/day, and for women- 29 mg/day). It is found in a wide range of available food items but most people do not take the required amounts of this mineral in their daily diet. In the studied area, anaemia is a common health issue among the *Santal* children (Chowdhury and Ghosh 2013; Stiller et al. 2020). This problem can be addressed by incorporating iron rich locally available food items in the everyday's diet plan. In the present study, the total Fe content was estimated maximum (63.02 mg/100 g) in *Grangea maderaspatana* (L.)Poir. followed by *Cotula anthemoides* L.(61.04 mg/100 g) which can be taken into consideration to alleviate the anaemic condition of the tribal children in the studied area.

Some other trace minerals like Mn, Cu, and Zn are required in very nominal amounts but essential for the human body and if, these elements are taken in the required amount one can achieve healthy bones, finely tuned nervous system, strong immune system, and metabolic power (Winiarska-Mieczan et al. 2019). Specifically, RDA of Zn for Indian adult men is 17 mg/day and 13.2 mg/day for women (RDA 2020). But there is a persistently worsening tendency for inadequate zinc intake by a majority of the Indian population which causes several health hazards like retarded growth, cognitive impairment, gut infection, immune dysfunction, and many more (Prasad 2013; Smith et al. 2019). In this context, the present analysis elucidates the convincing potential of three herbs namely *Eclipta prostrata* (L.) L., *Artemisia nilagirica* (C. B. Clarke) Pamp, and *Elephantopus scaber* L., as very good sources of the trace minerals like Mn, Cu, and Zn, and for their further scientific intervention to design herbal food. So the presence of a significant amount of proximate and mineral components in the studied WGLVs highlights their potential to be an effective substitute for the so-called cultivated 'highly nutritious' vegetables.

Water soluble vitamin content of WGLVs

In the present study, vitamin C, thiamine (B_1), and riboflavin (B_2) were estimated and presented in (Table 6). All these three water-soluble vitamins play immensely an important role in maintaining human health. Vitamin C, a powerful antioxidant is also well known for controlling seasonal infections and healing wounds (Chambial et al. 2013). Freshly collected raw herbs like *Cotula anthemoides* L., *Emilia sonchifolia* (L.) DC., *Sonchus arvensis* L., and *Sphaeranthus indicus* L. contain significant amount of vitamin C (range 69.48 ± 1.14 to 86.77 ± 1.77 mg/100 g) which is even greater than the natural popular sources like orange (53.2 mg/100 g), spinach (28.1 mg/100 g), and broccoli (89.2 mg/100 g). Vitamin B_1 (thiamin) is one of the eight water-soluble B vitamins that is very much crucial for human health; especially its involvement in glucose metabolism and neuro-muscular functioning (Lonsdale 2006). Here, vitamin B_1 content was estimated as maximum in *Emilia sonchifolia* (L.) DC. (2.038 ± 0.67 mg/100 g) followed by *Eclipta prostrata* L. (1.329 ± 0.21 mg/100 g). Likewise, riboflavin or vitamin B_2 is also very important for human health. It helps in the gradual breaking down of food items, absorbing vital mineral nutrients in the intestine, synchronizing the functions of sensory organs, and many more (Suwannasom et al. 2020). A recent study has revealed that a healthy-looking population mostly suffers from Vitamin B_2 deficiency in India (Sivaprasad et al. 2019). The high content of Vitamin B_2 (0.112 ± 0.05 to 0.216 ± 0.07 mg/100gm) was estimated in the studied plants like *Mikania micrantha* Kunth, *Emilia sonchifolia* (L.) DC., *Cyanthillium cinereum* (L.) H.Rob., *Cotula anthemoides* L., and *Ageratum conyzoides* L. These plant species can be promoted nationally in the nutraceutical sectors as an effective and alternative choice for alleviating vitamin B_2 deficiency.

Heavy metal contamination in leafy vegetables and its consequences

Wild green leafy vegetables are the natural sources of several valuable nutrients but consumption of these edible greens sometimes cause serious health issues related to dysfunction of the nervous system, immune system, digestive and renal system, skin problem, vascular damage, birth defects, and cancer (Balali-Mood et al. 2021). The main cause of this adverse effect is identified as the presence of heavy metals in the vegetables (Sharma and Nagpal 2020; Sulaiman et al. 2020). No corner of today's world whether is it wild or urban is bereft of contamination of toxic materials and pollution. The contaminated soil due to countless anthropogenic activities is the sole source of this heavy metal accumulation in leafy vegetables. There are ample numbers of evidence where scientists have reported the presence of toxic heavy metals in the vegetable sample (Sharma et al. 2016; Anarado et al.

Table 2 Proximate content of the wild green leafy vegetables (WGLVs)

Species name	Carbohydrate (%)		Protein (%)	Fibre (%)	Fat (%)	Ash (%)	Moisture (%)	NFE (%)
	(Soluble)	(Insoluble)						
Acmella calva (DC.) R.K.Jansen	5.13 ± 1.89^{d}	9.7 ± 0.04^{a}	2.61 ± 0.03^{c}	6.03 ± 0.27^{b}	3.55 ± 0.03^{k}	17.85 ± 0.02^{h}	8.897 ± 2.76^{d}	69.96 ± 0.79^{k}
Ageratum conyzoides L.	4.14 ± 0.85^{d}	18.003 ± 0.11^{i}	2.35 ± 0.13^{b}	18.34 ± 0.53^{f}	5.86 ± 0.05^{m}	24.24 ± 0.05^{o}	8.523 ± 0.21^{d}	49.21 ± 1.01^{e}
Artemisia nilagirica (C.B.Clarke) Pamp.	5.97 ± 0.73^{d}	10 ± 0.15^{b}	2.27 ± 0.06^{b}	19.51 ± 0.44^{g}	2.82 ± 0.03^{h}	10.84 ± 0.02^{b}	7.821 ± 0.33^{c}	64.56 ± 0.87^{i}
Chromolaena odorata (L.) R.M.King & H.Rob.	5.06 ± 1.02^{d}	18.03 ± 0.06^{i}	2.21 ± 0.03^{b}	16.33 ± 0.52^{e}	1.26 ± 0.01^{b}	12.04 ± 0.03^{c}	5.905 ± 3.01^{a}	68.16 ± 0.12^{j}
Cotula anthemoides L.	7.15 ± 0.86^{d}	26.01 ± 0.04^{k}	2.08 ± 0.16^{a}	16.53 ± 0.5^{e}	2.56 ± 0.01^{g}	18.88 ± 0.01^{j}	6.661 ± 0.91^{b}	59.95 ± 0.82^{h}
Cyanthillium cinereum (L.) H.Rob.	4.83 ± 0.82^{d}	12.64 ± 0.17^{d}	2.12 ± 0.23^{a}	2.39 ± 0.35^{a}	3.28 ± 0.03^{j}	13.49 ± 0.02^{d}	8.171 ± 0.86^{c}	78.72 ± 0.6^{l}
Eclipta prostrata L.	6.9 ± 0.86^{d}	13.01 ± 0.05^{e}	2.44 ± 0.04^{b}	2.22 ± 0.19^{a}	2.11 ± 0.04^{d}	13.9 ± 0.03^{e}	7.94 ± 2.68^{c}	79.33 ± 0.39^{l}
Elephantopus scaber L.	4.13 ± 1.07^{d}	50.01 ± 0.02^{o}	2.32 ± 0.07^{b}	21.78 ± 0.65^{h}	2.02 ± 0.01^{c}	25.1 ± 0.04^{p}	8.219 ± 1.42^{c}	48.78 ± 0.04^{e}
Eleutheranthera ruderalis (Sw.) Sch.Bip.	1.07 ± 0.06^{a}	36 ± 0.04^{m}	2.42 ± 0.22^{b}	29.07 ± 0.67^{i}	6.04 ± 0.03^{n}	22.32 ± 0.04^{k}	7.941 ± 2.71^{c}	40.15 ± 0.57^{b}
Emilia sonchifolia (L.) DC	10.78 ± 0.49^{e}	16.4 ± 0.03^{h}	2.39 ± 0.22^{b}	11.44 ± 0.46^{c}	2.82 ± 0.06^{h}	18.01 ± 0.05^{i}	9.034 ± 3.07^{d}	65.34 ± 0.17^{i}
Erigeron sublyratus Roxb. ex DC.	3.43 ± 1.07^{d}	15.71 ± 0.03^{g}	2.04 ± 0.16^{a}	29.49 ± 0.5^{j}	3.31 ± 0.01^{j}	15.20 ± 0.03^{f}	7.839 ± 1.79^{c}	49.96 ± 0.3^{e}
Gnaphalium polycaulon Pers.	2 ± 0.29^{c}	32.99 ± 0.04^{l}	2.26 ± 0.01^{b}	27.54 ± 0.51^{i}	2.23 ± 0.02^{e}	25.82 ± 0.02^{n}	7.714 ± 3.11^{c}	42.19 ± 0.15^{c}
Grangea maderaspatana (L.) Poir.	5.07 ± 1.50^{d}	11.45 ± 0.04^{c}	2.14 ± 0.02^{a}	34.07 ± 0.62^{k}	2.49 ± 0.01^{f}	30.8 ± 0.02^{q}	7.985 ± 1.96^{c}	30.49 ± 0.33^{a}
Mikania micrantha Kunth	7.52 ± 0.51^{d}	43.6 ± 0.02^{n}	2.62 ± 0.10^{c}	33.38 ± 0.81^{k}	3.36 ± 0.04^{j}	10.5 ± 0.06^{a}	8.763 ± 2.4^{d}	50.14 ± 0.11^{f}
Sonchus arvensis L.	1.3 ± 0.1^{b}	15 ± 0.05^{f}	2.26 ± 0.04^{b}	18.33 ± 0.41^{f}	2.86 ± 0.01^{i}	19.91 ± 0.02^{l}	9.004 ± 1.97^{d}	56.65 ± 0.2^{g}
Sphaeranthus indicus L.	6.41 ± 1.29^{d}	10.3 ± 0.06^{b}	2.67 ± 0.14^{c}	28.69 ± 0.64^{i}	3.87 ± 0.02^{l}	19.13 ± 0.03^{k}	7.455 ± 1.94^{c}	45.65 ± 0.21^{d}
Synedrella nodiflora (L.) Gaertn.	4.49 ± 0.35^{d}	19 ± 0.01^{j}	2.81 ± 0.27^{c}	21.03 ± 0.42^{h}	3.43 ± 0.01^{j}	16.27 ± 0.02^{g}	7.683 ± 2.16^{c}	56.46 ± 0.17^{g}
Tridax procumbens L.	1.99 ± 0.24^{c}	15.6 ± 0.03^{g}	2.15 ± 0.02^{a}	15.17 ± 0.24^{d}	1.18 ± 0.03^{a}	17.75 ± 0.02^{h}	8.876 ± 2.21^{d}	63.75 ± 0.18^{i}

Alphabet superscripted against each entry in a column indicate significant differences between mean values. (One way ANOVA, DMRT, $P < 0.05$)

Table 3 Dietary minerals present in wild green leafy vegetable taxa

Species name	Na (mg/100 gm)	K (mg/100 gm)	Ca (mg/100 gm)	Mg (mg/100 gm)	Fe (mg/100 gm)	Mn (mg/100 gm)	Zn (mg/100 gm)	Cu (mg/100 gm)
Acmella calva (DC.) R.K.Jansen	170.13 ± 14.15^{d}	2251 ± 5.57^{c}	460.13 ± 13.65^{b}	110.37 ± 2.59^{a}	17.03 ± 0.384^{a}	11.4 ± 1.15^{b}	3.22 ± 0.04^{a}	3.63 ± 1.10^{a}
Ageratum conyzoides L.	90.03 ± 7.87^{c}	3640 ± 175.07^{e}	1750 ± 64.37^{g}	330.67 ± 6.11^{f}	11 ± 0.64^{b}	12.97 ± 1.15^{b}	5.14 ± 0.08^{c}	3.73 ± 0.72^{a}
Artemisia nilagirica (C.B.Clarke) Pamp.	200.23 ± 8.36^{d}	3400 ± 77.38^{d}	520.4 ± 7.61^{c}	370.43 ± 7.61 g	5.35 ± 0.54^{c}	4.37 ± 1.30^{a}	4 ± 0.12^{b}	41.2 ± 2.67^{d}
Chromolaena odorata (L.) R.M.King & H.Rob.	30.27 ± 3.24^{b}	3481 ± 21^{d}	950.27 ± 25.48^{e}	160.33 ± 11.41^{c}	4.8 ± 1.027^{c}	6.77 ± 1.1^{a}	6.79 ± 0.23^{e}	2.57 ± 0.52^{a}
Cotula anthemoides L.	619.97 ± 15.20^{f}	4220.3 ± 203.1^{f}	480 ± 19.73^{b}	180 ± 7.42^{c}	61.04 ± 1.365^{d}	21.63 ± 1.71^{c}	6.05 ± 0.21^{d}	5.43 ± 1.25^{a}
Cyanthillium cinereum (L.) H.Rob.	180.13 ± 12.29^{d}	2460 ± 59.65^{c}	840.4 ± 10.35^{d}	160.27 ± 4.67^{c}	4.42 ± 0.65^{c}	7.7 ± 1.21^{a}	5.3 ± 0.16^{c}	15.73 ± 2.21^{c}
Eclipta prostrata L.	70.13 ± 5.33^{c}	2180.3 ± 196.6^{c}	1280.37 ± 28.34^{f}	230.33 ± 10.23^{e}	29.04 ± 1.79^{e}	55.73 ± 2.39^{e}	8.46 ± 0.29^{g}	3 ± 0.46^{a}
Elephantopus scaber L.	80.3 ± 2.92^{c}	2211 ± 161.06^{c}	550.3 ± 18.3^{c}	230.27 ± 10.45^{e}	24.02 ± 1.029^{f}	36.53 ± 1.15^{d}	8.87 ± 0.09^{g}	3.07 ± 0.57^{a}
Eleutheranthera ruderalis (Sw.) Sch.Bip.	80.27 ± 2.91^{c}	3590.67 ± 11.4^{e}	1650.03 ± 30.8^{g}	330.47 ± 9.76^{f}	13.03 ± 0.829^{b}	12.93 ± 1.36^{b}	5.05 ± 0.09^{c}	4.2 ± 0.6^{a}
Emilia sonchifolia (L.) DC.	220.83 ± 3.49^{d}	1520.3 ± 24.70^{b}	1119.97 ± 118.01^{e}	170.27 ± 6.67^{c}	22.04 ± 1.48^{f}	14.73 ± 1.55^{b}	3.31 ± 0.09^{a}	3.67 ± 1.2^{a}
Erigeron sublyratus Roxb. ex DC.	200.43 ± 5.73^{d}	2509.8 ± 102.9^{c}	930.17 ± 15.86^{e}	160.33 ± 13.07^{c}	9.51 ± 0.895^{b}	8.1 ± 2.1^{a}	5.89 ± 0.23^{d}	16.77 ± 1.59^{c}
Gnaphalium polycaulon Pers.	80.23 ± 6.05^{c}	3320 ± 25.24^{d}	990.4 ± 49.78^{e}	370.33 ± 21.58^{g}	25.98 ± 0.94^{ef}	34.8 ± 2.70^{d}	6.05 ± 0.22^{d}	10.33 ± 2.42^{b}
Grangea maderaspatana (L.) Poir.	650.43 ± 5.31^{g}	1190.3 ± 13.05^{a}	470.2 ± 13.9^{b}	210.03 ± 6.70^{d}	63.02 ± 1.27^{d}	21.5 ± 1.61^{c}	6.12 ± 0.17^{d}	3.33 ± 0.68^{a}
Mikania micrantha Kunth	240.07 ± 10.99^{e}	2340 ± 308.31^{c}	410 ± 4.87^{a}	120.3 ± 7.85^{a}	6.92 ± 1.298^{c}	5.83 ± 1.15^{a}	4.4 ± 0.1^{c}	2.8 ± 0.7^{a}
Sonchus arvensis L.	210 ± 4.36^{d}	4420.7 ± 84.03^{f}	1870.03 ± 66.41^{g}	360.3 ± 5.55^{g}	13.29 ± 1.72^{b}	18.43 ± 1.66^{c}	5.11 ± 0.01^{c}	15.87 ± 1.11^{c}
Sphaeranthus indicus L.	160.1 ± 8.28^{d}	2110 ± 78.58^{c}	390 ± 23.55^{a}	120.2 ± 9.29^{a}	17.05 ± 1.595^{a}	11.53 ± 1.4^{b}	3.03 ± 0.25^{a}	4.07 ± 1.15^{a}
Synedrella nodiflora (L.) Gaertn.	210.13 ± 7.91^{d}	2270. 7 ± 71.53^{c}	530.13 ± 14.18^{c}	140.3 ± 5.41^{b}	8.43 ± 1.47^{bc}	7.33 ± 0.9^{a}	4.5 ± 0.25^{c}	1.63 ± 0.55^{a}
Tridax procumbens L.	20.07 ± 0.81^{a}	3410 ± 45.51^{d}	1720.2 ± 44.01^{g}	360.17 ± 18.16^{g}	8.45 ± 0.964^{bc}	8.13 ± 1.41^{a}	7.5 ± 0.4^{f}	2.07 ± 0.85^{a}

Alphabets superscripted against each entry in a column indicate significant differences between mean values. (One way ANOVA, DMRT, $P < 0.05$)

2019; Kfle et al. 2020) and medicinal plants (Bolan et al. 2017; Tschinkel et al. 2020; Luo et al. 2021). In the present study, the occurrence of toxic heavy metals like Pb, Cr, Hg, As, and Cd in edible vegetables were quantified to highlight their probable threat if present (Table 4). Traces of mercury (Hg) and arsenic (As) were just detected only in *Elephantopus scaber* L., *Erigeron sublyratus* Roxb. ex DC., *Grangea maderaspatana* (L.) Poir, *Sonchus arvensis* L., and *Acmella calva* (DC.) R.K. Jansen.

It was observed that the quantified values of the heavy metal concentration in most of the studied WGLVs were within the permissible limit as recommended by the Food Safety and Standards Authority of India (FSSAI 2020). Though the concentration of Pb in five studied leafy greens like *Elephantopus scaber* L. (0.93 ± 0.176 mg/Kg), *Grangea maderaspatana* (L.) Poir. (0.46 ± 0.098 mg/Kg), *Eleutheranthera ruderalis* (Sw.) Sch.Bip. (0.44 ± 0.104 mg/Kg), *Eclipta prostrata* L. (0.39 ± 0.092 mg/Kg), and *Sonchus arvensis* L. (0.31 ± 0.08 mg/Kg) exceed the standard limit of 0.3 mg/Kg for leafy vegetables. Likely, Cd concentration was found to be little bit higher than the acceptable level (0.2 mg/Kg) in the case of *Erigeron sublyratus* Roxb. ex DC. (0.77 ± 0.078 mg/Kg), and *Grangea maderaspatana* (L.) Poir. (0.23 ± 0.046 mg/Kg). Additionally, Cr concentration in *Sonchus arvensis* L. (1.11 ± 0.082) was found slightly higher than the permitted limit of 1.0 mg/Kg (FSSAI 2020). As the daily average consumption amount was less than 100 g, the risk from those contaminated WGLVs was found insignificant. This is one of the reasons that despite consuming such a large number of wild edibles for a long time in the *Santal* community of the study area, any health issue related to heavy metal toxicity have not been reported yet. So, all the studied taxa can be considered safe for daily consumption. Certainly, it is a blessing of nature in the form of nutritionally rich, non-toxic, naturally growing WGLVs. So, local people should always be cautious and take the initiative to keep the wild and semi-wild populations of such edible species free from any sort of heavy metal contamination and pollution.

Antioxidant capacity of the WGLVs, IC_{50} value, and correlation with total phenolic and flavonoid contents

The total phenolic content (TPC) and the total flavonoid content (TFC) of the ethanolic extract of 18 selected WGLVs had been presented in Table 5. TPC of ethanolic extract of 18 investigated taxa ranged from 5.81 ± 0.09 to 66.75 ± 0.115 mg/g tissue. Here highest value was recorded for *Eleutheranthera ruderalis* (Sw.) Sch.Bip. (66.75 ± 0.115 mg GAE/g) followed by *Synedrella nodiflora* (L.) Gaertn. (58.5 ± 0.71 mg GAE/g), *Cotula anthemoides* L. (58.2 ± 0.27 mg GAE/g), *Sphaeranthus indicus* L. (49.05 ± 0.38 mg GAE/g), and *Gnaphalium polycaulon* Pers. (42.39 ± 0.17 mg GAE/g). From the statistical analysis, it was found that there is a highly significant variation (P = 2.78E-31) in the value of total phenolic content of the studied members of *Asteraceae*.

Total flavonoid content (TFC) of the selected WGLVs ranged from 01.55 ± 0.27 to 32 ± 0.01 mg CE/g. Among all the studied taxa highest flavonoid content (32 ± 0.01 mg CE/g) was measured in *Cotula anthemoides* L. followed by *Chromolaena odorata* (L.) R.M.King & H.Rob. (26.5 ± 0.14 mg CE/g), and *Synedrella nodiflora* (L.) Gaertn. (23.5 ± 0.13 mg CE/g). Though all the studied taxa belong to the same family *Asteraceae*, total flavonoid content showed a highly significant variation (P = 1.34E-25) among the taxa (Table 6).

The DPPH radical scavenging activity of eighteen plant species ranged from 1.73 ± 0.04% to 43.33 ± 0.08% in minimum concentration of 10 µg/ml and the maximum concentration of 200 µg/ml, the scavenging activity varied from 51.48 ± 0.12% to 85.81 ± 0.06% (Supplementary table-1). At a minimum concentration of 10 µg/ml, ethanolic extract of *Cotula anthemoides* L. showed highest scavenging activity (43.33 ± 0.08%) and *Sphaeranthus indicus* L. showed maximum scavenging activity (85.81 ± 0.06%) at a highest concentration of 200 µg/ml of ethanolic extract. The IC_{50} value was determined for eighteen investigated taxa that ranged from 27 to 173 µg/ml (Fig. 2). In this study, IC_{50} value of three plants were found very much closer to the value of standard i.e., ascorbic acid (26 µg/ml) and it was recorded lowest in the case of *Sonchus arvensis* L. (27 µg/ml). Out of 18 investigated species 7 taxa were identified as very strong antioxidants (IC_{50}

value < 50 µg/ml), three were found as strong antioxidants (50–100 µg/ml), six plants as moderate antioxidants (101–150 µg/ml) and two plant species were identified as weak antioxidants (IC_{50} value > 150 µg/ml.).

Antioxidant activity largely depends on important phytochemical groups like phenolics and flavonoids (Agati et al. 2012; Silva-Beltrán et al. 2015). There is a significant correlation found between radical scavenging power and the presence of total content of phenolic and flavonoid compounds in the analyzed species. Such type of correlation was also observed in several studies on angiospermic taxa where high content of phenolics is directly related to the higher radical scavenging activity (Del Ré and Jorge 2012; Demiray et al. 2009; Zhang et al. 2011; Singh et al. 2016). The phenolic content of *Cotula anthemoides* L. and *Synedrella nodiflora* (L.) Gaertn. was found 5 to 6 fold higher than the total phenolic content found in the popular sources of natural antioxidant like, blueberry (9.44 ± 0.22 mg GAE/g), blackberry (5.58 ± 0.18 mg GAE/g) and strawberry (2.72 ± 0.18 mg GAE/g) (Huang et al. 2012). Among these two, *Cotula anthemoides* L. was the most potent antioxidant agent in respect of its high DPPH radical scavenging activity and low IC_{50} value. The high radical scavenging activity of this plant is possibly due to its higher total phenolic and flavonoid content i.e. 58.2 ± 0.27 mgGAE/g and 32 ± 0.01 mg CE/g, respectively. So, plants like *Cotula anthemoides* L. and *Synedrella nodiflora* (L.) Gaertn. should be exploited further as alternative potent source of phenolics, flavonoids, and other antioxidant substances for the development of natural products of therapeutic as well as dietary importance.

Eat natural stay healthy- a fallacy towards the non-toxic nature of wild edibles

The use of herbs as therapeutic agents, functional foods, and food supplements for health care has been increasing worldwide day to day. But what is natural or so-called 'herbal' is not always safe and devoid of any side effects. There is ample evidence that commonly used edible plants have a wide range of toxic effects due to the presence of accumulated magnified concentrations of heavy metals and overdose of plant secondary metabolites (Nasri and Shirzad 2013; Jaramillo et al. 2016; Madariaga-Mazón et al. 2019; Kaltner 2022). The in vitro cytotoxicity study of the investigated WGLVs on the HepG2 and THP-1 cell lines did not show any significant cell death even at the highest dose of 200 µg/ml. At this concentration, only *Ageratum conyzoides* L. showed slight cytotoxicity in both cell lines (Fig. 3). It might be due to the presence of a pyrrolizidine group of alkaloids in this herb which is hepatotoxic, carcinogenic, genotoxic, teratogenic, and sometimes pneumotoxic (Wiedenfeld 2011; Bosi et al. 2013). Apart from it, the cell survivability percentage varied from 88.1 to 92.1% in THP-1 cell line and 91.4% to 93.9% in HepG2 cell line at the highest dose. Previous workers have also shared similar types of observation in some of these selected green edibles. For example, the non-toxic nature of the ethanolic extract of *Chromolaena odorata* (L.) R.M.King & H.Rob. has been established. (Asomugha 2015). *Cyanthillium cinereum* (L.) H.Rob. was found slightly cytotoxic in XTT assay (Guha et al. 2011). *Emilia sonchifolia* (L.) DC., one of the preferred herbs in the locality, is found non-toxic to normal human lymphocytes (Shylesh and Padikkala 2000). Ethyl acetate extract of *Sonchus arvensis* L. was noticed nontoxic in acute and subchronic toxicity assay (Nurianti et al. 2014). Leaf of *Synedrella nodiflora* (L.) Gaertn. has also been found less toxic in the experimental concentration which was effective for other potent pharmacological activity (Chaniad et al. 2021). So, the nontoxic nature of the studied plants makes them more acceptable as edible items and establishes the herbs attractive to the pharmaceutical and nutraceutical sectors for producing dietary supplements.

Food-medicinal continuum of the selected WGLVs and its rationale of traditional uses

Many medicinal plants are equally popular as food plants and vice versa (Shikov et al. 2017; Xu et al. 2020; Wali et al. 2022). Through years of experience and practice local tribes have understood the nutritional as well as medicinal benefits of food plants, and later scientific world has explored what synergy lies in it. All the eighteen WGLVs which were found nutritionally rich are having a varied range of popularity in respect of their medicinal properties among the tribal people of the studied area. This food-medicinal continuum of the selected WGLVs indicates the

Table 4 Quantitative value of the heavy metals detected in the wild green leafy vegetables (WGLVs)

Name of the species	Detected value (mg/Kg)				
	Pb	Cr	Hg	Cd	As
Acmella calva (DC.) R.K.Jansen	0.23 ± 0.036^{a}	0.28 ± 0.06^{a}	0.002 ± 0.001	0.12 ± 0.02^{a}	–
Ageratum conyzoides L.	0.009 ± 0.003^{b}	0.13 ± 0.03^{b}	–	–	–
Artemisia nilagirica (C.B.Clarke) Pamp.	0.011 ± 0.003^{b}	0.16 ± 0.027^{ab}	–	–	–
Chromolaena odorata (L.) R.M.King & H.Rob.	0.29 ± 0.07^{a}	0.07 ± 0.01^{b}	–	0.01 ± 0.001^{b}	–
Cotula anthemoides L.	0.17 ± 0.04^{ab}	0.05 ± 0.02^{b}	–	0.05 ± 0.0155^{ab}	—
Cyanthillium cinereum (L.) H.Rob.	0.08 ± 0.026^{ab}	0.09 ± 0.03^{b}	–	–	–
Eclipta prostrata L.	0.39 ± 0.092^{a}	0.07 ± 0.02^{b}	–	0.08 ± 0.0115^{ab}	–
Elephantopus scaber L.	0.93 ± 0.176^{d}	–	0.001 ± 0.00	–	0.001 ± 0.00
Eleutheranthera ruderalis (Sw.) Sch.Bip.	0.44 ± 0.104^{a}	0.05 ± 0.01^{b}	–	0.01 ± 0.0053^{b}	–
Emilia sonchifolia (L.) DC.	0.3 ± 0.036^{a}	0.05 ± 0.02^{b}	–	0.021 ± 0.004^{b}	–
Erigeron sublyratus Roxb. ex DC.	0.058 ± 0.0098^{ab}	–	0.002 ± 0.001	0.77 ± 0.078^{c}	–
Gnaphalium polycaulon Pers.	0.017 ± 0.004^{ab}	0.11 ± 0.026^{b}	–	–	–
Grangea maderaspatana (L.)Poir.	0.46 ± 0.098^{c}	0.59 ± 0.108^{c}	–	0.23 ± 0.046^{d}	0.001 ± 0.00
Mikania micrantha Kunth	0.17 ± 0.0265^{ab}	0.55 ± 0.072^{c}	–	0.03 ± 0.0135^{b}	–
Sonchus arvensis L.	0.31 ± 0.08^{ac}	1.11 ± 0.082^{d}	0.002 ± 0.001	0.09 ± 0.02^{ab}	0.002 ± 0.001
Sphaeranthus indicus L.	0.25 ± 0.076^{ac}	0.19 ± 0.044^{ab}	–	–	–
Synedrella nodiflora (L.) Gaertn.	0.18 ± 0.046^{ab}	0.09 ± 0.036^{b}	–	–	–
Tridax procumbens L.	0.15 ± 0.036^{ab}	0.11 ± 0.02^{b}	–	0.03 ± 0.002^{b}	–
Permissible limit (mg/Kg) according to FSSAI standard[1]	**0.3**	**1.0**	**1.0**	**0.2**	**1.1**

Alphabets superscripted against each entry in a column indicate significant differences between mean values. (One way ANOVA, DMRT, $P < 0.05$)

Table 4 represents the heavy metal concentration in the studied samples. Heavy metals are toxic when consumed beyond the permissible limit. To emphasize the permissible limit of the studied heavy metals in comparision to their presence in the plant samples, we have presented the digit in bold

[1]The Food Safety and Standards Authority of India (FSSAI) https://www.fssai.gov.in/upload/uploadfiles/files/Compendium_Contaminants_Regulations_20_08_2020.pdf

(Accessed on 28.04.2023)

rationale of their ongoing traditional uses. For example, dietary fibres act as laxatives in the human system, and crude fibre content was found significantly high (34.07%) here in *Grangea maderaspatana* (L.) Poir. which is specifically taken as leafy vegetables in high amounts when they suffer from stomach pain and dyspepsia due to prolonged constipation. Such a traditional food-medicinal attribute of this plant is also supported by earlier researchers who have also observed its effectiveness against stomach disorders (Khare 2008; Panda and Misra 2011). Total Ca content was estimated maximum (1870.03 mg/100 g) in *Sonchus arvensis* L., leaf decoction of which is traditionally used to cool down the nerves (Shinwari and Khan 2000) and it is a well-known fact that Calcium has an effective role in neuromuscular functions (Murray et al. 2000). Plants like *Cotula anthemoides* L. and *Synedrella nodiflora* (L.) Gaertn. are traditionally used as anti-inflammatory agent. This pharmacological property is highly correlated with the presence of significant amounts of phenolics and flavonoids as well as their potent radical scavenging activity. Similarly, other investigated taxa which are found rich in their different nutritional components, phytochemicals and marked antioxidant property can also be attributed to the rationale of their many food-medicinal uses. It is clear from the above discussion that all the studied WGLVs not only provide nutritional benefits but also function as a source for the prevention and cure of various human diseases. So they are

Table 5 Total phenolic and flavonoid content estimated in wild green leafy vegetable taxa

Studied taxa	Total phenolic content (mg GAE/g)	Total flavonoid content (mg CE/g)
Acmella calva (DC.) R.K.Jansen	14.26 ± 0.09^{c}	6.49 ± 0.06^{e}
Ageratum conyzoides L.	28.56 ± 0.53^{d}	15 ± 0.05^{f}
Artemisia nilagirica (C.B.Clarke) Pamp.	32.5 ± 0.15^{e}	18.32 ± 0.35^{a}
Chromolaena odorata (L.) R.M.King & H.Rob.	34.04 ± 0.03^{f}	26.5 ± 0.14^{g}
Cotula anthemoides L.	58.2 ± 0.27^{a}	32 ± 0.01^{h}
Cyanthillium cinereum (L.) H.Rob.	20.06 ± 0.24^{g}	13 ± 0.26^{b}
Eclipta prostrata L.	38.12 ± 0.41^{h}	4.6 ± 0.23^{c}
Elephantopus scaber L.	22.13 ± 0.08^{i}	7.5 ± 0.3^{i}
Eleutheranthera ruderalis (Sw.) Sch.Bip.	66.75 ± 0.12^{j}	4.5 ± 0.16^{c}
Emilia sonchifolia (L.) DC.	36.57 ± 0.18^{b}	8.97 ± 0.16^{d}
Erigeron sublyratus Roxb. ex DC.	36.006 ± 0.13^{b}	3.5 ± 0.07^{j}
Gnaphalium polycaulon Pers.	42.39 ± 0.17^{k}	13.44 ± 0.35^{b}
Grangea maderaspatana (L.) Poir.	26.5 ± 0.54^{l}	13.01 ± 0.2^{b}
Mikania micrantha Kunth	5.81 ± 0.09^{m}	1.55 ± 0.27^{k}
Sonchus arvensis L.	13.25 ± 0.29^{n}	8.42 ± 0.23^{d}
Sphaeranthus indicus L.	49.05 ± 0.38^{o}	18.51 ± 0.21^{a}
Synedrella nodiflora (L.) Gaertn.	58.5 ± 0.71^{a}	23 ± 0.13^{l}
Tridax procumbens L.	10.51 ± 0.24^{p}	5.5 ± 0.21^{d}

Alphabets superscripted against each entry in a column indicate significant differences between mean values. (One way ANOVA, DMRT, $P < 0.05$)

Table 6 Water soluble vitamin content in the wild green leafy vegetables

Name of the species	Ascorbic acid/Vitamin C (mg/100gm)	Thiamin/Vitamin B_1 (mg/100gm)	Riboflavin/Vitamin B_2 (mg/100gm)
Acmella calva (DC.) R.K.Jansen	19.43 ± 0.78^{a}	0.898 ± 0.076^{e}	0.008 ± 0.001^{a}
Ageratum conyzoides L.	29.21 ± 0.96^{j}	0.273 ± 0.037^{a}	0.153 ± 0.02^{b}
Artemisia nilagirica (C.B.Clarke) Pamp.	13.62 ± 1.464^{b}	0.189 ± 0.059^{a}	0.075 ± 0.012^{c}
Chromolaena odorata (L.) R.M.King & H.Rob.	55.03 ± 2.219^{e}	0.076 ± 0.012^{b}	0.055 ± 0.004^{c}
Cotula anthemoides L.	85.903 ± 1.02^{f}	0.0813 ± 0.006^{b}	0.232 ± 0.022^{d}
Cyanthillium cinereum (L.) H.Rob.	12.22 ± 0.35^{b}	0.634 ± 0.104^{c}	0.166 ± 0.018^{b}
Eclipta prostrata L.	19.13 ± 0.75^{a}	1.206 ± 0.144^{d}	0.055 ± 0.008^{c}
Elephantopus scaber L.	16.34 ± 0.349^{g}	0.13 ± 0.033^{ab}	0.059 ± 0.008^{c}
Eleutheranthera ruderalis (Sw.) Sch.Bip.	66.3 ± 0.516^{h}	0.042 ± 0.006^{ab}	0.088 ± 0.013^{c}
Emilia sonchifolia (L.) DC.	70.97 ± 0.796^{c}	2.036 ± 0.065^{f}	0.172 ± 0.012^{b}
Erigeron sublyratus Roxb. ex DC.	13.657 ± 0.424^{b}	0.218 ± 0.02^{ab}	0.064 ± 0.004^{c}
Gnaphalium polycaulon Pers.	22.147 ± 0.807^{i}	0.523 ± 0.034^{c}	0.018 ± 0.002^{ac}
Grangea maderaspatana (L.) Poir.	19.037 ± 0.812^{a}	0.061 ± 0.011^{b}	0.023 ± 0.004^{ac}
Mikania micrantha Kunth	58.233 ± 0.309^{d}	0.054 ± 0.0096^{b}	0.111 ± 0.004^{c}
Sonchus arvensis L.	69.957 ± 0.424^{c}	0.084 ± 0.011^{b}	0.019 ± 0.002^{ac}
Sphaeranthus indicus L.	69.897 ± 0.627^{c}	0.071 ± 0.003^{b}	0.083 ± 0.005^{c}
Synedrella nodiflora (L.) Gaertn.	58.483 ± 0.39^{d}	0.063 ± 0.004^{b}	0.029 ± 0.004^{ac}
Tridax procumbens L.	11.607 ± 0.294^{b}	0.208 ± 0.009^{ab}	0.047 ± 0.004^{c}

Alphabets superscripted against each entry in a column indicate significant differences between mean values. (One way ANOVA, DMRT, $P < 0.05$)

not just wild greens rather they should be accepted as potent "functional foods" in the tribal vegetable basket.

Wild edible vegetables-its acceptance, domestication, and accountability in food security of the Indian tribes

Santals and other Indian tribes are still marginalized in society with enough economic and educational backwardness. This is one of the many reasons; they are largely dependent on naturally occurring, freely accessible resources for their existence. Indigenous people like *Santals* have a very strong inherent bonding with nature. It reflects in their trustful attitude toward local biodiversity and wide acceptance of the wild-growing resources. Apart from the medicinal uses of the studied 18 WGLVs, they were cumulatively cited 202 times as wild edible vegetables by the 150 participants. This is a strong indication of their acceptance of WGLVs. The dependency of the other Indian tribes on wild edible green vegetables has been explored by scientists from different corners of the country also (Misra et al. 2008; Horo and Topno 2015; Konsam et al. 2016; Kumari and Solanki 2019). Members of the *Asteraceae* possess a wide range of essential oils and phytochemicals responsible for its attractive aroma, pungency, and sometimes bitterness. On the other hand dark green appearance of the fresh leaves with optimum delicacy attracts consumers towards it. The fact is acceptance of any edible vegetables primarily depends on the consumer's multisensory perception attached to visual, odour, taste, and texture cues (McCrickerd and Forde 2016; Michell et al. 2020).

Wild leafy vegetables are very delicate herbs, accessibility is effortless but availability is seasonal. To overcome the constrain related to seasonal availability and their perishableness, traditional processing and storage techniques have been practiced by the *Santal* women to preserve some of the WGLVs like *Elephantopus scaber* L., *Emilia sonchifolia* (L.) DC., *Gnaphalium polycaulon* Pers., *Grangea maderaspatana* (L.) Poir., and *Sonchus arvensis* L. for future use. The effectiveness of such a storage technique should be scientifically validated as the nutrient composition in a fresh plant is subjected to alteration upon changes in certain physiochemical parameters like moisture content, chemical constituents, enzymatic reactions, and others (Gupta et al. 2013; Bighaghire et al. 2021). Some of the plants like *Tridax procumbens* L., *Eclipta prostrata* L., and *Cyanthillium cinereum* (L.) H.Rob. are maintained in most of the home gardens for their frequent use in the kitchen as well as medicinal purposes. Food scientists have evaluated the enormous contribution of home gardens or kitchen gardens towards nutritional and food security (Chadha and Oluoch 2003; Ijinu et al. 2011; Bucher and Bucher 2018). Seasonal availability of the herbs here in the study region is compensated to some extent through the long-term preservation technique practiced locally by the women and by the home garden practice. Thus

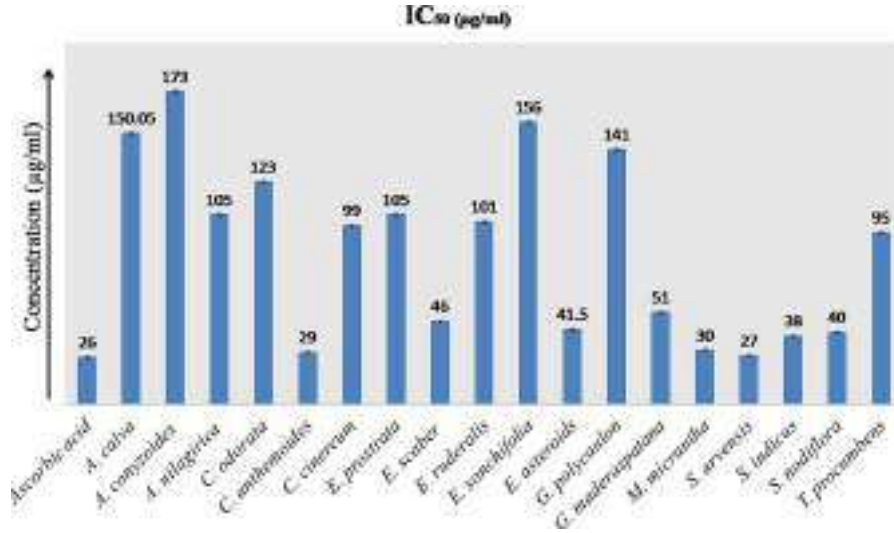

Fig. 2 IC_{50} values of the tested plant extracts towards their antioxidant activity

some herbs are available in their dried form to users during the off-season.

Food security has an all-around aspect covering nutritional proficiency, availability, adequacy, accessibility, and safety of the food items. All of our study materials are nutritionally rich, having varied degree of food value, abundance in growth, easy accessibility, and no toxicity threats. All these characteristics indicate that selected WGLVs can play a significant role in the food security of the local *Santals* and other tribes of India if they are recommended in regular diet with scientifically measured daily intake amount.

A large part of the tribal communities in the studied area is still fighting with their poor economic condition and for achieving a proper diet. Mainstreaming the studied WGLVs and growing social awareness about the food value of such wild herbs can be a good option for the economic upliftment of the local tribes through marketing those edible greens. On the other hand incorporation of those WGLVs in daily cuisine may help in getting a balanced nutritional input. For sustainable livelihood and to keep good health, scientific education on nutrition and proper conservation strategies for maintaining the important herbs in the home gardens or kitchen gardens, or even cultivated fields should be encouraged.

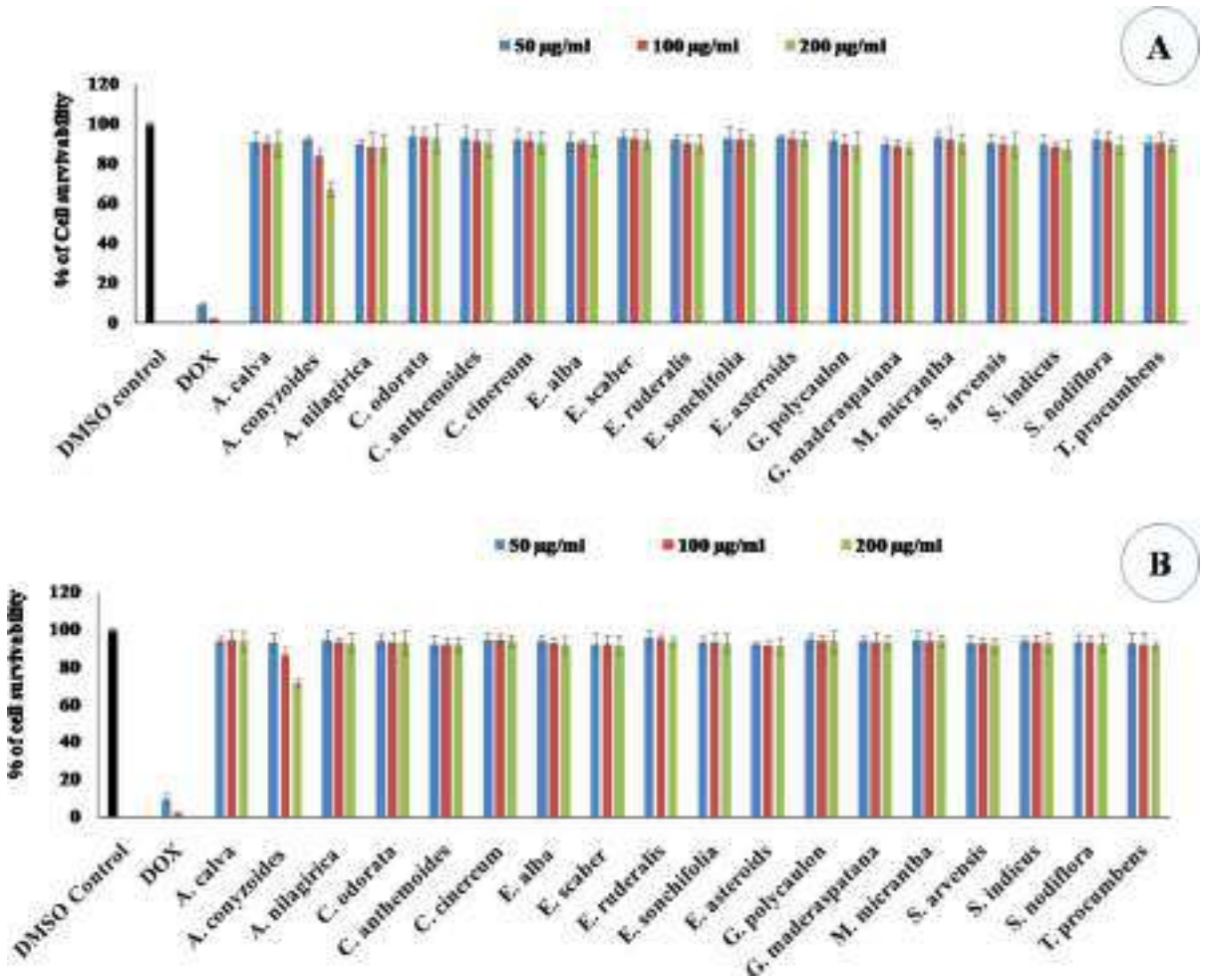

Fig. 3 MTT assay exhibit non-toxic nature of three experimental dose of ethanolic plant extracts (50 µg/ml, 100 µg/ml, and 200 µg/ml) with no significant cell death in **A** THP-1 cell line and **B** HepG2 cell line

Limitations

Due to some financial and instrumental limitations, we could not able to perform the in vivo toxicity studies and post-cooking effects on nutritional and essential oil composition in the investigated WGLVs. The in-depth research would be helpful to further investigate the toxic, anti-nutritive, enzymatic, and molecular effects on the human health of both the products and plant species. So, there is a need to further conduct more studies on the utilization pattern of WGLVs in the studied area, their social acceptance, resilience, and complete nutritional profile.

Conclusion

In the present study, we have tried to better understand the correlation between traditionally used WGLVs, their contribution to nutritional effectiveness, health benefits, food security, and in dietary diversity of the tribes of West Bengal. All the studied plants are nutritionally rich and good sources of natural antioxidants. These ravishing properties of the investigated WGLVs demand their inclusion as economically important alternative genetic resources of food plants which expand the list of edible plant database. The inclusion of such wild vegetables in daily cuisine will provide some nutritional and health benefits; as well as the diversity of abundant edible greens in the locality will increase the food security of the local tribes. Beyond their local importance, all the studied WGLVs can be recommended as functional food with standardized intake values. We may popularize those WGLVs not only among the tribal people or the urban and rural poor but also among the urban health-conscious elites.

In contrast, among the younger generation of the tribal communities, a potential lack of interest in using those nutritionally rich leafy greens was experienced throughout the field survey. This alarming situation can be overcome by raising awareness among the younger ones of the local tribes, developing faith in their own traditional culture, practicing sustainable utilization of local food plants, and educating them about the interrelationship between a healthy diet and nutritionally potential phytoresources of the locality. The rapidly growing world population faces two way challenges like food crisis and malnutrition which can be overcome by incorporating a greater variety of wild plants in the food basket after checking their nutritional potentials and toxicity. And for translating this into reality a collaborative effort is urgently needed from anthropologists, geographers, botanists, food scientists, phytochemists, nutritionists, health professionals, and sociologists. The strength of the present study lies in the comparative analysis of nutritional aspects of 18 wild green leafy vegetables of the family *Asteraceae*. It will provide a strong foundation for further research in pharmacological as well as nutraceutical aspects of the respective plant taxa. The present study will also help in policy making to overcome national challenges attached to mass malnutrition.

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Author contributions SS & CHR designed the work; SS & SKM conducted the field survey, collected ethnomedicinal data; SS, SS, SKM & CHR analyzed the data; SS performed the vitamin and heavy metal analysis and in vitro toxicity; SS, SKM & CHR wrote the manuscript and checked critically; all the authors finalized the draft.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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Fading but still existing: some new observations on *Santals'* Ethnoveterinary medicinal practices from the Purba and Paschim Bardhaman districts of West Bengal (India)

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Research

Abstract

Background: The *Santals* have innate expertise in managing their livestock's health and it is still actively practiced in the districts of rural West Bengal, India. Perusal of literature indicates that no research work exclusively on ethnoveterinary medicine has been carried out till date from Purba and Paschim Bardhaman districts of West Bengal. In this regard, indigenous therapeutic knowledge (ITK) for livestock health care is being studied among the *Santal* ethnic group inhabited in the various corners of these districts.

Materials and Methods: In the current study, data were gathered using both *in situ* and *ex situ* techniques after taking prior informed consent (PIC) from each of the 57 participants. Group discussion and semi-structured open-ended questionnaire was used to conduct the interviews. To identify the important folk-medicinal species, three quantitative indices like factor of informant consensus (F_{ic}), use-mentions factor (UM) and relative frequency of citation (RFC) have been employed here.

Results: Altogether 62 plant species have been documented here for 12 types of disease categories. In most of the cases, roots and underground parts (30%) were used. In 69.49% cases, remedies were applied orally. F_{ic} value ranges from 0.6 to 0.94, RFC value ranges from 0.79 to 8.7 and *Achyranthes aspera* L. has been identified as mostly exploited species. Impact of plants like *Aristolochia indica* L., *Pueraria tuberosa* (Willd.) DC. and *Strychnos nux-vomica* L. has also been found deep in the *Santal* people's culture of the studied area.

Conclusion: The collected ethnoveterinary medicinal datasets and the statistically analyzed information can contribute a lot to build up bioprospecting objectives, conservation strategies, and socioeconomic agendas.

Keywords: ITK, ethnoveterinary phytomedicine, quantitative ethnobotany, *Santals*, Purba and Paschim Bardhaman, West Bengal

Background

From the onset of human civilization, livestock have been a vital part of human existence, providing companionship, labor, and useful goods. (Cucchi and Arbuckle 2021, Rahman *et al*. 2023). Understanding the importance of pet animals in daily life, early people have developed skills to take care of their animals which is the basis of 'ethnoveterinary medicine' today (McCorkle 1986). Like all other forms of traditional knowledge, ethnoveterinary medicinal knowledge is still surviving as non-codified and orally transmitted form in most of the folk cultures. Due to the urbanization and ongoing modernization of the ethnic societies, the main stakeholders and their upcoming generations are silently losing their interest in folk medicinal practices (Buenz 2005, Ramirez 2007, Arjona-García *et al*. 2021). Realizing this alarming situation, scientists from different parts of the world have started documenting this folk medical heritage before its extinction forever (Xiong and Long 2020, Khan *et al*. 2021, Radha *et al*. 2022, Uprety *et al*. 2022, Khan *et al*. 2023). The custom of raising animals is ancient and sacred in Indian culture. In recent past, many research articles have been published on ethnoveterinary medicine from India which indicates the growing attitude towards this field of ethnobotany (Bhatt *et al*. 2019, Radha *et al*. 2022). Since last two decades, to get more objectivity in this branch of ethnobotanical studies different quantitative tools have been employed by various researchers throughout the world including India (Njoroge and Bussmann 2006, Kumar and Bharati 2013, Mandal and Rahaman 2014, Parthiban *et al*. 2016). A few research articles have been published earlier from different districts of West Bengal exclusively on ethnoveterinary medicine (Mandal and Chauhan 2000, Ghosh 2003, Bandyopadhyay and Mukherjee 2005, Saha *et al.* 2014, Mandal and Rahaman 2022). Perusal of literature on ethnobotany so far published from this state indicate that quite a good number of works on ethnomedicine have been published from the districts of Purba and Paschim Bardhaman but no research work exclusively on ethnoveterinary medicine has been carried out till date (Biswas 2013, Bouri and Mukherjee 2013). Rural economy of these districts is dependent mainly on agriculture and livestock farming. Large number of milk producing indigenous cattle and crossbred cattle has been found here (Livestock census 2012) and this zone is the 2nd highest milk producing area in West Bengal after West Medinipur (NDDB 2017).

The *Santals* are one of the oldest and largest ethnic stocks in India and a major tribal group of the state of West Bengal (Pal and Jain 1998). Like some other tribal communities, *Santal* people also have close association with the livestock and forest resources. Ill health of livestock seriously affects socio-economic condition of this marginalized ethnic group. So, they have a rich oral tradition of herbal therapies and practiced actively till now as the distal region of the state remains almost out-reached from the government-supported healthcare facilities for livestock. Present study has been undertaken to document the existing ethnoveterinary medicinal knowledge of the *Santal* tribe resides in various parts of Purba and Paschim Bardhaman, West Bengal.

Materials and Methods

Study area

On 7th April 2017, the district Burdwan has been bifurcated into Purba Bardhaman district and Paschim Bardhaman district. The district Burdwan is situated from 22^{o}56′ to 23^{o}53′ North Latitudes and from 86^{o}48′ to 88^{o}25′ East Longitudes. It is bordered on the north by the districts of Birbhum and Murshidabad, on the east by the district of Nadia, on the southeast by the district of Hooghly, on the southwest by the districts of Bankura and Purulia, and on the northwest by the district of Dhanbad in Jharkhand state. Burdwan district extends over the land area of about 7024 sq km within which 277 sq km belongs to forest area.

The survey has been conducted in 11 blocks from these two newly formed districts where *Santal* tribes are predominant than the other tribal groups. From Purba Bardhaman district, 5 blocks namely Khandaghosh, Galsi-I, Galsi-II, Ausgram-I, and Ausgram-II have been explored. On the other hand 6 blocks from Paschim Bardhaman namely Kanksa, Pandabeswar, Faridpur-Durgapur, Raniganj, Jamuria and Barabani have been visited for ethnoveterinary medicinal data collection (Fig. 1). Morphogenetically the selected area falls under the undulating lateritic agro-climatic region. The climatic condition belongs to 'Tropical Wet-Dry Savanna Region' as well as humid subtropical climate inclined by monsoonal rainfall. In last 100 years, this region contains annual average rainfall of 1380 mm with mean temperature is 25.8°C. The forest type is mostly wet deciduous type dominated by the species *Shorea robusta* C.F.Gaertn. though three types of forest categories are existed over the regions i.e., dry peninsula sal forest, northern dry mixed deciduous forest and dry deciduous scrub jungles (Dutta *et al*. 2020).

In Purba and Paschim Bardhaman, population of the *Santals* is nearly 7% of the state schedule tribe population and 76% of the district's total tribal population (Census 2011). Most of the economically underprivileged and small-landowner *Santals* in this area make a living primarily as a daily labourer, and via agriculture, cattle raising, and small-scale dairy production.

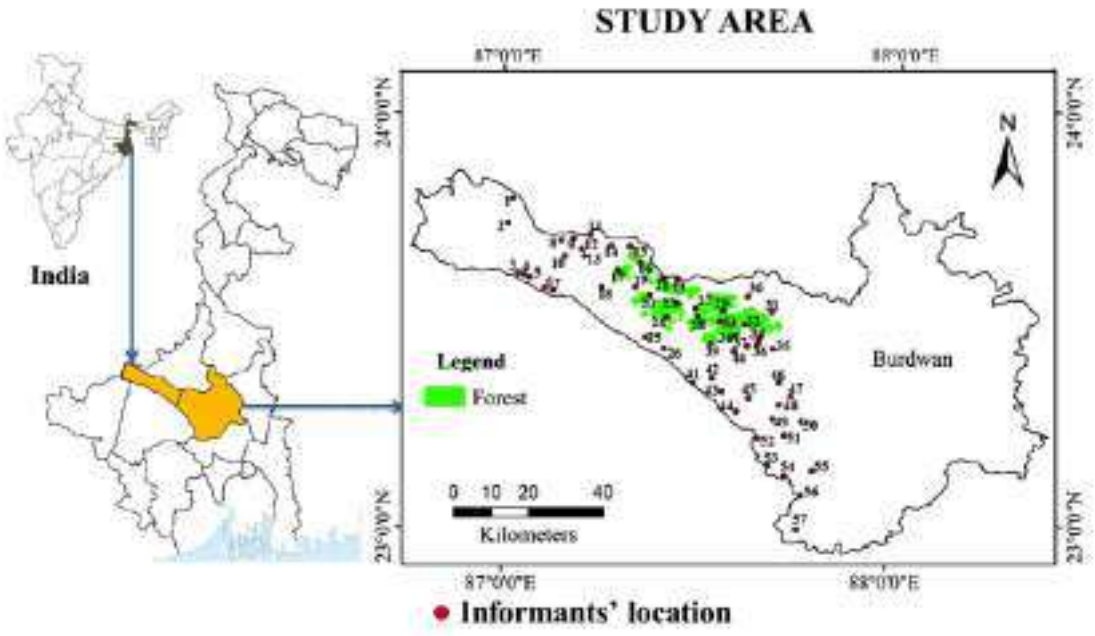

Figure 1. Study area shows GPS coordinates of 57 informants of Purba and Paschim Bardhaman districts

Ethnographic composition and Ethnomedicinal data collection

The survey was conducted for a period from September 2022 to November 2022. Before collection of the data, prior informed consent (PIC) has been taken from the informants to protect the intellectual property right of those traditional people. Altogether 57 informants were interviewed, of which 23 were women and 34 men. Forty-one informants are aged between 60 to 85 years, 11 are of 40 to 60 years and only 5 informants are found to be aged bellow 40 years. Among 57 informants, 80.7% informants have no primary education, 14.03% have school education and only 5.26% have higher education and engaged in government services. Among the 57 informants, 26 people were locally known as '*Go-Vaidya*' or herbal healer for cattle diseases. The folk healers gather their knowledge mainly from their ancestors and knowledgeable persons of the same or other localities. The flow of this traditional knowledge is found very much vertical coexisted with transverse way of knowledge dissemination. In few cases it has been found that the knowledge transfer is restricted within the family descendants. The member of the family, who is genuinely interested in traditional healing system as well as capable of doing so, becomes the right choice to whom the knowledge is conveyed.

Both *in situ* and *ex situ* methods of data collection were applied in the present study. In the "walk-in-the-wood" (*in situ*) method, informants were taken to the field individually to identify the plants that they use to cure the diseases or ailments which produces much reliable data. Sometimes freshly collected plant specimens (*ex situ* method) were shown to the informants (mainly women and aged persons) for proper identification of the plants of relevant medicinal uses (Thomas *et al*. 2007). Interviews were taken with the help of semi-structured and open-ended questionnaire, and it was done in a very informal way (Martin 2004). Sometimes interaction with the tribal people had been made with the help of local interpreter.

The survey was executed following the best field practice proposed earlier (Heinrich and Verpoorte 2014, Heinrich *et al*. 2018), and maintaining Code of Ethics suggested by International Society of Ethnobiology (ISE, 2008). Sample specimens have been collected following the national guidelines (NMPB, 2015). Collected plant specimens have been identified with the help of different Floras (Sanyal 1994, BSI 1997, Paul *et al*. 2015, Ranjan *et al*. 2016) and confirmed the identification of few plants consulting the herbarium specimens housed at Central National Herbarium (CAL), Howrah, India. The collected plant species have been preserved as herbarium specimen following standard herbarium techniques and kept in the Department of Botany, Krishna Chandra College, Hetampur, India for future references (Jain and Rao 1977). Updated botanical names of the documented plant specimens were provided according to a standard websites like Plants of the World Online (https://powo.science.kew.org/).

Quantitative tools for ethnomedicinal data analysis

Three quantitative indices have been employed here for analyzing the collected data on ethnoveterinary medicinal plants used by the *Santal* community of the study area. The indices used here are factor of informant consensus (F_{ic}), use mention factor (UM), and relative frequency of citation (RFC).

Factor of informant consensus (F_{ic})

Factor of informant consensus, an extensively popular quantitative ethnobotanical tool have been used globally to determine the consensus between the informants for the treatment of certain illness and it also helps to identify the most potential medicinal plant species used by the people of the study area (Heinrich *et al*. 1998). F_{ic} is expressed by the formula:

$$F_{ic} = \frac{\mathrm{Nur} - \mathrm{Nt}}{\mathrm{Nur} - 1}$$

where, Nur is the number of use-reports in each disease category, a use-report is a single record for use of a plant taxa mentioned by an informant, and Nt refers to the total number of plants used in each disease category. The value of F_{ic} ranges from 0 to 1. For F_{ic} analysis, similar type of health conditions and ailments are grouped into a particular 'disease category'. It gives a value for a certain group of ailments/diseases treated by a set of medicinal plants. The higher value indicates that very limited numbers of plants are used frequently in curing particular disease or ailment and the lower value indicates the disagreement regarding the use of variable phyto-remedies for a particular disease or ailment.

The use-mentions factor (UM)

The UM is defined as the number of mentions for one plant given by all of the informants for a specific health condition (Andrade-Cetto and Heinrich 2011).

Relative frequency of citation (RFC)

For each medicinal plant used to treat a particular ailment/disease, the frequency of citation is determined, and it is compared with all other medicines cited by all of the informants in the study through relative frequency of citation (RFC). Value of RFC provides additional information about the relative value of the informants' consensus for a particular medicine for a health condition (Kumar and Bharati 2013).

$$\text{Relative frequency of citation (RFC)} = \frac{\text{Frequency of citation}}{\Sigma\ \text{Frequency of citation for all plants}} \times 100$$

$$\text{Frequency of citation} = \frac{\text{Number of informants who cited the medicinal plants}}{\text{Total number of informants interviewed}} \times 100$$

Results and Discussion

Ethnomedicinal data

The investigated plant taxa spread over 62 species, 60 genera and 43 families of the flowering plants. Two of the reported plant families like *Convolvulaceae* and *Euphorbiaceae* were found represented by the highest number of species (4 species each), followed by the families *Amaranthaceae*, *Apocynaceae*, *Compositae* and *Leguminosae* (3 species each), then *Acanthaceae*, *Apiaceae*, *Sapotaceae*, *Vitaceae* and *Zingiberaceae* (2 species each), whereas rest of the 32 families were represented by only one species.

According to the plant habit, it has been observed that most of the recorded plants are herbaceous in nature (50%) which is followed by the trees (24.19%), climbers (19.35%) and shrubs (6.45%). The probable reason for using the herbs in highest number may be due to their abundant growth in the locality and easy accessibility (Albuquerque *et al*. 2005). Out of 62 recorded plant species, parts of 58 species were collected from wild, materials of 3 plants procured from local market and 1 plant from their cultivation. Dominance of wild herbaceous medicinal plants in most of the ethnobotanical studies has been evident from other parts of the state as well as the country (Phondani *et al*. 2010, Prakash *et al*. 2021, Mandal and Rahaman 2022).

The present study revealed that 59 types of ethnomedicinal preparations were used to cure 28 types of health conditions. All these recorded health conditions have been grouped into 12 disease categories. Among these disease categories four

disease categories were reported most of the times by the informants. The category of gastro-intestinal disorders was mentioned maximum numbers of time (39 times) by the informants, followed by the category of dysentery and diarrhea (35 times), reproductive organ disorders (35 times) and musculoskeletal disorders (34 times). The results here clearly indicated that incidence of all the health conditions grouped under these 4 disease categories is very common among the domesticated animals in the study area (Jas and Pandit 2017, Shit *et al*. 2017). *Santal* people of the study area have effective knowledge of herbal therapy which helps in combating all those diseases and ailments.

From the present investigation it has been evident that the *Santal* people of the studied area use different plant parts like leaf, bark, whole plant, fruit, stem, seed, latex, root and other underground parts in the preparation of 59 types of phyto-remedies for livestock health care. Among the plant parts, the root and other underground parts were used in highest percentage (30%) followed by leaf (17%), bark (13%), whole plant (13%), etc. (Fig. 2). The underground parts of the plants are known as one of the major sites where many of the bioactive compounds are synthesized and / or accumulated (Signs and Flores 1990) which highlights their inherent knowledge of effective plant parts used for its medicinal purposes.

Some ingredients like particulated rice, rice bran, rice gruel, molasses, coconut oil, mustard cake, common salt, soil collected from the mouth of crab hole, paddy straw and bamboo sticks were used during remedy preparation and/or its application.

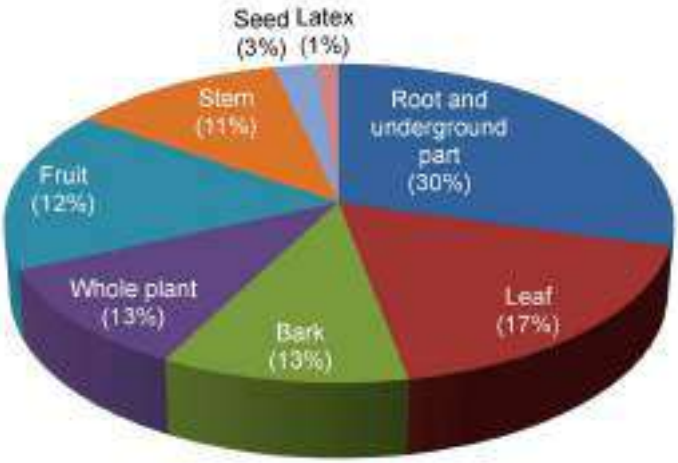

Figure 2. Percentage proportion of plant parts used in the preparation of ethnoveterinary medicine

Regarding mode of administration, the most common route of remedy application is oral (69.49%) and remedies are administered in the forms of fresh juice, paste, infusion, water emulsion, etc. In 30.51% cases, remedies were administered topically in the form of poultice, eye drop and as surface disinfectant (Fig. 3).

Examining pertinent literature on ethnoveterinary medicine indicates that most of the reported taxa's uses are quite similar to how *Santals* of Purba and Paschim Bardhaman's neighbouring areas prescribe medicinal plants for livestock diseases (Ghosh 2002, Dey and De 2010, Mandal and Rahaman 2016).

Quantitative analysis

The collected ethnomedicinal data of each plant species have been statistically analyzed with the help of use-mentions factor (UM) and relative frequency of citation (RFC) to figure out the range of importance of a medicinal species for a particular health condition (Table 1). All the diseases and health conditions documented here have been grouped into 12 disease categories and their F_{ic} scores have been determined (Table 2).

The present study reveals that the F_{ic} value of different disease categories varies from 0.6 to 0.94 which indicates high level of consensus among the informants regarding the usages of ethnoveterinary medicinal plants. Dysentery and diarrhea, retention of milk, poisonous animal bite, fever and related problems, these four disease categories show higher F_{ic} value which ranges from 0.85 to 0.94. High level of consensus regarding a plant used in the treatment of a disease or disease

category highlights the cultural importance of that ethno-species which is consistently associated with the tribal people's culture in the area.

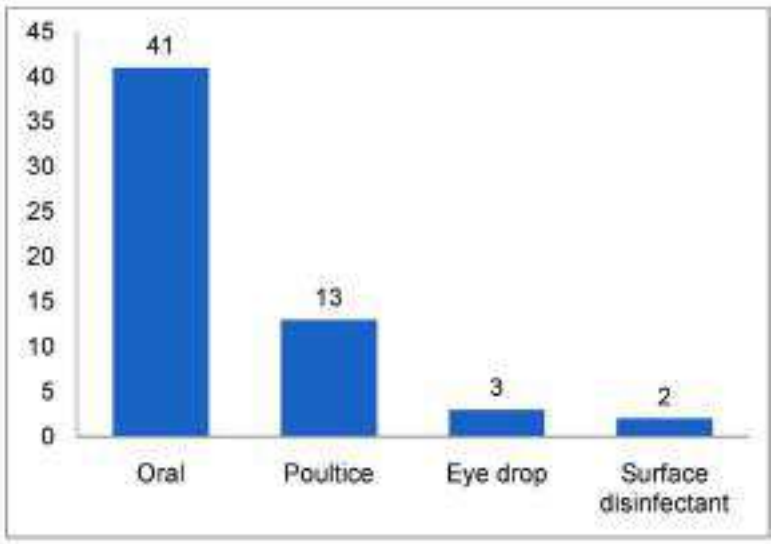

Figure 3. Modes of administration of remedies and its number of mentions

Value of RFC for all the 62 recorded species varies from 0.79 - 8.7. In case of plants with multipurpose uses, RFC value of the species has been calculated for each separate use considering it as an individual event. Eight plant species, namely *Achyranthes aspera* L., *Pueraria tuberosa* (Willd.) DC., *Aristolochia indica* L., *Strychnos nux-vomica* L., *Amaranthus spinosus* L., *Rivea hypocrateriformis* Choisy, *Soymida febrifuga* (Roxb.) A. Juss., *Bryophyllum pinnatum* (Lam.) Oken. having RFC value greater than three (>3) indicates their popularity as a frequently cited species in the studied area. In the contrary, there is a most possible chance of their overharvesting which may be one of the causes that some of the plants like *Strychnos nux-vomica, Soymida febrifuga, Aristolochia indica* gradually become rare in the study area but still local people are very familiar with their usefulness.

Value of use mention factor (UM) varies from 2 to 22. The highest value assigned to the plant *Achyranthes aspera* L. (UM=22) followed by *Pueraria tuberosa* (Willd.) DC. (UM=13), *Aristolochia indica* L. (UM=11) and *Strychnos nux-vomica* L. (UM=11) which indicate their wide acceptance regarding disease curing ability. So, the plants which are cited frequently having maximum RFC value and greater use mentions can be considered as potent candidate for pharmacological investigations (Heinrich 2000, Miller 2011). So, all these 8 ethnoveterinary medicinal plants with higher RFC and UM value can be considered as culturally valuable and promising medicinal plants in the studied area, side by side an attempt should be prioritized for their local level conservation.

It has been also found that the change in the score of RFC is proportionally related to the value of UM i.e., there is a linear correlation between them (Fig. 4). For example- for the treatment of fever of domesticated animals, *Achyranthes aspera* L. has been mentioned maximum numbers of times (UM- 22) by the informants and thus produce highest RFC value of 8.7 among all the documented taxa. Similarly for the treatment of corneal opacity, leaf juice of *Careya arborea* Roxb. as eye drop has been recorded only 2 times (UM=2) and very minimum value of RFC has been calculated for that species (RFC=0.79).

Throughout the survey few plants have been mentioned only once or twice. We have considered those plants which were cited at least twice. It is a matter of concern that few commonly growing medicinal herbs got very low (UM=2) use mention, such as *Blumea lacera* (Burm.f.) DC., *Colocasia antiquorum* Schott, *Datura stramonium* L., *Portulaca oleracea* L., *Senna occidentalis* (L.) Link, and *Xanthium strumarium* L. On the other hand plants like *Argyreia nervosa* (Burm. f.) Bojer, *Careya arborea* Roxb., *Curculigo orchioides* Gaertn., *Dillenia pentagyna* Roxb., *Echinops echinatus* Roxb., *Ipomoea obscura* (Linn.) Ker.-Gowl., *Jatropha nana* Dalzell & A. Gibson, *Manilkara hexandra* (Roxb.) Dubard, *Nerium oleander* L., and *Phoenix acaulis* Roxb. which are becoming rare in the studied area also having very low (UM=2) use mention (Fig. 5). In both the cases, sustenance of the ethnoveterinary medicinal knowledge in the *Santal* community directed towards its gradual extinction. The fact can be crosschecked by executing more extensive field studies on ethnoveterinary medicinal knowledge of the studied area.

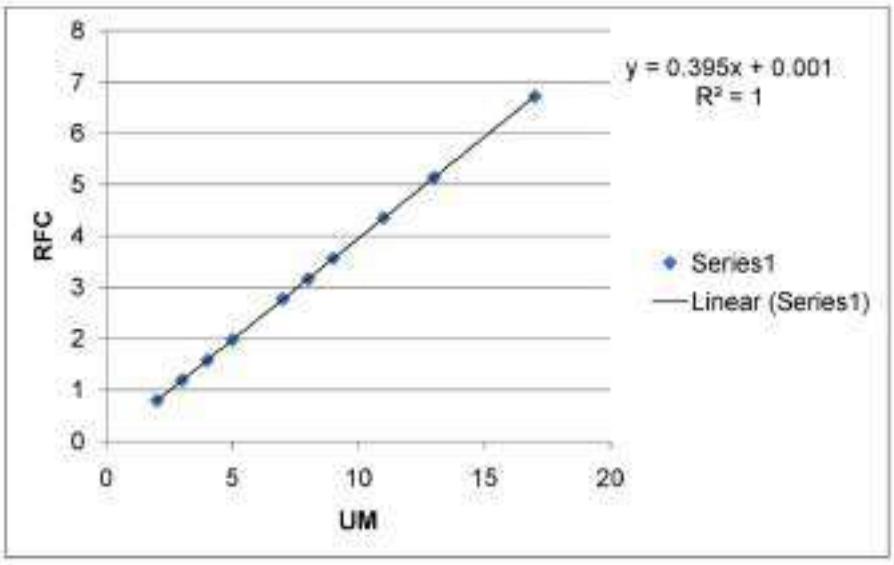

Figure 4. Linear correlation between Relative Frequency of Citation (RFC) and Use Mention factor (UM)

Conclusion

From the present study it can be concluded that identification of efficacious plant is equivalent to the identification of promising source of effective bioactive agents. Plants like *Achyranthes aspera* L., *Pueraria tuberosa* (Willd.) DC., *Aristolochia indica* L., *Strychnosnux-vomica* L., *Amaranthus spinosus* L., *Rivea hypocrateriformis* Choisy, *Soymida febrifuga* (Roxb.) A. Juss., *Bryophyllum pinnatum* (Lam.) Oken. showed very good efficacy against a wide range of diseases occurred among the domesticated animals in the studied area. Most of these reported plant species are used in different traditional systems of medicine and also by various ethnic communities throughout the world. Some of them have already been established by the researchers as good source of bioactive agents; further research may lead towards identification of new bioactive compounds and drug development.

The present study witnessed that the traditional herbal knowledge regarding domesticated animal's health care still exists in the *Santal* community of that region but to some extent in a fragile form. The preservation of this traditional knowledge and its accompanying ethno-flora is a major priority for us right now. The first step should be to raise awareness of herbal knowledge and associated plant resources among the district's indigenous youth. Simultaneously, to improve the knowledge base, the homogeneity of ethnoveterinary medicinal knowledge should be maintained by establishing an oblique knowledge transmission network through recurring group discussions, workshops, and seminars that include community members of all ages. Furthermore, sustainable utilization of local flora should be promoted. As the majority of traditional knowledge is linked to local biodiversity, if the local flora is preserved, the accompanying traditional knowledge will be preserved as well.

Table 1. Enumeration of the recorded ethnoveterinary medicinal plants with their respective quantitative analyses (UM- use-mentions factor; FC- frequency of citation and RFC- relative frequency of citation)

Tribal/local name, botanical name, family and voucher no.	**Parts used**	**Diseases/ailments cured, mode of remedy preparation and its administration**	**Treated animal**	**UM**	**FC**	**RFC**
"Chir-chiti/ Sitakanta" *Achyranthes aspera* L. [Amaranthaceae] SS-19	Root	(i) Fever- root paste+ black pepper; oral; twice/day; 5-7 days. (ii) Liver trouble- root paste; oral; once/day; 3 days	Bullock, Goat and calf	22	38.59	8.7
"Lupani-ara" *Aerva lanata* (L.) Juss. [Amaranthaceae] SS-23	Whole plant	Gastric ulcer, liver trouble, stomachache- whole Plant paste+ turmeric+ black cumin; oral; twice/day; 7 days	Cow, buffalo, goat, sheep	3	5.26	1.19

"Jenum-leper-ara" *Amaranthus spinosus* L. [Amaranthaceae] SS-7	Whole plant	Retention of milk- boiled plant+ particulate rice; oral; once/day; 15-20 days	Cow	9	15.79	3.56
"Ijer/Angur-lata" *Ampelocissus latifolia* (Roxb.) Planch. [Vitaceae] *SS-17*	Root	Snake bite- root paste; oral; twice/day; 3 days	All ruminants	4	7.02	1.58
"Kaalmegh/ Bhuin-nim" *Andrographis paniculata* (Burm.f.) Nees [Acanthaceae] SKM-54	Aerial part	Foot and mouth disease- dried aerial part paste+ fresh turmeric+ molasses; oral; once/day; 7 days	Large ruminants	4	7.02	1.58
"Panespu/ Marang-haru" *Argyreia nervosa* (Burm. f.) Bojer [Convolvulaceae] SS-29	Leaf	Safe delivery- fresh leaves (9-11 in nos.); oral; once/day; 15 days (before the estimated time of parturition)	Cow and buffalo	2	3.51	0.79
"Gond/ Ishwarmul" *Aristolochia indica* L. [Aristolochiaceae] SS-13	Root	Snake bite- root paste+ black pepper (21 grains); oral; twice/day (after an interval of 8 hours); 3 days	All types of ruminants	11	19.29	4.35
"Dant-rese/ Kanta-jhanti" *Barleria prionitis* L. [Acanthaceae] SKM-11	Shoot	Post partum debility- plant paste+ black pepper (21 grain); oral; twice/day; one month.	Cow	3	5.26	1.19
"Kukshime" *Blumea lacera* (Burm.f.) DC. [Compositae] SS-15	Leaf	Retention of placenta- leaf juice; oral; twice/day; 3 days	Cow	2	3.51	0.79
"Kichu-ara" *Boerhavia diffusa* L. [Nyctaginaceae] SS-25	Stem	Post parturition bleeding- stem paste+ black pepper (9-11 grains); oral; once/day; 3 days	Cow and buffalo	5	8.77	1.98
"Patharkuchi" *Bryophyllum pinnatum* (Lam.) Oken [Syn. *Kalanchoe pinnata* (Lam.) Pers.] [Crassulaceae] SS-5	Leaf	Retention of urine- leaf paste; poultice on the lower abdomen; once a day for 3 days	Goat and sheep	8	14.04	3.16
"Akan" *Calotropis procera* (Aiton) Dryand. [Apocynaceae] SS-35	Bark	Swelling- bark paste+ leaves of *Jatropha curcas* L. + fresh turmeric; poultice; once/day; 5-7 days	All types of ruminant	5	8.77	1.98
"Laiputki" *Cardiospermum halicacabum* L. [Sapindaceae] SKM-72	Root	Dysentery- root paste as water emulsion; oral; once/day; 3 days	young ruminant	7	12.28	2.77
"Kumbhi-dari" *Careya arborea* Roxb. [Lecythidaceae] SKM-118	Leaf	Corneal opacity- leaf juice; eye drop (2-3 drops); till the cure	Sheep	2	3.51	0.79

"Hanrumala" *Cascuta reflexa* Roxb. [Cascutaceae] SKM-19	Whole plant	Food poisoning- plant paste (250 gm); water emulsion; oral; once	Large ruminant	3	5.26	1.19
"Chorchi-dari" *Casearia tomentosa* Roxb. [Salicaceae] SKM-157	Bark	Dysentery- bark extract; oral; once/day; 3 days	Small ruminants	3	5.26	1.19
"Har-jora" *Cissus quadrangularis* L. [Vitaceae] SS-76	Stem	Helminthiasis- stem paste+ black pepper (9 grains); oral; once/day in morning; 5-7 days	Bullock, buffalo	3	5.26	1.19
"Kiduri" *Coccinia grandis* (L.) Voigt [Cucurbitaceae] SS-48	Leaf	Whitening of eyes and watering of eyes- leaf juice; eye drop; once/day; 3 days	Cow, bullock, buffalo	5	8.77	1.98
"Jalerkachu" *Colocasia antiquorum* Schott [Araceae] SKM-81	Corm	Tumor/swelling- corm paste+ table salt; poultice; once/day; 5-7 days	Buffalo, bullock	2	3.51	0.79
"Bon-piyaz" *Crinum asiaticum* L. [Amaryllidaceae] SKM-93	Bulb	Swelling warts- tuber paste; poultice; twice/day, 3 days	All types of ruminants	3	5.26	1.19
"Tos-kati" *Croton persimili*s Müll. Arg. (Syn. *Croton oblongifolius* Roxb.) [Euphorbiaceae] SKM-127	Root	Galactagague- root paste; oral; once/day in evening; 15-20 days	Cow	3	5.26	1.19
"Tal-muli" *Curculigo orchioides* Gaertn. [Hypoxidaceae] SKM-133	Root	Foot and mouth disease- dried root powder+ rice bran; oral; once/day; 5-7 days	Cows, bullock, buffalo	2	3.51	0.79
"Bon-haldi" *Curcuma aromatica* Salisb. [Zingiberaceae] SKM-139	Rhizome	Food poisoning- rhizome paste+ black pepper (9-21 grains); oral; twice/day; 2 days	Cow, bullock, buffalo	5	8.77	1.98
"Dhutro" *Datura stramonium* L. [Solanaceae] SS-69	Root	Watering of eyes- root paste+ roots of *Chrysopogon zizanioides* (L.) Roberty ("Bena") and *Cyperus rotundus* L. ("Mutho"); oral; once/day; 3 days	Bullock and buffalo	2	3.51	0.79
"Sim" *Dendrophthoe falcata* (L.f.) Ettingsh. [Loranthaceae] SS-91	Leaf	Prolapsed uterus- leaf extract; surface disinfectant; oozed out uterus is washed immediately and then replacement is done	Cow	3	5.26	1.19
"Sarha-dari" *Dillenia pentagyna* Roxb. [Dilleniaceae] SKM-17	Bark and leaf	(i)Helminthiasis- bark powder; oral; once/day (night); 7 days (ii) Gastrointestinal problems- leaves paste (5-6 pieces)+ black pepper (11 grains); oral; once/day; 3 days	Small and large ruminant	4	7.02	1.58

"Panshunt/ Marang-konga" *Dregea volubilis* (L.f.) Benth. exHook.f. [Syn. *Wattakaka volubilis* (L. f.) Stapf.] [Apocynaceae] SKM-51	Stem and leaf	(i) Liver trouble- stem paste+ ajwain; oral; once/day; 5 days (ii) Tumours- leaves paste+ table salt; lukewarm poultice; twice/day; 3 days (iii) Unusual urination- fresh stems are boiled with particulated rice ("Jewli"); oral; once/day; 7 days. (iv) Mastitis- leaf paste (4-5 pieces)+ fresh turmeric; poultice; once a day till the cure	Cow, bullock, milching buffalo, small ruminant	12	21.05	4.75
"Tandi-jenum" *Echinops echinatus* Roxb. [Compositae] SS-72	Tender shoot	Infertility- finely grounded tender twigs; oral; once/day (fed along with paddy straw after the onset of normal heat period)	Barren cow	2	3.51	0.79
"Teshira/ Etke" *Euphorbia antiquorum* L. [Euphorbiaceae] SKM-66	Latex	Whitening of eyes- fresh latex; eye drop; 2 drops are applied once in the first morning till cure	Bullock	3	5.26	1.19
"Ratin" *Glochidion multiloculare* (Rottler ex Willd.) Voigt [Phyllanthaceae] SKM-11	Bark	Stiffness of shoulder- bark paste+ bark of *Madhuca longifolia*; poultice; thrice/day; 3-4 days	Bullock and buffalo	3	5.26	1.19
"Siming-sam-ara" *Gloriosa superba* L. [Colchicaceae] SS-91	Tuber	Prolapsed uterus- tuber extract; applied externally as surface disinfectant; once	Cow	4	7.02	1.58
"Vacha-ara" *Ipomoea obscura* (Linn.) Ker.-Gowl. [Convolvulaceae] SS-59	Leaf	Broken horn- leaf paste+ coconut oil; lukewarm poultice; once/day; 5-6 days (lukewarm paste is applied at the base of the broken area and tightly wrapped with cloth)	Bullock	2	3.51	0.79
"Bir-eradom" *Jatropha nana* Dalzell & A. Gibson [Euphorbiaceae] SS-149	Tuber	Retention of milk- dried root powder; oral; once/day; 10-15 days (fed along with finely grounded mustard cake)	Cow	2	3.51	0.79
"Baghlaal/Ponjo" *Litsea glutinosa* (Lour.) C.B.Rob. [Lauraceae] SS-109	Bark	Dislocation of joints- bark paste; poultice; once (bark paste is applied on the affected area and tied with bamboo stick)	Cattle	5	8.77	1.98
"Khir-kul" *Manilkara hexandra* (Roxb.) Dubard [Sapotaceae] SKM-133	Bark	Tonsillitis- bark paste+ mud of crab hole; lukewarm poultice; twice/day; till the cure (applied on the outer side of lower jaws)	Cow, bullock	2	3.51	0.79
"Jamjuri ara" *Merremia tridentata* (L.) Hallier f. [Convolvulaceae] SKM-70	Whole plant	Stomachache- plant paste+ black pepper (21 grains); water emulsion; oral; once/day (morning); 3 days	Goat and sheep	3	5.26	1.19

"Bishalyakarabi/ Kanaili" *Nerium oleander* L. [Syn. *Nerium indicum* Mill. (Apocynaceae)] SS-136	Leaf	Mastitis- leaf paste; poultice; twice/day; till the cure	Cow	2	3.51	0.79
"Bir-khejuri" *Phoenix acaulis* Roxb. [Arecaceae] SKM-194	Leaf and root	(i) Retention of milk- finely chopped fresh tender leaves; oral; once/day; 10-15 days (ii) Safe delivery- soft root paste+ rice gruel; oral; once a day	Cow, buffalo	7	12.28	2.77
"Bhuin-okra" *Phyla nodiflora* (L.) Greene [Verbenaceae] SS-111	Whole plant	Dyspepsia- finely chopped fresh plants; oral; once/day; 15-20 days (fed along with any cattle feed)	Calf	3	5.26	1.19
"Nuni-ara" *Portulaca oleracea* L. [Portulacaceae] SS-89	Whole plant	Mastitis- plant paste; oral; once a day for 7 days	Goat, sheep	2	3.51	0.79
"Bhuinkumro/ Patalkondha" *Pueraria tuberosa* (Willd.) DC. [Leguminosae] SKM-169	Tuber	Retention of milk- sliced pieces of tuber (fresh or dried form); oral; once/day (morning); 3 days (fed along with rice gruel).	Cow	13	22.81	5.14
"Bon-pui" *Rivea hypocrateriformis* Choisy [Convolvulaceae] SKM-160	Aerial part	Fractured bone- plant paste+ table salt; poultice; once (paste is applied on the affected area and wrapped tightly with bamboo sticks)	Cow, bullock, buffalo	9	15.79	3.56
"Berela" *Scoparia dulcis* L. [Plantaginaceae] SKM-158	Whole plant	Retention of placenta- plant paste (two or three plants)+ tender shoot of *Ziziphus jujube* Mill., + ajwain + turmeric; water emulsion; oral; once/day (morning); 3 days	Cow, buffalo	3	5.26	1.19
"Bhela" *Semecarpus anacardium* L.f. [Anacardiaceae] SS-144	Seed	Liver disorder- mature seeds (2-3 pieces); oral; once/week	Bullock	4	7.02	1.58
"Veradiring" *Senna occidentalis* (L.) Link [Leguminosae] SS-138	Root	Diarrhoea- root paste+ black pepper (9 grains); water emulsion; oral; once/day; 5-7 days	Sheep	2	3.51	0.79
"Bon-jowan" *Seseli diffusum* (Roxb. ex Sm.) Santapau &Wagh [Apiaceae] SKM-165	Whole plant	Drop wise continuous urination- freshly collected plant; oral; once/day; till the cure	Goat, sheep	3	5.26	1.19
"Raj-pan / Ram-pan" *Smilax ovalifolia* Roxb. ex D.Don [Smilacaceae] SS-141	Root	Blood dysentery- root paste+ black pepper (11 grains); oral; once/day; 3 days	Cow, bullock, buffalo, goat, sheep	7	12.28	2.77

"Rahet- rahim / Rohin" *Soymida febrifuga* (Roxb.) A. Juss. [Meliaceae] SKM-172	Bark	Post partum debility- dried bark of *S. febrifuga* + dried plants of *Cocculus hirsutus* (L.) W.Theob.; infusion; oral; once/day; 15 days	Cow	9	15.79	3.56
"Kuchila" *Strychnos nux-vomica* L. [Loganiaceae] SKM-77	Bark	Dysentery- stem bark paste with+ table salt; water emulsion; oral; once/day; till the cure	Cow, bullock, buffalo	11	19.29	4.35
"Tentul / Jojo" *Tamarindus indica* L. [Leguminosae]	Fruit	Food poisoning- fruit pulp mixed in water; oral; once as soon as possible	Cow, bullock, buffalo	5	8.77	1.98
"Gokhur" *Tribulus terrestris* L. [Zygophyllaceae] SKM-45	Leaf	Colic pain- fresh leaves; oral; twice/day; 3 days	Sheep	3	5.26	1.19
"Okra" *Xanthium strumarium* L. [Compositae] SS-44	Leaf	Retention of urine- leaf paste+ table salt; poultice; once/day; 5-7 days (applied on the lower abdomen)	Cattle	2	3.51	0.79
"Jenum-dari" *Ziziphus jujube* Mill. [Rhamnaceae] SS-13	Tender shoot	Diarrhoea- shoot paste+ black pepper (9–21 grains); water emulsion; oral; twice/day; 3 days	Cattle	5	8.77	1.98

Table 2. Factor of informant consensus (F_{ic}) value for the recorded disease categories

Disease categories	**Number of plant taxa used (Nt)**	**Number of use reports (Nur)**	**F_{ic}**
Fever and related problems	02	19	0.94
Poisonous animal bite	02	15	0.93
Retention of milk	05	32	0.87
Dysentery & diarrhea	06	35	0.85
Foot and mouth disease	02	06	0.8
Musculoskeletal disorders	08	34	0.79
Urinary disorders	04	15	0.79
Helminthiasis	02	05	0.75
Gastro-intestinal disorders	11	39	0.74
Reproductive organ disorders	10	35	0.74
Diseases of sensory organ	04	12	0.73
Mastitis	03	06	0.6

Declarations

Ethical approval: The present study was carried out in accordance with the terms of the convention on biological diversity's Nagoya protocol on access to genetic resources and the fair and equitable sharing of benefits resulting from their utilization.

Participants' consent: Before interviewing a verbal consent was taken each time from the participating individuals.

Data availability: All the data curetted during the study presented in the article and there is no supplementary data.

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Data and materials accessibility: The raw data without disclosing the names of informants can be provided by the corresponding author.

Author's contributions: SS and SKM conceptualized and designed the research, collected and analyzed the data, wrote the manuscript and agreed to submit it.

Conflict of interests: We have no competing or conflict of interest.

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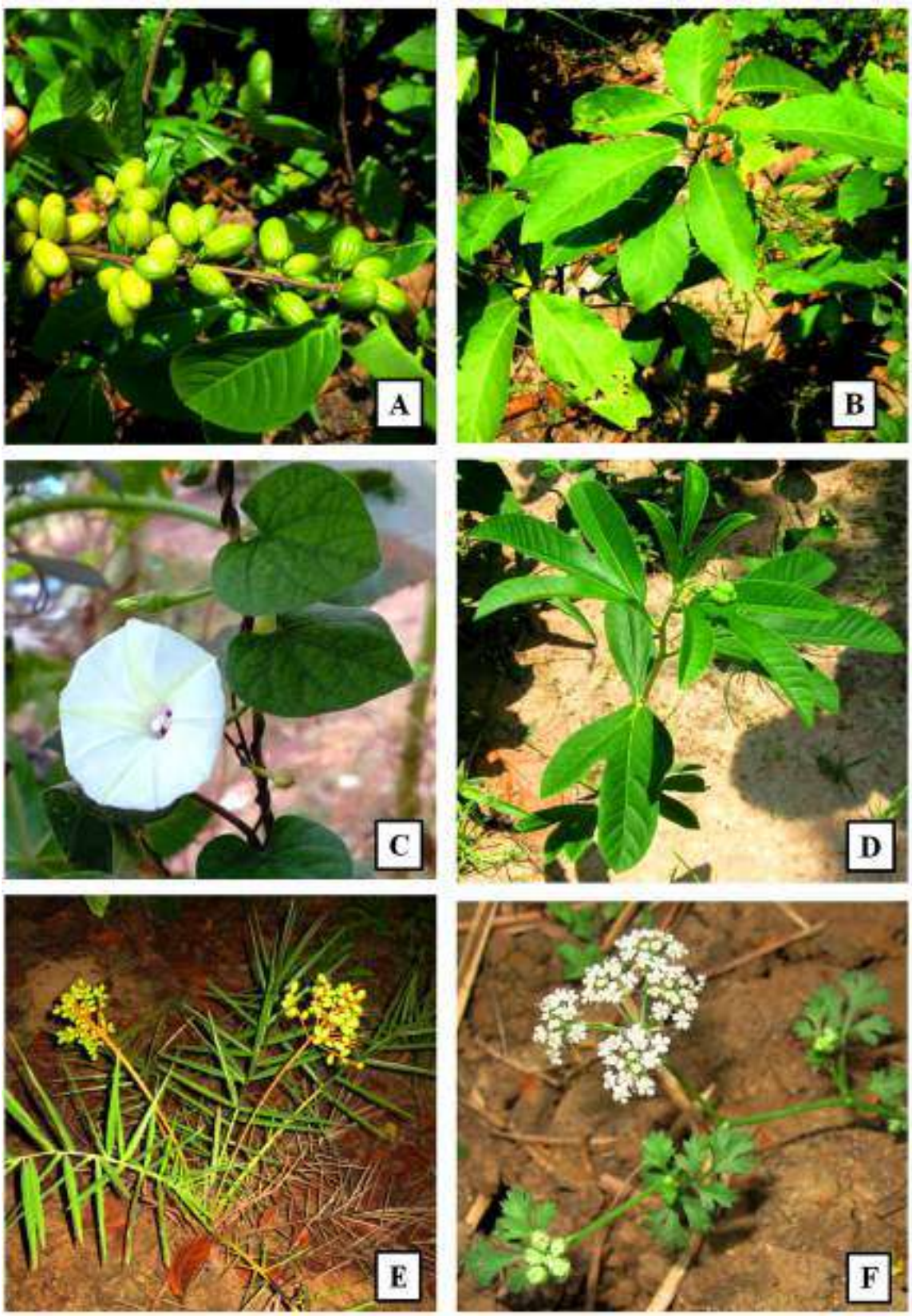

Figure 5. Photographs of some less known ethnoveterinary medicinal plants of Purba and Paschim Bardhaman districts (**A.** *Casearia tomentosa* Roxb., **B.** *Croton persimilis* Müll. Arg., **C.** *Ipomoea obscura* (L.) Ker.-Gowl., **D.** *Jatropha nana* Dalzell & A.Gibson **E.** *Phoenix acaulis* Roxb. and **F.** *Seseli diffusum* (Roxb. ex Sm.) Santapau &Wagh

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The importance of wild edible plant and macrofungi diversity to attain food security for the tribes of eastern India—a quantitative study

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Background: Inventorization and promotion of traditionally used local flora can be a better option to gain a wide range of alternative edible resources and multiple nutritional benefits. A perusal of literature highlighted the poor nutritional status of the tribal community living in eastern India and pointed out the potential lack of information regarding locally available wild edible resources.

Objective: Present study aimed to document detailed information on wild edibles of eastern India, evaluate their cultural significance, and understand their role in achieving food security for the local tribes.

Materials and methodology: Traditional knowledge of wild edibles was collected using a semi-structured questionnaire. Standard protocols were followed for collecting data. The collected data were analyzed using specific statistical tools like Relative frequency of citation (RFC), and Cultural food significance index (CFSI) to identify the most cited and culturally significant species. Jaccard similarity index (JI) was used to check the similarity of food plant use in different localities and adjoining areas of the laterite region in eastern India.

Results: A total of 2,603 citations were made by the 153 participants for 83 types of wild edibles spread across 48 families. Among the 83 species, 65 species were angiosperms, three species were pteridophytes and the rest 15 were from fungal groups. The RFC value ranged from 0.04 to 0.76, and *Madhuca longifolia* (L.) J.F.Macbr. was identified as the most frequently cited species (FC = 116; RFC = 0.76). The Cultural food significance index (CFSI) value varied from 0.2 to 844, and thirteen wild edibles like *Colocasia esculenta* (L.) Schott, *Enydra fluctuans* Lour., *Marsilea vestita* Hook. & Grev., *Termitomyces heimii* Natarajan, etc. were identified as culturally most important in the locality.

Conclusion: Present study concludes that the local flora and macrofungi diversity is a treasure trove for fulfilling human hunger and gaining enough nutritional benefit. Scientific and sustainable utilization of these wild edibles can be a wise step to attain multiple health benefits and food security for the tribal community of eastern India. Moreover, culturally accepted species can be opted as a good source for bioprospecting nutraceuticals.

KEYWORDS

wild edibles, ethnogastronomy, relative frequency of citation (RFC), cultural food significance index (CFSI), food security, *Santal* tribe, eastern India

Introduction

In the twenty-first century world, approximately 870 million individuals are anticipated to lack desired calories, and additional two billion individuals are micronutrient deficient (FAO, 2009). Such an undesirable phenomenon is very much linked to the fact that we have nearly 20,000 edible plant species, yet only a few (~20 species) supply 90% of our food today. Monotonous diets lacking in food diversity and proper diet planning resulted in malnourished conditions, which is regarded as one of the top 10 risk factors contributing to the burden of chronic health issues worldwide (GBD 2019 Risk Factors Collaborators, 2020). This challenge can be overcome by a food-based strategy incorporating wild edibles into daily diets (Chadha and Oluoch, 2003). Wild edible plants grow in the wild or semi-wild areas and are not domesticated, cultivated, or consumed as a regular food (Tardío et al., 2006). The contribution of wild edible plants to man's food heritage is as old as human civilization itself (Flyman and Afolayan, 2006). They are not only the store house of a wide range of essential nutrients (Duguma, 2020; Åhlberg, 2021; Mishra et al., 2021) but also the crucial source of genetic diversity for breeding and improving today's domesticated crops (Bharucha and Pretty, 2010; Ulian et al., 2020).

The World is now witnessing rapid changes in socio-economic and environmental conditions as well as rapid loss of biodiversity globally, which reduces the possibilities for finding new food and crop genetic resources. Realizing such alarming facts, scientists from every corner of the world have started documenting local food heritage and associated biodiversity components (Cruz-Garcia and Price, 2011; Ahmad and Pieroni, 2016; Garekae and Shackleton, 2020; Opazo-Navarrete et al., 2021; Cheng et al., 2022; Khalid et al., 2023). Many researchers have enlisted several emergency food consumed during famine, war, pandemic, or prolonged natural disasters (Reyes-García, et al., 2015; Zhang et al., 2016; Bhushi, 2021). Apart from the plant groups, wild edible fungi and animal resources have also been documented from different parts of the world (Christensen et al., 2008; Redžić et al., 2010; Łuczaj and Nieroda, 2011; Alves et al., 2013; Guyu and Muluneh, 2015; Adi et al., 2020; Łuczaj et al., 2021). Since last two decades researches on wild edibles have gained momentum in the Asian continent also. Series of articles have been published from different parts of Southeast Asia (Erskine et al., 2015; Sujarwo et al., 2016; Bernadas and Peralta, 2017; Ong and Kim, 2017; Shin et al., 2018; Pawera et al., 2020; Punchay et al., 2020; Seav et al., 2021; Tharmabalan, 2023) and South Asia, particularly from China (Kang et al., 2013; Sachula et al., 2020; Cheng et al., 2022, 2023), Pakistan (Ahmad and Pieroni, 2016; Ijaz et al., 2022; Khalid et al., 2023), and India (Mallick et al., 2020; Harisha et al., 2021; Angmo et al., 2022).

India is a land of diversified topography, climate, and ecology, providing a strong foundation for its wide range of phytodiversity. This rich phytodiversity has historically played a significant role in the religious, cultural, social and health spheres of Indians' rural and ethnic lives. To explore such domain of interrelationship between man and nature across India, scientists have prioritized the documentation of medicinally important plants over the edible ones. But later, realizing the importance of conserving the local food heritage and knowledge associated with the local biodiversity, Indian scholars have also engaged themselves in this domain of food science, and ample numbers of articles on ethnobotany of wild edible food plants and their nutritional contribution have been reported so far (Singh and Singh, 2007; Vishwakarma and Dubey, 2011; Misra et al., 2013; Kumar and Shiddamallayya, 2021; Talang et al., 2023).

In the state of West Bengal, perusal of literature published in last two decades indicates an opposite scenario which results in scanty and diffuse research on wild edibles (Chowdhury and Mukherjee, 2012; Majumder and Mukherjee, 2015; Panda, 2015; Chakraborty, 2017; Ghosh et al., 2020). Laterite region of West Bengal is uniquely characterized by its topography, biodiversity and ethnicity. This region extends over five districts like Bankura, Medinipur, Purulia, Burdwan and Birbhum. Till date a few works have been carried out from this region except Birbhum district where no ethnogastronomic exploration ever conducted before (Banerjee et al., 2013; Dey and Mukherjee, 2015; Bouri and Ganguly, 2016; Banerjee, 2018; Chatterjee et al., 2022). All these works are based on simple enumeration of collected data without any quantitative analysis. Use of quantitative ethnobotanical tools for analyzing collected data is becoming very much crucial now a day to add more objectivity to this field of research (Leonti et al., 2002; Hoffman and Gallaher, 2007; Rahaman, 2017). Perusal of literature revealed that a large portion of the tribal community including *Santals* living in the laterite region of West Bengal uses wild edibles in their daily diet (Bandyopadhyay and Mukherjee, 2009; Roy et al., 2015) but still suffer from malnutrition mainly due to lack of optimum amount of food intake and other socio-cultural limitations (Bisai, 2014; Stiller et al., 2020; Chandra et al., 2021). On the other hand, with ongoing anthropogenic activity in the forest, shifting cultivation, reliance on the limited number of high-yielding crop varieties, climate change, and changes in socio-economic conditions of the ethnic people, the traditional societies are silently losing their traditional food heritage along with the related phyto-resources (Łuczaj et al., 2012; Downs et al., 2020; Ghosh-Jerath et al., 2021). Long-term inattention towards such a treasure trove of wild edibles raises the risk of overlooking the provisioning of biodiversity and supportive local knowledge systems that may make these food resources fade away from the society in near future. So there is an urgent need to document persisting knowledge on wild edibles available in the laterite region of west Bengal.

In this context, present work is aimed to document detailed information on wild edibles available in the laterite region of West Bengal, determine the importance of local flora to attain the food security of the local tribes and identify culturally significant wild edible species using quantitative data analysis techniques.

Materials and methods

Study area

For the present study, we have focused mainly on the district Birbhum, the land of varied topography, dry deciduous *Saal* forest, and diverse tribal groups resides in remote villages as well as urban and semi-urban areas of this district. The study area is located in between 23°32′30″ and 24°35′00″ North latitudes and 87°5′25″ and 88°1′40″ East longitudes, and occupies an area of 4,545 sq. km (Figure 1). In Birbhum, 15,927 hectares of land is covered by forest; out of which 2,849 hectares of land is under the reserved forest areas, 6,242 hectares is protected forest areas and 6,835 hectares of land is unclassified state forest land. Some of the main forests in the district are Ballavpur forest, Gonpur forest, Chaupahari forest, Chorchor

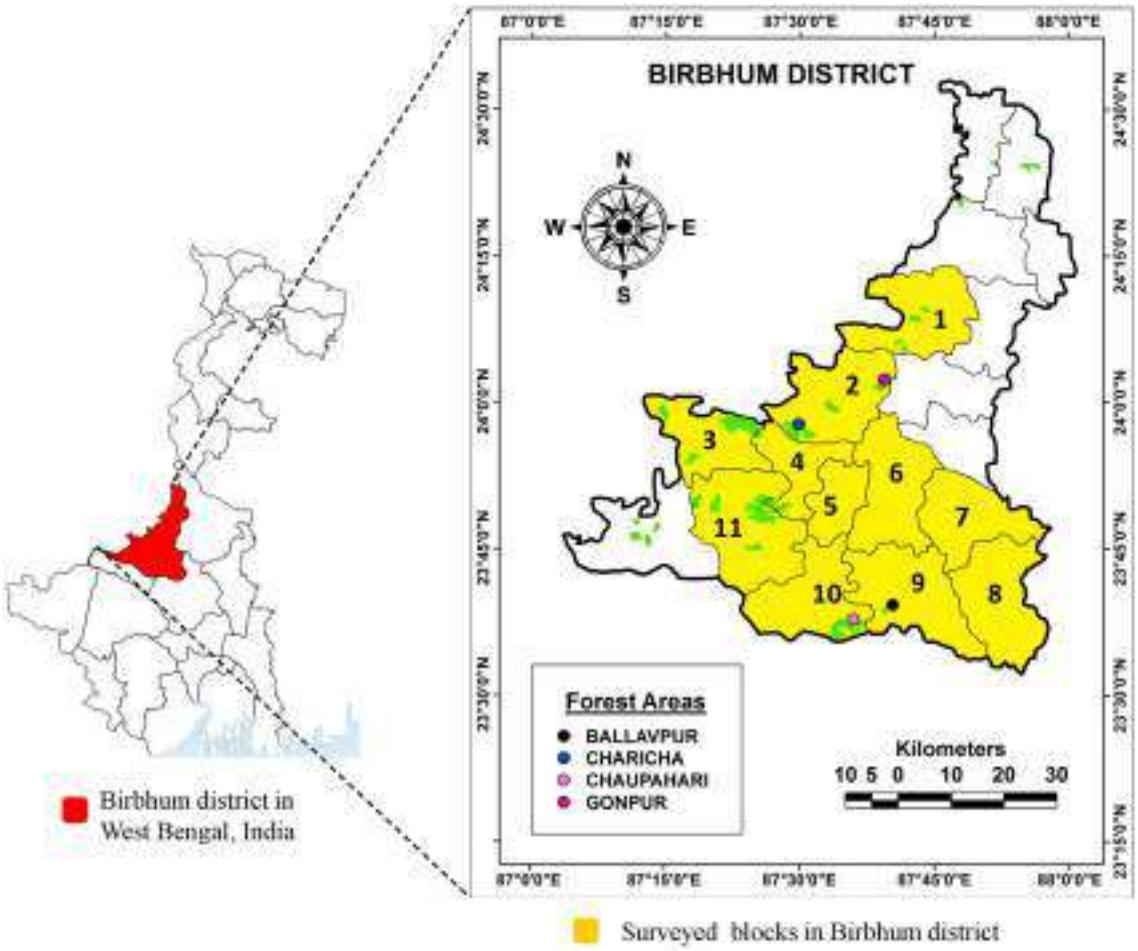

FIGURE 1
Study area showing 11 surveyed blocks (1. Rampurhat-I, 2. Mohammad Bazar, 3. Rajnagar, 4. Suri-I, 5. Suri-II, 6. Sainthia, 7. Labpur, 8. Nanoor, 9. Bolpur-Sriniketan, 10. Illambazar, and 11. Dubrajpur) and four major forest areas in Birbhum district.

forest, forest of Chinpai and Bhandibon. All these natural forests are rich in varieties of medicinal and edible species of diverse plant groups which are gathered mainly by the tribal people for partial fulfillment of their daily diet and primary healthcare needs. Apart from the *Santals*, ethnic communities like *Konra, Mahali, Sardar, Dhangar*, etc. also reside here (Mandal and Rahaman, 2022).

Santals' ethnicity, socio-economic status, food heritage, and health burden

The *Santals* are the third largest ethnic group in India having unique cultural heritage. They are the descendants of pre-Dravidian people who migrated to eastern India nearly three centuries ago (Sarkar and Singha, 2019). Greater portion of the *Santal* reside in the Indian states namely West Bengal, Odisha, Jharkhand and Bihar. In West Bengal, population of the *Santal* tribe is 5.5% of the state population. In this state, majority of the *Santals* reside in the districts of Purulia, Bankura, Birbhum, and Midnapore that comprise the greater part of the laterite region in West Bengal.

Once the *Santals* were purely a nomadic tribe but later they embraced a settled livelihood. Nowadays, they have adopted multidimensional strategies for income generation. Small-scale agriculture and cattle rearing are the primary means of earning their sustenance. *Santals* are also engaged in making musical equipment, mats, baskets, crafts, ornaments, brooms, leaf plates and cups out of the plants and supplement their income by selling these items in the nearby markets. A large section of *Santal* people acts as daily labourers in the neighboring agricultural field, industrial setups, mining and urban areas. They are occasionally engaged in hunting and fishing also. In spite of all these means of revenue generation, till date *Santal* people in the area face certain hardships of life such as poverty, social and economic backwardness, low level of education and poor health status.

Poor economic condition reflects in their food and feed culture. Plain rice is the main staple food. Frequently this rice is taken in a unique way after soaking it in water overnight. Some common vegetables like brinjal, pumpkin, papaya, sweet potato, chili, etc. are mostly grown in their home garden and cultivated field for daily use. Apart from that, *Santals* use several wild and semi-wild fruits and vegetables most frequently in cooking to fill the stomach as well as to enhance the flavor of their food or for preservation purposes. Rice beer or "*daka-handi*" is a traditional drink and remains very popular among the after from *Santals*. They also like to drink "*mahua*" liquor, a drink made from the fermented dried flower of *Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.

In West Bengal, the researchers evidenced the poor growth rate and high prevalence of undernutritional condition among the *Santal* people of all ages (Das and Bose, 2012; Stiller et al., 2020). They also highlighted several factors like poverty, low educational level, poor knowledge of health care, insufficient intake of nutritional food, social taboos and belief in supernatural powers. All these factors become vital obstacles to the tribal people in achieving the desired health status (Sarkar and Singha, 2019).

Data collection

For ethnogastronomical data collection, field surveys were conducted for a period of 1 year (July, 2021 – June, 2022) in purposefully selected 11 Blocks of Birbhum district in West Bengal, India where approximately 80% of district's tribal population resides at present. "Block" represents one of many administrative units under a Subdivision of a district usually consisting of several villages. We have randomly selected 10 localities from villages and cities from each of the studied blocks like Rampurhat-I, Mohammad Bazar, Rajnagar, Suri-I, Suri-II, Sainthia, Labpur, Nanoor, Bolpur-Sriniketan, Illambazar, and Dubrajpur. At first, 528 inhabitants of the studied area have randomly been asked whether they use wild edibles as vegetables or for medicinal purposes. Among them, 153 inhabitants have responded positively. From them, data were collected through informal interviews, group discussion, and using semi-structured questionnaire (Supplementary File S1). Plants were identified and collected as voucher specimens during *in loco* interaction and use of visual stimuli. Knowledge holding capacity of each of the key participants has been estimated as follows-

$$\text{Knowledge holding capacity} = \frac{\text{the numbers of wild edibles known to the individual}}{\text{total numbers of wild edibles recorded}} \times 100$$

The data on local name of the wild edible species, its traditional uses, cooking methods, season of availability, frequency of use in a week, side effects if any, and market value have been recorded. Free and Prior Informed Consent (FPIC) was requested from each of the participants before starting the interviews as their participation was voluntary. Participating children under the age of 15 years were requested to provide the FPIC of their own and their parents. At the time of field survey we have strictly followed the best field practice as proposed earlier by the scientists (Heinrich and Verpoorte, 2014; Heinrich et al., 2018), and the Code of Ethics recommended by International Society of Ethnobiology (2008). The collected data have been compared with the available literature on ethnobotany of wild edibles from Laterite region in West Bengal (Banerjee et al., 2013; Bouri and Ganguly, 2016; Banerjee, 2018; Chatterjee et al., 2022).

Plant specimen collection, identification, preparation of herbarium, and nomenclature update

Sample specimens have been collected following the national guidelines (NMPB, 2015) and preserved as herbarium specimens following conventional techniques (Jain and Rao, 1977). These specimens have been kept in the Departmental Herbarium, Department of Botany, Krishna Chandra College, Hetampur, India for future references. For identification of the collected wild edibles, both consultation of different Floras and expert opinions have been considered (Dixit, 1984; Guha Bakshi, 1984; Purkayastha and Chandra, 1985; Bilgrami et al., 1991; Sanyal, 1994; Fraser-Jenkins, 2008; Ranjan et al., 2016; Deb et al., 2018). The updated scientific names are used here following the standard websites like Plants of the World Online,[1] and Germplasm Resources Information Network.[2]

Data analysis

The collected data have been analyzed using specific statistical tools like Relative frequency of citation (RFC), and Cultural food significance index (CFSI) to identify the most popular and culturally accepted species in the area. Jaccard similarity index (JI) is used to draw a comparative account among the recent studies conducted in and around the surveyed area.

Relative frequency of citation

The RFC was used to quantify the frequency of use of certain species, which was determined using the following formula- $RFC = \frac{FC}{N}$, where FC is the total number of participants who cited a particular species as wild edible and N indicates the total number of participants involved in the study. The value of RFC varies from 0 to 1; the value close to 1 signifies the higher importance or popularity of the plant in the study area (Tardío and Pardo-de-Santayana, 2008).

Cultural food significance index

The cultural food significance index was effectively framed to assess the overall acceptability and importance of edible plants in a culture (Pieroni, 2001). It was formulated as-

$$CFSI = QI \times AI \times FUI \times PUI \times MFFI \times TSAI \times FMRI \times 10^{-2}.$$

The CFSI is the product of seven indices that include frequency of quotation (QI), availability (AI), frequency of use (FUI), plant parts used (PUI), multi-functional food use (MFFI), taste score appreciation (TSAI), and the food-medicinal role (FMRI).

Jaccard similarity index

The similarity of documented food plant knowledge from different parts of the laterite region and adjoining states is assessed by the Jaccard index (JI)= $\frac{c}{(a+b)-c} \times 100$, where a and b are the number of edible species documented from the areas A and B respectively, and c is common to both A and B (Hamers, 1989).

1 https://powo.science.kew.org/

2 http://www.ars-grin.gov

Venn diagram

Venn diagram is a popular and extensively used illustration style that points out the logical relationship between multiple sets of data. To draw a logical comparison among different ethnogastronomic works conducted in eastern India, an Area-Proportional Venn diagram was drawn (Heberle et al., 2015).

Results and discussion

Key informant's socio-demography and knowledge-holding capacity

Among the 153 key participants, age ranged from 10 to 87 years which included 87 women, 37 men, 21 girls and 8 boys from 132 households scattered in the remote rural areas, semi-urban and urban settlements in Birbhum district (Table 1). Among the participants 17 were traditional healers having versatile knowledge of plants and well-recognized in the respective localities for their healing skills. In the folk culture of eastern India, the knowledge of locally available wild edibles was found to be extensive among the female informants those who are mainly attached with household activity and working as daily labourers. Attachment of female individuals with the local food plants have also been observed in other parts of the world also (Tbatou et al., 2016; Ghanimi et al., 2022). Participants aged above 50 years collectively can able to identify, recalling local names and ethnogastronomic uses of 77 wild edible species. Greater knowledge-holding capacity of the aged participants is quite common in most of the ethnobotanical studies (Beltrán-Rodríguez et al., 2014; Ghanimi et al., 2022). Aging is accompanied by learning that helps one individual to gather knowledge and experiences throughout his/her life. Gathering of wild edibles is independent of education and literacy level of the participants but mostly dependent on their socio-economical conditions, type of settlements, social recognition and faith in local biodiversity. Few young participants have expressed their fondness toward urbanized lifestyle and commercially available, cultivated fruits and vegetables which is a matter of concern.

Taxonomical information of wild edibles

A total of 83 wild edible species (WES) were documented that spread across 48 families. Among the 83 species, 65 species were angiosperms, 3 species were pteridophytes and the rest 15 were from

TABLE 1 Socio-demographic profile of the participants ($n = 153$).

Variables	Categories	Numbers	Percentage (%)	Nos. of wild edible known	Knowledge holding capacity (%)
Gender	Male	45	29.41	43	51.8
	Female	108	70.59	61	73.49
Ethnic identity	*Santal*	79	51.63	72	86.75
	Mahali	45	29.41	58	69.88
	Dhangar	11	7.19	47	56.63
	Konra	18	11.76	46	55.42
Age group (years)	10–30	29	18.95	24	28.92
	31–49	32	20.92	38	45.78
	50–69	53	34.64	67	80.72
	70–90	39	25.49	59	71.08
Education	Without formal education	89	58.17	64	77.11
	Primary level	44	28.76	43	51.81
	Secondary level	13	8.5	23	27.71
	Higher education (University/college, Govt. job)	7	4.6	25	30.12
Residence	Rural	96	62.75	75	90.36
	Semi-urban	41	26.8	44	53.01
	Urban	16	10.46	19	22.89
Principal occupation	Daily labourer	68	44.44	52	62.65
	Farmer	11	7.19	47	56.63
	Shepherd	8	5.23	49	59.04
	House wife/household activity	27	17.65	68	81.93
	"*Vaidya*" or traditional herbalist	17	11.11	38	45.78
	Others	22	14.38	33	39.76

fungal groups. Among the 15 edible mushrooms, 12 were soil fungi, 2 wood fungi, and one grew on paddy straw. Among the reported 46 families, Amaranthaceae was represented by the highest number of WES (6 species) followed by Fabaceae and Rubiaceae (5 species). This data was in contrast with the observation made earlier from India where Leguminosae and Compositae represent highest number of edible species (Ray et al., 2020). Families like Asteraceae, Lyophyllaceae, and Malvaceae were represented by four species each. Three species were recorded under Dioscoreaceae and Araceae. Nine families, Agaricaceae, Amanitaceae, Boletaceae, Apocynaceae, Commelinaceae, Convolvulaceae, Cucurbitaceae, Moraceae, and Rhamnaceae were represented by two species each. Only one species represented rest of the 31 families.

In the present study, maximum number of edible species recorded under the family Amaranthaceae, which may be due to their ease availability in the studied area, herbaceous nature, and preference as leafy vegetables. Potentiality of Amaranthaceae members as food items endowed with nutritional value has already been established (Preetha et al., 2018; Nuñez-Estevez et al., 2021; Ruth et al., 2021). So, diverse nature of this plant family in relation to accessibility, palatability and food value can contribute a lot toward achieving food security.

Habitual categories of the recorded WES

According to the habits, most of the recorded WES were found herbaceous in nature (40%) followed by mushroom (18%), tree (19%), climber (15%), and shrubs (8%). Uses of the herbaceous species in greater number are a characteristic of many folk cultures. It is a fact that humans would prefer to search for food and medicine, which are very easy to access, most abundantly growing, and have long span of availability (Albuquerque et al., 2005). For these reasons, herbaceous plants have played a significant role in folk people's food and medicinal heritage (Cheng et al., 2022; Khalid et al., 2023).

Diversity of edible parts

Local inhabitants of the study area collect various edible parts like flower, calyx, fruit, fruiting body, leaf, petiole, young coiled fronds, seed, stem, shoot, underground parts like root, tuber, and corm. Leaves were the mostly collected plant parts (28.41%) that are mainly used as leafy vegetables followed by fruit (22.73%), fruiting body (17.05%), shoot and stem (17.05%), underground parts (7.95%), flower and calyx (4.55%), and seed (2.27%). In the present study most frequently cited leafy vegetables were *Ipomoea aquatica*, *Azadirachta indica*, *Enydra fluctuans*, *Colocasia esculenta*, *Marsilea vestita*, *Centella asiatica*, and *Hygrophila auriculata*. These observations are in line with the previous work conducted in eastern India (Sinha and Lakra, 2005; Banerjee et al., 2013; Bouri and Ganguly, 2016; Banerjee, 2018; Das, 2018; Kumar and Saikia, 2020). On the other hand, fruits of *Ficus racemosa*, *Madhuca longifolia*, *Coccinia grandis*, *Neolamarckia cadamba*, *Ziziphus nummularia*, and *Artocarpus lacucha* were informed as popular choices for the local people. Both the plant parts (leaves and fruits) were mostly utilized by the local tribes and in agreement with the current study, those edible parts were found as the main source of wild food in other areas of the Asian continent including India (Khan et al., 2015; Bhatia et al., 2018; Mallick et al., 2020; Cheng et al., 2022; Amin et al., 2023).

Traditional knowledge of wild edible species, their gathering pattern, postharvest processing, and preservation techniques

A total of 2,603 citations were made by the 153 participants for 83 types of different wild edible species. In the present study, among the 83 WES, 60 species were collected solely for edible purposes. On the other hand, 23 edible species were attached with both ethnomedicine and local food heritage. Local people have deep understanding and knowledge of the therapeutic properties of those wild edible species. As for example- butter fried leaves of *Centella asiatica* and *Bacopa monnieri* are consumed for their brain boostering properties, *Hygrophila auriculata* is mainly taken for its anti-anemic capacity, soup of *Termitomyces heimii* is taken as cure for dysentery, tuber of *Dioscorea alata* is attached with its anthelmintic potentialities, etc. Local people consciously consumed those species as medicinal food in spite of their low test appreciation score. It is an establish fact that those herbs can provide both high nutritional inputs and medicinal effectiveness.

Documented wild edibles were mostly gathered from late monsoon to mid-winter. Maximum collection rates were informed during March–April and September–November. The highest collection of wild mushrooms occurs in the month of October. Participants informed that most of the leafy vegetables were collected during the period of May–July. Edible leafy vegetables were mostly collected from marshy land (e.g., *Alternanthera philoxeroides*), agricultural fields (e.g., *Centipeda minuta*), water bodies (e.g., *Ipomoea aquatica*), fallow lands (e.g., *Ouret lanata*), and road sides (e.g., *Amaranthus viridis*). Herbaceous leafy greens which are easily accessible were mostly collected by women and children. In the contrary, male members of the community harvest edible underground parts and fruits which need extra physical strength and the support of mechanical tools. Some participants pointed out sustainable harvesting practice followed by folk taboos and beliefs attached with ethno-conservation practices (Kala, 2006; Oka, 2018). As for example, during collection of root vegetables (e.g., *Asparagus* sp.) some parts were left behind which will hopefully help in reviving the plant and sprouting occurs from the remains under favorable condition.

In 17 cases plant parts were eaten raw and mostly they were the ripe fruits. Rest of the cases edible parts were taken in the form of boiled and cooked vegetables, curry, chutney, pakora, pickles, traditional drinks, and recreational tea (Figures 2A–C). Plant like *Pandanus amaryllifolius* is used as flavoring agent only.

Despite the potential for wild edibles as food in the future, some people are concerned about their alleged toxicity because of pesticide residues, heavy metals, chemical additives, microorganisms, and/or the synthesis of hazardous chemical compounds (Xu et al., 2016; Sai Latha et al., 2018; Urugo and Tringo, 2023). The scientific community is deeply divided on this issue. The non-toxic character of naturally occurring wild foods is defended by one group, while the existence of heavy metals, oxalic acids, cyanogenic glycosides, lectins, pyrrolizidine alkaloids, and several other poisonous chemicals is warned of by the

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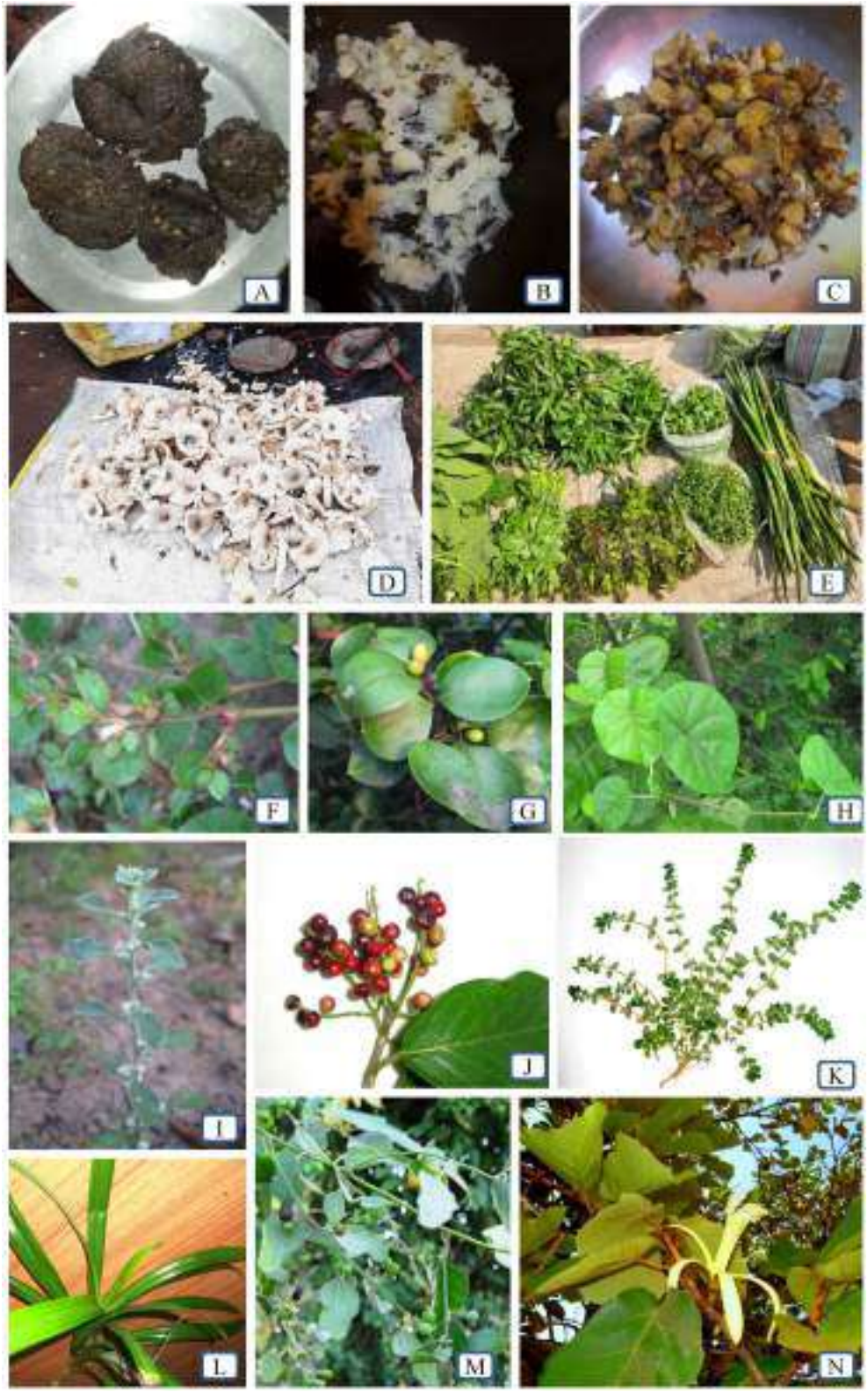

FIGURE 2
Wild edibles of eastern India and their utilization: **(A)** "*Pakora*" made from leaves of *Typhonium trilobatum* (L.) Schott; **(B)** fried leaves of *Cocculus hirsutus* (L.) W.Theob. is mixed in smashed potato; **(C)** traditional ethnic dish made with *Amanita vaginata* (Bull. ex. Fr.) Vitt.; **(D)** *Amanita vaginata* var. *alba* (De Seynes) Gillet in a semi-urban market; **(E)** several wild edible green leafy vegetables are sold in a urban market; **(F)** *Trianthema portulacastrum* L.; **(G)** *Carissa spinarum* L.; **(H)** *Rivea hypocrateriformis* (Desr.) Choisy; **(I)** *Ouret lanata* (L.) Kuntze; **(J)** *Antidesma ghaesembilla* Gaertn.; **(K)** *Euphorbia thymifolia* L.; **(L)** *Pandanus amaryllifolius* Roxb. ex Lindl.; **(M)** *Cocculus hirsutus* (L.) W.Theob.; **(N)** *Pterospermum acerifolium* (L.) Willd.

opposing party (Liu et al., 2015; Buenavista et al., 2021; Saha et al., 2023). Tribes in the studied area have an inherent knowledge of how to treat wild foods after gathering, which aids them in avoiding such harmful dangers. Before consumption in fresh form, washing with clean water is a very common practice that helps in removal of dirt, putrid residue, or other unwanted things from surface (Ruan-Soto et al., 2017). In few cases specialized treatment were given to the edible parts before cooking. In case of wild edible mushrooms, after thorough washing with water, boiling once or twice in plain water or saline water or lime water or with tamarind juice were done according to the local tribe's *emic* perception of collected mushroom's habit, external features and palatability (Sharma, 2015). It was informed that the cuticle of the pileus and stipe was peeled off in case of species like *Amanita vaginata*, *Russula emetic*, *Boletus edulis*, *Amanita vaginata* var. *alba*, and *Astraeus hygrometricus* to reduce their bitterness and to enhance softness. Hot water treatment and boiling are the best possible pre-cooking methods for reducing soluble oxalate content and pyrrolizidine alkaloids in some wild leafy vegetables and underground parts (Chai and Liebman, 2005; Savage and Dubois, 2006; Hajšlová et al., 2018; Takenaka et al., 2022). Local tribes of eastern India followed this method for processing the leaves and petioles of *Colocasia esculenta*, leaves of *Typhonium trilobatum*, tuber of *Dioscorea* spp., and corm of *Amorphophallus sylvaticus*. The use of organic acids, such as lime or tamarind juice, as part of local custom greatly reduces the concentration of insoluble oxalate crystals in food items. Regular usage of ginger, garlic, and turmeric while cooking may potentially serve as effective detoxifiers (El-Barbary, 2016; Ajanaku et al., 2022).

Most of the wild edibles are seasonal and only harvested during their time of availability. For future use, long-term storage is required without compromising their nutritional quality. Recorded wild edible mushrooms like *Termitomyces heimii*, *Amanita vaginata* var. *alba*, *Russula emetic*, and *Termitomyces clypeatus* were first thoroughly cleaned with lukewarm saline water, made sun-dried completely, and then stored in airtight containers for future uses. Local tribes of Himachal Pradesh in India preserved *Morchella* sp. in the same way (Kumari et al., 2022). Most of the time, ripe fruits were consumed fresh, while pickles were preferred for storage. In the present study, tribes of eastern India preserved fruits of *Artocarpus lacucha*, *Grewia asiatica*, *Carissa spinarum*, and *Ziziphus nummularia* in the form of pickle. Traditional pickling methods for preserving perishable fruits and vegetables have long history and have been opted universally (Behera et al., 2020). In few cases leafy vegetables like *Hibiscus sabdariffa*, *Trigonella stellata*, *Cocculus hirsutus*, *Cajanus scarabaeoides*, and *Sonchus oleraceus* were made shade dried for long-term use.

Wild edibles as livelihood support

Many of the recorded wild edibles are gradually finding their place beside the cultivated ones and becoming a source of income generation for the local tribes. As for example, it has been reported that from August to October, in this duration of 3 months a huge income (nearly Rs. 35,000/household) is generated by selling the wild edible mushrooms like, *Agaricus campestris*, *Amanita vaginata*, *Termitomyces heimii*, *Volvariella volvacea*, and *Astraeus hygrometricus* (Figure 2D). Similar observations were made by the earlier workers also (Pradhan et al., 2010; Singha et al., 2020). Not only that, presence of highly demanding, nutritious, non-cultivated edibles parts like leaves of *Marsilea vestita, Azadirachta indica, Enydra fluctuans, Ipomoea aquatica, Alternanthera sessilis,* and *Typhonium trilobatum;* leaves, petioles and corms of *Colocasia esculenta;* tubers of *Amorphophallus sylvaticus,* and *Dioscorea alata;* petioles of *Nymphaea nouchali;* fruits of *Ficus racemosa,* and *Artocarpus lacucha;* medicinal food like *Hygrophila auriculata, Centella asiatica, Mollugo spergula,* and *Bacopa Monnier* are very common in the vegetable markets of rural, urban and semi-urban areas and sold in an average price of Rs.100-150/Kg (Figure 2E). So, there are strong reasons for domesticating some of these economically beneficial wild edibles which can strengthen the arena of food security as well as supply steady nutritional inputs and opens up new avenue for income generation to the local people (N'Danikou and Tchokponhoue, 2020). Collaborative efforts from the government, social activist, ecologist, agriculture and food scientists, local tribes can achieve the sustainable development goals by employing the strategies of food sovereignty, food security or a mixed method approach (Charoenratana et al., 2021).

Enumeration and quantitative analysis of the recorded wild edibles

Recorded wild edibles are presented in Table 2 describing their local names, updated taxonomic information, habits, duration of availability, edible parts, mode of eating or cooking, and traditional uses. Side by side, numbers of quotation (FC), value of relative frequency of citation (RFC) and CFSI score are also tabulated here. RFC value for the recorded species varied from 0.04 to 0.76. In the present study, *Madhuca longifolia* was identified as mostly cited edible species with maximum number of food use mentions (FC-116; RFC-0.76). Higher RFC value (i.e., close to 1) indicates greater importance of the species in the locality. Some other wild edibles like *Colocasia esculenta* (FC-72; RFC-0.47), *Azadirachta indica* (FC-83; RFC-0.54), *Volvariella volvacea* (FC-64; RFC-0.44), etc. were cited frequently also by the local tribes.

Ethnogastronomical data of 83 WES were analyzed using the most effective quantitative index like CFSI and the value ranged from 844 to 0.2. Plants like *Colocasia esculenta*, *Hibiscus sabdariffa*, *Madhuca longifolia* which have multiple edible parts, to them CFSI is calculated separately for each of the edible parts and then combined score is given to the edible species. All the wild edibles are arranged in a descending order according to their CFSI score along with detail calculations in Supplementary File S2. The enlisted wild edibles are then classified into six groups (Pieroni, 2001); species with very high cultural significance (CFSI $\geq$ 300), species with high significance (CFSI ranges from 100 to 299), moderate significance (CFSI varies from 20 to 99), low significance (CFSI ranges from 5 to 19), species with very low significance (CFSI ranges from 1 to 4) and species with negligible cultural significance (CFSI $<$ 1).

Thirteen wild edibles were found very highly significant (CFSI value ranges from 315 to 844) and highest CFSI value was estimated for *Colocasia esculenta* (CFSI = 844) followed by *Enydra fluctuans*, *Ipomoea aquatica*, *Mollugo spergula*, *Azadirachta indica*, *Bacopa monnieri*, *Volvariella volvacea*, *Madhuca longifolia*, *Amaranthus viridis*, *Hygrophila auriculata*, *Centella asiatica*, *Marsilea vestita*, and *Termitomyces heimii*. In this group most of the plants are wild edible

TABLE 2 Enumeration of the wild edible species and projection of their cultural significance.

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Pluteaceae	*Volvariella volvacea* (Bull.) Singer SS-13	*Poal Chhatu/Basub Onthe*	Mushroom	May–December	Edible	Fruiting body; boiled mushroom is cooked with mustard oil and spices and taken with rice	67	0.44	482	Manna et al. (2014) and Singha et al. (2020)
Lyophyllaceae	*Termitomyces heimii* Natarajan SKM-09	*Durga Chhatu*	Mushroom	June–October	Edible and ethnomedicinal	Fruiting body; boiled mushroom is cooked with mustard oil and spices and taken with rice or taken as a soup	56	0.37	315	Manna et al. (2014) and Singha et al. (2020)
Sclerodermataceae	*Astraeus hygrometricus* (Pers.) Morgan SKM-14	*Kurkure Chhatu/ Putko Onthe*	Mushroom	June–September	Edible	Fruiting body; boiled twice and then cooked with mustard oil and spices and taken with rice	48	0.31	75	Manna et al. (2014) and Ganguly et al. (2021)
Amanitaceae	*Amanita vaginata* (Bull. ex. Fr.) Vitt. SS-18	*Sal Chhatu/Budhi Onthe*	Mushroom	July–October	Edible	Fruiting body; boiled mushroom is cooked with tamarind and garlic; taken with rice	42	0.27	123	Pradhan et al. (2010) and Dutta and Acharya (2014)
Agaricaceae	*Agaricus campestris* L. SKM-20	*Sal Chhatu*	Mushroom	August–October	Edible and ethnomedicinal	Fruiting body; boiled mushroom is cooked with mustard oil, onion and spices and taken with rice	27	0.18	194	Singha et al. (2020) and Ganguly et al. (2021)
Agaricaceae	*Apioperdon pyriforme* (Schaeff.) Vizzini SKM-93	*Shib Chhatu*	Mushroom	July–September	Edible	Fruiting body; immature fruiting body is boiled twice with tamarind juice and cooked with mustard oil and spices; taken with rice	19	0.12	67	Ganguly et al. (2021)
Auriculariaceae	*Auricularia auricular* (Bull.) J. Schröt. SKM-87	*Lutur Onthe*	Mushroom	May–September	Edible and ethnomedicinal	Fruiting body; soaked in hot saline water for 30 min then boiled with coriander leaf, garlic and cinnamon; taken as a soup	17	0.11	45	Singha et al. (2020)
Amanitaceae	*Amanita vaginata* var. *alba* (De Seynes) Gillet SKM-26	*Tarmal Onthe*	Mushroom	June–October	Edible	Fruiting body; boiled mushroom is cooked with tamarind and garlic; taken with rice	16	0.1	108	Pradhan et al. (2010) and Dutta and Acharya (2014)
Cantharellaceae	*Cantharellus* sp. SKM-32	*Hinde Onthe*	Mushroom	July–October	Edible	Fruiting body; boiled twice and cooked with mustard oil and spices and taken with rice	13	0.085	30	Singha et al. (2020)

(Continued)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Lyophyllaceae	*Termitomyces microcarpus* (Berk. & Broome) R. Heim SKM-81	*Bulung Onthe*	Mushroom	June–October	Edible	Fruiting body; boiled once for 15 min and then fried with onion and mustard oil; taken with rice	11	0.07	37	Pradhan et al. (2010) and Manna et al. (2014)
Pleurotaceae	*Pleurotus ostreatus* (Jacq.) P. Kumm. SKM-75	*Lutur Onthe*	Mushroom	May–October	Edible	Fruiting body; boiled mushroom is cooked with mustard oil and spices and taken with rice	11	0.07	27	Manna et al. (2014) and Singha et al. (2020)
Lyophyllaceae	*Russula emetic* (Schaeff.) Pers. SKM-38	*Murgi Onthe*	Mushroom	June–November	Edible	Fruiting body; boiled in lime water for 15 min; after discarding the water cooked with black pepper, garlic and black cumin; taken with rice.	9	0.06	16	Pradhan et al. (2010) and Manna et al. (2014)
Boletaceae	*Tylophilus* sp. SKM-44	*Rahet Onthe*	Mushroom	June–October	Edible	Fruiting body; boiled with tamarind juice for 30 min then cooked with coriander leaf, garlic and cinnamon; taken as a soup	8	0.052	23	Ganguly et al. (2021)
Boletaceae	*Boletus edulis* Bull. SKM-50	*Timbe Onthe*	Mushroom	July–September	Edible	Fruiting body; boiled mushroom is used as an ingredient of snacks like "*Pakora*."	7	0.05	14	Singha et al. (2020)
Lyophyllaceae	*Termitomyces clypeatus* R. Heim SKM-56	*Bali Chhatu/Orto Onthe*	Mushroom	July–October	Edible	Fruiting body; boiled in water, after discarding the water fried with onion and mustard oil; taken with rice.	7	0.05	14	Pradhan et al. (2010), Manna et al. (2014), and Singha et al. (2020)
Aspleniaceae	*Thelypteris prolifera* (Retz.) C.F.Reed SKM-61	*Dheki shak*	Herb	March–July	Edible and ethnomedicinal	Young coiled frond (leaf); cooked with garlic and mustard oil; taken with rice	19	0.12	17	
Marsileaceae	*Marsilea vestita* Hook. & Grev. SS-82	*Sushni shak*	Herb	May–August	Edible	Leaf; fried with garlic and mustard oil; taken with rice	92	0.6	331	Chowdhury et al. (2014)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Pteridaceae	*Ceratopteris thalictroides* (L.) Brongn. SKM-69	*Pani shak*	Herb	March–July	Edible	Young frond; cooked with garlic and mustard oil; taken with rice	8	0.05	4	Chowdhury et al. (2014)
Sapotaceae	*Madhuca longifolia* (L.) J.F.Macbr. SS-03, SKM-62	*Mole dari*	Tree	March–July	Edible and ethnomedicinal	(i) Flower; fresh fleshy flowers are eaten raw, used to make "*chutney*," and dried flowers are used to make traditional drink called "*mahua*" (ii) Fruit; unripe fruits are used as an ingredient in vegetable curry; (iii) Seed; seed oil is used as an edible oil in cooking	116	0.76	464	Banerjee et al. (2013) and Bouri and Ganguly (2016)
Meliaceae	*Azadirachta indica* A.Juss. SKM-84	*Neem*	Tree	January–March	Edible and ethnomedicinal	Leaf; young tender leaves are fried with seasonal vegetables like brinjal and/or potato; taken with rice	83	0.54	672	
Araceae	*Colocasia esculenta* (L.) Schott SS-58	*Alati kachu/Anja*	Herb	Throughout the year	Edible	(i) Leaf; before cooking fresh leaves are boiled in water for some time and then cooked with spices, condiments and mustard oil; taken with rice (ii) Petiole; peeled and sliced mature petioles are boiled in water for some time and then cooked with spices, condiments and mustard oil; taken with rice or "*roti*" (iii) Corm; peeled and sliced thin pieces are boiled in water for few minutes and then cooked with black cumin, condiments and mustard oil; taken with rice	72	0.47	844	Banerjee et al. (2013)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Asteraceae	*Enydra fluctuans* Lour. SKM-78	*Jal-helencha*	Herb	September–November	Edible and ethnomedicinal	Shoot; cooked with black cumin, garlic and mustard oil; taken with rice	58	0.38	835	Bouri and Ganguly (2016)
Convolvulaceae	*Ipomoea aquatica* Forssk. SKM-103	*Kalmi shak*	Herb	Throughout the year	Edible	Leaf; tender leaves are cooked with garlic and "*ghee*" (clarified butter); taken with rice	51	0.33	826	Banerjee et al. (2013) and Bouri and Ganguly (2016)
Acanthaceae	*Hygrophila auriculata* (Schumach.) Heine SKM-105	*Kulekhara/ Gokhura janum ara*	Herb	Throughout the year	Edible and ethnomedicinal	Leaf; tender leaves are cooked with garlic and "*ghee*" (clarified butter); taken with rice	47	0.31	349	Banerjee et al. (2013), Bouri and Ganguly (2016), and Banerjee (2018)
Apiaceae	*Centella asiatica* (L.) Urb. SKM-97	*Thankuni*	Herb	April–August	Edible and ethnomedicinal	Leaf; cooked with black cumin and butter; taken with rice	47	0.31	338	Banerjee et al. (2013), Bouri and Ganguly (2016), and Banerjee (2018)
Molluginaceae	*Mollugo spergula* L. SS-71	*Gime-shak*	Herb	Throughout the year	Edible	Shoot; tender shoots are first boiled and then mixed with boiled or fried potato; taken with rice.	47	0.31	571	Banerjee et al. (2013)
Rubiaceae	*Paederia foetida* L. SKM-91	*Gandhavaduli*	Climber	Throughout the year	Edible and ethnomedicinal	Leaf; freshly collected leaves are made into paste along with lentil and garlic, mixed with black cumin and salt, fried to cook in mustard oil; taken with rice	47	0.31	165	Banerjee et al. (2013) and Bhattacharyya and Mandal (2015)
Apocynaceae	*Carissa spinarum* L. SS-92	*Bir karamcha/ Baghjata*	Shrub	August–October	Edible	Fruit; mature fruits are eaten raw and used as an ingredients of mixed pickle.	48	0.31	23	
Rhamnaceae	*Ziziphus nummularia* (Burm.f.) Wight & Arn. SKM-108	*Bhuin kul*	Tree	November–March	Edible	Fruit; (i) ripe fruits are eaten raw, (ii) mature fruits are used to make sweet pickle	45	0.29	171	
Plantaginaceae	*Bacopa monnieri* (L.) Wettst. SS-101	*Bramhi*	Herb	Throughout the year	Edible and ethnomedicinal	Shoot; cooked with black cumin garlic, and butter; taken solely or with rice	42	0.275	491	Banerjee et al. (2013) and Banerjee (2018)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Dioscoreaceae	*Dioscorea bulbifera* L. SS-98	*Methe-alu*	Climber	October–January	Edible and ethnomedicinal	Tuber; peeled and sliced tubers are boiled in water for few minutes and cooked with mustard oil, onion and spices; taken with rice	41	0.27	96	Bouri and Ganguly (2016)
Fabaceae	*Pithecellobium dulce* (Roxb.) Benth. SKM-114	*Jilipi gachh*	Tree	June–July	Edible	Fruit; fleshy seed arils are eaten raw	39	0.255	30	
Rhamnaceae	*Ziziphus oenopolia* (L.) Mill. SKM-119	*Shia kul*	Shrub	December–February	Edible	Fruit; ripe fruits are eaten raw	39	0.255	19	Bouri and Ganguly (2016)
Rubiaceae	*Meyna spinosa* Roxb. ex Link SS-66	*Bainchi kul/Loto*	Shrub	June–August	Edible	Fruit; ripe fruit is eaten raw	38	0.25	15	Bouri and Ganguly (2016)
Amaranthaceae	*Amaranthus viridis* L. SKM-123	*Bon-notey-shak*	Herb	Throughout the year	Edible	Shoot; tender shoots are cooked with black cumin and mustard oil; taken with rice	37	0.24	400	Banerjee et al. (2013)
Malvaceae	*Hibiscus sabdariffa* L. SKM-99	*Mesta/takdhanros*	Shrub	May–November	Edible	(i) Leaf; tender leaves are cooked with black cumin, garlic, ginger flecks, and mustard oil; taken with rice. (ii) Calyx; Fleshy mature calyx is used to prepare chutney	37	0.24	209	
Aizoaceae	*Trianthema portulacastrum* L. SS-70	*Kulpha-shak/Swet purundi*	Herb	August–December	Edible	Leaf; cooked with garlic and mustard oil; taken with rice	34	0.22	90	
Amaranthaceae	*Alternanthera sessilis* (L.) R.Br. ex DC. SKM-90	*Sanchi-shak*	Herb	June–January	Edible	Shoot; tender shoots are cooked with black cumin and mustard oil; taken with rice	34	0.22	274	Banerjee et al. (2013)
Rubiaceae	*Randia aculeata* L. SKM-49	*Maina-kanta*	Shrub	June–August	Edible	Fruit; ripe fruit is eaten raw and sometimes "*chutney*" is made from it	34	0.22	13	Bouri and Ganguly (2016)

(Continued)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Araceae	*Typhonium trilobatum* (L.) Schott SS-88	*Kharkan*	Herb	Throughout the year	Edible	Leaf; freshly collected leaves are first boiled into water for few minutes, then a paste is made from the boiled leaves, mixed with lime juice and "*Pakora*" is made with black cumin, garlic, finely chopped onion, and fried in mustard oil; taken as snacks or with rice.	33	0.22	97	Banerjee et al. (2013)
Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb. SS-25	*Shalunche*	Herb	May–October	Edible	Shoot; tender shoots are cooked with black cumin and mustard oil; taken with rice	32	0.21	259	
Cucurbitaceae	*Coccinia grandis* (L.) Voigt SKM-41	*Kundri/Telakucha*	Climber	Throughout the year	Edible	Fruit; mature unripe fruits are fried in mustard oil with black cumin and onion; taken with rice, *chapati* or *roti*.	31	0.2	92	Banerjee et al. (2013) and Banerjee (2018)
Amaranthaceae	*Amaranthus spinosus* L. SS-26	*Kanta-notey-shak*	Herb	June–September	Edible and ethnomedicinal	Leaf; tender leaves are cooked with black cumin, garlic and mustard oil; taken with rice	29	0.19	235	Banerjee et al. (2013)
Asteraceae	*Centipeda minuta* (G.Forst.) C.B.Clarke SKM-33	*Mecheta shak*	Herb	May–August	Edible	Shoot; cooked with garlic and mustard oil; taken with rice	29	0.19	102	
Dioscoreaceae	*Dioscorea pentaphylla* L. SKM-28	*Kanta alu*	Climber	October–December	Edible	Tuber; after peeling sliced tubers are soaked in water overnight then used as an ingredient of mixed vegetable curry; taken with rice	29	0.19	147	
Malvaceae	*Melochia corchorifolia* L. SKM-21	*Tikiok-ara*	Herb	June–September	Edible	Leaf; tender leaves are first made shade dried and then boiled with pulses, black cumin, garlic and mustard oil; taken with rice	29	0.19	51	Bouri and Ganguly (2016)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Araceae	*Amorphophallus sylvaticus* (Roxb.) Kunth SKM-16	*Bir Shuran*	Herb	January–April	Edible	Corm; sliced and boiled in water with salt and a pinch of turmeric till fully cooked; boiled sliced pieces are then smashed and mixed with black mustard seed paste; served with rice	27	0.18	73	
Convolvulaceae	*Rivea hypocrateriformis* (Desr.) Choisy SKM-129	*Ban pui*	Climber	June–September	Edible and ethnomedicinal	Shoot; tender shoots are first boiled in water for few minutes then fried with black cumin and mustard oil; taken with rice	27	0.18	243	
Rubiaceae	*Neolamarckia cadamba* (Roxb.) Bosser SKM-131	*Kadam*	Tree	October–December	Edible	Fruit; ripe fruits are eaten raw and used to prepare "*chutney.*"	27	0.18	55	
Anacardiaceae	*Buchanania lanzan* Spreng. SKM-7	*Piyal*	Tree	April–June	Edible	Fruit; ripe fruits are eaten raw	26	0.17	15	Bouri and Ganguly (2016)
Malvaceae	*Grewia asiatica* L. SKM-11	*Falsa*	Tree	May–July	Edible	Fruit; ripe fruits are eaten raw; used to make chutney and pickle.	25	0.16	12	Banerjee et al. (2013), Bhattacharyya and Mandal (2015), and Bouri and Ganguly, 2016
Fabaceae	*Melilotus albus* Medik. SS-102	*Ban methi/Senji shak*	Herb	November–January	Edible	Shoot; tender shoots are cooked with garlic and butter; taken with rice	24	0.16	65	
Moraceae	*Artocarpus lacucha* Buch.-Ham. SS-17	*Baral/Deuphal*	Tree	May–July	Edible	Fruit; mature fruits are used as an ingredients of mixed vegetable curry, chutney and to make pickle.	24	0.16	122	Bouri and Ganguly (2016)
Cornaceae	*Alangium salviifolium* (L.f.) Wangerin SKM-55	*Ankar/Dela*	Tree	May–July	Edible	Fruit; ripe fruits are eaten raw	23	0.15	11	Bouri and Ganguly (2016)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Dioscoreaceae	*Dioscorea alata* L. SKM-59	*Kham alu/Chupri alu*	Climber	October–December	Edible and ethnomedicinal	Tuber; after peeling sliced tubers are soaked in water overnight then used as an ingredient of mixed vegetable curry; taken with rice	23	0.15	155	Banerjee et al. (2013) and Bouri and Ganguly (2016)
Fabaceae	*Trigonella stellata* Forssk. SKM-64	*Ban paring*	Herb	June–December	Edible	Leaf; leaves are first made shade dried and then boiled with pulses, garlic and mustard oil; taken with rice	23	0.15	40	Banerjee et al. (2013)
Arecaceae	*Phoenix acaulis* Roxb. SKM-68	*Bir-khejari*	Shrub	June–July	Edible	Fruit; ripe fruit is eaten raw	23	0.15	2	Bouri and Ganguly (2016)
Menispermaceae	*Cocculus hirsutus* (L.) W.Theob. SKM-153	*Aarak-aan-ara*	Climber	September–December	Edible and ethnomedicinal	Leaf; tender leaves are first made parboiled, shade dried and then cooked with black cumin and mustard oil; taken with rice. Fat fried leaves are taken with smashed boiled potato.	22	0.144	98	
Polygonaceae	*Polygonum plebeium* R.Br. SKM-150	*Chimti shak/Tak shak*	Herb	January–March	Edible	Shoot; tender shoots are fried with black cumin and mustard oil; taken with rice	21	0.14	33	
Talinaceae	*Talinum portulacifolium* (Forssk.) Asch. ex Schweinf. SKM-131	*Tak palang/Bilati pui*	Herb	May–August	Edible	Leaf; cooked with garlic and mustard oil; taken with rice	19	0.12	87	
Amaranthaceae	*Ouret lanata* (L.) Kuntze SKM-136	*Chhai-shak/ Lupani-ara*	Herb	January–May	Edible and ethnomedicinal	Shoot; tender shoots are cooked with garlic and "*ghee*" (clarified butter); taken with rice	18	0.12	225	
Euphorbiaceae	*Euphorbia thymifolia* L. SS-148	*Nanha pushi toa*	Herb	Throughout the year	Edible and ethnomedicinal	Shoot; cooked with black cumin and mustard oil; taken with rice.	18	0.12	169	
Commelinaceae	*Commelina diffusa* Burm.f. SS-146	*Bans-kenduri*	Herb	June–September	Edible	Shoot; tender shoots are cooked with black cumin and mustard oil; taken with rice	17	0.11	22	

(Continued)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Ebenaceae	*Diospyros ebenum* J.Koenig ex Retz. SKM-147	*Kend dari*	Tree	April–June	Edible	Fruit; mature ripe fruits are eaten raw.	17	0.11	10	Banerjee et al. (2013) and Bouri and Ganguly (2016)
Ulmaceae	*Holoptelea integrifolia* (Roxb.)Planch. SKM-144	*Pata-badam*	Tree	April–July	Edible	Seed; seed is eaten raw	17	0.11	7	Bouri and Ganguly (2016)
Commelinaceae	*Commelina benghalensis* L. SS-45	*Kansira*	Herb	April–September	Edible	Leaf; tender leaves are cooked with garlic and "*ghee*" (clarified butter); taken with rice	16	0.105	28	Banerjee et al. (2013) and Bouri and Ganguly (2016)
Cucurbitaceae	*Luffa cylindrica* (L.) M.Roem. SS-83	*Dhundul*	Climber	June–August	Edible	Fruit; (i) used as an ingredient of mixed vegetable curry, (ii) fried to cook with black cumin and onion; taken with rice	16	0.105	43	Banerjee et al. (2013)
Fabaceae	*Cajanus scarabaeoides* (L.) Thouars SS-41	*Birhore*	Climber	July–October	Edible and ethnomedicinal	Leaf; tender leaves are first made parboiled, shade dried and then cooked with black cumin and mustard oil; taken with rice	15	0.1	89	Bouri and Ganguly (2016)
Rubiaceae	*Tamilnadia uliginosa* (Retz.) Tirveng. & Sastre SKM-140	*Piralo dari*	Tree	September–November	Edible	Fruit; ripe fruit is eaten raw	14	0.09	1	
Asparagaceae	*Asparagus racemosus* Willd. SKM-142	*Sadmul*	Climber	November–January	Edible and ethnomedicinal	Root; mature tuberous roots are eaten raw	14	0.092	16	Bouri and Ganguly (2016)
Apocynaceae	*Hemidesmus indicus* (L.) R.Br. SS-37	*Anantamul*	Climber	Throughout the year	Edible and ethnomedicinal	Root; dried root powder is used to make recreational tea	13	0.085	23	Bouri and Ganguly (2016)
Malvaceae	*Pterospermum acerifolium* (L.) Willd. SS-20	*Muchkunda*	Tree	April–July	Edible	Calyx; fleshy part of the calyx is made into fine paste and mixed thoroughly in water along with black salt, sugar candy and lemon juice; it is taken as a recreational drink	13	0.085	5	

(Continued)

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Nymphaeaceae	*Nymphaea nouchali* Burm.f. SS-9	*Shaluk*	Herb	June–October	Edible	Petiole; freshly collected petioles are cooked with mustard oil, cumin seed, turmeric, and black mustard seed paste; taken with rice	13	0.085	35	
Phyllanthaceae	*Antidesma ghaesembilla* Gaertn. SKM-111	*Suramatha*	Shrub	August–November	Edible	Fruit; ripe fruits are eaten raw	12	0.078	6	
Amaranthaceae	*Achyranthes aspera* L. SS-53	*Chorchore shak*	Herb	Throughout the year	Edible and ethnomedicinal	Leaf; tender leaves are cooked with black cumin and mustard oil; taken with rice	11	0.07	77	Bouri and Ganguly (2016)
Dilleniaceae	*Dillenia pentagyna* Roxb. SS-33	*Bon-chalta*	Tree	May–July	Edible	Fruit; ripe fruits are eaten raw as well as used in preparing "*chutney*"	11	0.072	0.2	
Moraceae	*Ficus racemosa* L. SKM-9	*Dumur*	Tree	December–April	Edible	Fruit; a delicious curry is made from immature fruits when cooked with condiment and spices; it is taken with rice, and "*roti.*"	11	0.072	54	Bouri and Ganguly (2016)
Asteraceae	*Emilia sonchifolia* (L.) DC. SS-25	*Sanchimodi/Kalai-lutur-ara*	Herb	March–July	Edible and ethnomedicinal	Shoot; tender shoots are cooked alone with black cumin and mustard oil and sometimes with other seasonal vegetables; taken with rice. It is also used occasionally as a garnishing agent which add extra aroma to the cooked food.	10	0.065	122	
Asteraceae	*Sonchus oleraceus* L. SS-94	*Titalea shak*	Herb	September–March	Edible	Leaf; tender leaves are cooked with black cumin, garlic and mustard oil; taken with rice	9	0.06	14	
Pandanaceae	*Pandanus amaryllifolius* Roxb. ex Lindl. SKM-19	*Payes gachh*	Herb	Throughout the year	Edible	Leaf; leaves are used as flavoring agent in cooking items	9	0.059	1	

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TABLE 2 (Continued)

Family	Wild edible species and voucher specimen numbers	Local name	Habit	Duration of availability	Traditional uses	Edible parts and way of eating	(FC*)	(RFC**)	(CFSI***)	Referred work from laterite zone of WB
Fabaceae	*Clitoria ternatea* L. SS-29	*Aparajita*	Climber	Throughout the year	Edible	Flower; dried flowers are used to make recreational tea	8	0.05	6	
Boraginaceae	*Cordia dichotoma* G.Forst. SS-49	*Bouri*	Tree	Throughout the year	Edible	Leaf; tender leaves are first made shade dried and then boiled with pulses, black cumin, garlic and mustard oil; taken with rice	6	0.04	6	Bouri and Ganguly (2016)
Poaceae	*Tripidium bengalense* (Retz.) H.Scholz SKM-15	*Sar gachh*	Herb	June–September	Edible	Stem; jiggery made from the stem juice is used as a sweetener in cooking occasionally and mainly used in different ethnomedicinal preparations	6	0.04	2	

*FC, Frequency of Citation; **RFC, Relative Frequency of Citation; ***CFSI, Cultural Food Significance Index.

greens that are easily accessible, mostly available, and mainly used as leafy vegetables by the local inhabitants. The plant with multiple edible parts has high plant parts used score (PUI) as well as multi-functional food use score (MFFI). Every food plant is designated with the identity "edible" due to its edible plant parts that are very much attached with the local food heritage (Sujarwo and Caneva, 2015). For this reason we first calculated CFSI value separately for each of the edible parts like, corm, petiole and leaf of *C. esculenta* and then considering the cultural significance of that plant as a whole we combined the CFSI values of corm, petiole and leaf (corm − 147 + petiole − 308 + leaf – 389 = CFSI value of *C. esculenta* − 844) which make the plant most culturally significant species in the surveyed area with maximum CFSI value. Interestingly two edible mushrooms like *V. volvacea*, and *T. heimii* also took a significant place in this group. It may be due to their huge acceptance as a healthy food, high test appreciation score and quotation number. Seventeen species were designated as highly significant as their CFSI score ranged from102 to 274. CFSI score of 29 moderately significant species varied from 22 to 98. Eighteen WES having low significance as their CFSI value ranged from 5 to 19. Very low significance (CFSI = 1–4) was attached with 5 WES like *Ceratopteris thalictroides*, *Phoenix acaulis*, *Tripidium bengalense*, *Tamilnadia uliginosa*, and *Pandanus amaryllifolius*. One species like *Dillenia pentagyna* was found having negligible significance (CFSI = 0.2) due to its rare occurrence in the locality and very poor utilization frequency.

The wild edibles recorded from Birbhum district is compared with the data published earlier from other districts of laterite region in West Bengal as well as adjoining states like Jharkhand and Odisha where ethnic composition and biodiversity is very much alike (Sinha and Lakra, 2005; Banerjee et al., 2013; Bouri and Ganguly, 2016; Banerjee, 2018; Das, 2018; Kumar and Saikia, 2020). Results of Jaccard similarity index (JI) revealed that for all the cases JI score is very low (varies from 0.11 to 0.21) which means there is a huge knowledge dissimilarity among the inhabitants of different parts of laterite region (Table 3). It is interesting to note that being a part of the similar type of phytodiversity, every region has some unique knowledge on food plant utilization. The scenario is supported by the Venn diagram analysis where it has been found that knowledge about 47 plants is unique among the inhabitants of the studied area (Birbhum district) in eastern India (Figure 3).

Some new observations from the laterite region of West Bengal

Perusal of ethnobotanical, and ethnogastronomical literature published earlier from laterite region of West Bengal revealed that out of 83 wild edibles, 29 species as a whole or its edible parts are the new addition to the existing inventory of the wild edibles (Figures 2F–N) of this area (Banerjee et al., 2013; Bouri and Ganguly, 2016; Banerjee, 2018; Biswas, 2021). Plants like *Alternanthera philoxeroides*, *Antidesma ghaesembilla*, *Carissa spinarum*, *Commelina diffusa*, *Emilia sonchifolia*, *Hibiscus sabdariffa*, *Rivea hypocrateriformis*, *Tamilnadia uliginosa*, *Sonchus oleraceus*, *Ziziphus nummularia*, *Tripidium bengalense*, and *Pandanus amaryllifolius* have been recorded first time as wild edibles from the studied region. Moreover in few cases some plant parts and few species have been documented here as wild edibles that differ from

the previous work of Bouri and Ganguly (2016). In the present study *Polygonum plebeium* is documented instead of *Polygonum barbatum* and *Nymphaea nouchali* is reported as an alternative for *Nymphaea pubescens* (Bouri and Ganguly, 2016). Similarly earlier workers have documented the plants *Cajanus scarabaeoides* and *Cordia dichotoma* for their edible fruits but here in both the cases only tender leaves of those plants have been enlisted (Bouri and Ganguly, 2016). This observation may have some impact on the local food heritage as it expands the list of wild edibles as well as provide the opportunity to opt alternative food sources in absence of one another.

Interlinking wild edibles with food security

The majority of research found a link between food insecurity and micronutrient insufficiency in consumers (Kirkpatrick and Tarasuk, 2008; Lowe, 2021; Lopes et al., 2023). Micronutrient deficit or "hidden hunger" is considerably one bigger problem than hunger, demonstrating the need of integrating food and nutrition security (Shetty, 2009). The phrase "food security" generally refers to a circumstance in which members of the population under consideration have access to enough food to meet their nutritional needs and to provide an adequate intake of calories. Dietary variety is one of the sustainable food-based ways for ensuring optimal micronutrient consumption and gaining calories. Many of the recorded wild edible fruits, roots, tubers, herbs, and mushrooms are high in micronutrients and they may help improve food security by addressing concerns like hidden hunger. Present study documented 83 wild edible species, different parts of which are collected by the local inhabitants throughout the year. They are consumed with relish mainly as to accompany the main cereal based staple dishes. Most of the recorded wild edibles are good source of food and are mostly rich in micronutrients (Ghosh-Jerath et al., 2016). For example- previous researchers have already explored that *Colocasia* leaf characterized by rich dietary fiber, micronutrients, proteins, and very low in calories (Mitharwal et al., 2022). It contains significant amount of β-carotene, ascorbic acid, folic acid, riboflavin, B vitamins, vitamin A, iron, calcium, potassium, phosphorus, and magnesium. Corms of this culturally most valuable species are also a rich source of carbohydrates, proteins, minerals and vitamins (Rashmi et al., 2018). It can be utilized as an additional tuber vegetable next to potato, and sweet potato which can be a great contribution toward achieving food security. It can also be processed as a food ingredient in nutraceutical industry also.

The plant *Madhuca longifolia* has been inextricably linked to the tribal culture of eastern India and remains as a cultural touchstone species for ages both for its food value and holiness. Flower, unripe fruit and seeds of this plant were recorded as edible items, among which flower was the mostly used plant part. Among the ethnic people of eastern India, utilization of *Madhuca* flower to make a traditional beverage called "mahua" or "mahuli daaru" is very common. *Madhuca* flower contains high amount of reducing sugars, Ca, P, Vitamin C, and Carotene (Pinakin et al., 2018). Regular use of this food item in its dried, fresh or processed form will be an advantage to combat malnutrition. Not only that, seed of *Madhuca* contain 50–61% oil which is edible and having lucrative fatty acid profile includes palmitic acid, stearic acid, and oleic acid. Nutritionists prefer vegetable oils with high oleic acid content because it lowers blood cholesterol, which in turn lowers the risk of coronary heart disease (Ramadan et al., 2016).

In rural and semi-urban vegetable market, presence of *Marsilea vestita* or "Sushni shak" is very common which indicate its wider use. Fondness for this edible leafy green mostly attached with its sleep boosting and antidepressant activity (Bhattamisra et al., 2008). Additionally, *Marsilea* contains high amount of essential vitamins like Thiamine (394 mg/100 g), Riboflavin (2.5 mg/100 g), and Vitamin C (240 mg/100 g) which provide added advantage of gaining required micronutrients in consumer's daily diets (Jadhao and Wadekar, 2010).

Human beings have been consuming mushrooms as an important food source for centuries due to their attractive and multiple functional attributes (Bhambri et al., 2022). Local tribes of the laterite region of West Bengal preferably consumed wide array of wild macro-fungi which are nutritious and medicinally important (Dutta and Acharya, 2014; Das et al., 2015). Edible fungi like *Volvariella volvacea, Termitomyces heimii,* and *Astraeus hygrometricus* possess lots of essential minerals, amino acids, bioactive compounds, and vitamins (Paloi and Acharya, 2014; Roy et al., 2014; Pavithra et al., 2016). On the other hand *Amanita vaginata, Agaricus campestris,* and *Amanita vaginata* var. *alba* are also well recognized in the studied area for their deliciousness but their nutritional profiling is still not scientifically validated thoroughly.

Many of these locally growing nutritious wild edibles can be a potent substitute for commercially available costly marketed vegetables and fruits. Earlier workers from different parts of the world have experienced the same (Bvenura and Sivakumar, 2017; Duguma, 2020). Larger parts of the recorded species belong to the herbaceous group and can easily be accessed and raised in home gardens simultaneously which will help in maintaining a continuous food supply chain in the local tribe's kitchen. Besides, 23 wild edibles having several medicinal properties which can provide additional advantage of health benefit along with food security. So the recorded species have high possibilities of providing the desired food security and micronutrient sufficiency if they are included in regular dishes.

Threats, sustainable harvesting, and conservation practice

Biodiversity loss due to anthropogenic activity, ecological factors and natural causes are a matter of ongoing discussion worldwide. Threats for wild edible resources are not bereft out of it (Oluoch et al., 2023). In the present study, during group discussion some threats for the local WES have been identified. Habitat destruction was identified as a most potential threat to the wild edibles of laterite region in West Bengal. Forest lands of this region have currently been encroached rapidly mostly for developmental activities and less for expansion of agricultural lands. Secondly, a competitive unsustainable harvest practice for species with good market value received substantial attention among the informants and was pointed out as a cause of population decline of species like *Amorphophallus sylvaticus*, *Asparagus racemosus*, and *Dioscorea alata* in the locality. So, habitat preservation and sustainable harvesting of wild edibles are very much crucial for the protection of these important wild crop genetic resources. Day by day socio-economic status of the rural tribals is changing rapidly which directly influence their consumeristic attitude

TABLE 3 Comparative account of data similarity among the six ethnogastronomic studies conducted in different parts of the laterite region in eastern India with the present study.

Previous work and study site	Similar plant species recorded earlier (N)	JI coefficient
Banerjee et al. (2013) (Bankura)	*N* = 15 *Alternanthera sessilis, Amaranthus spinosus, Amaranthus viridis, Azadirachta indica, Bacopa monnieri, Centella asiatica, Coccinia grandis, Commelina benghalensis, Dioscorea alata, Enydra fluctuans, Grewia asiatica, Hygrophila auriculata, Madhuca longifolia, Paederia foetida, Typhonium trilobatum*	0.13
Bouri and Ganguly (2016) (Burdwan)	*N* = 27 *Achyranthes aspera, Alangium salviifolium, Amaranthus spinosus, Artocarpus lacucha, Asparagus racemosus, Azadirachta indica, Buchanania lanzan, Cajanus scarabaeoides, Centella asiatica, Commelina benghalensis, Cordia dichotoma, Dillenia pentagyna, Dioscorea alata, Dioscorea bulbifera, Diospyros ebenum, Enydra fluctuans, Ficus racemosa, Grewia asiatica, Hemidesmus indicus, Holoptelea integrifolia, Hygrophila auriculata, Ipomoea aquatic, Madhuca longifolia, Melochia corchorifolia, Meyna spinosa, Phoenix acaulis, Ziziphus oenopolia*	0.21
Banerjee (2018) (Purulia)	*N* = 14 *Alternanthera sessilis, Amaranthus spinosus, Amaranthus viridis, Asparagus racemosus, Bacopa monnieri, Centella asiatica, Coccinia grandis, Colocasia esculenta, Commelina benghalensis, Dioscorea alata, Enydra fluctuans, Hygrophila auriculata, Paederia foetida, Typhonium trilobatum*	0.11
Das (2018) (Jharkhand)	*N* = 11 *Alangium salviifolium, Artocarpus lacucha, Buchanania lanzan, Carissa spinarum, Cordia dichotoma, Ficus racemosa, Holoptelea integrifolia, Madhuca longifolia, Neolamarckia cadamba, Pithecellobium dulce, Ziziphus oenopolia*	0.11
Sinha and Lakra (2005) (Odisha)	*N* = 9 *Antidesma ghaesembilla, Buchanania lanzan, Dillenia pentagyna, Dioscorea bulbifera, Dioscorea pentaphylla, Ficus racemosa, Grewia asiatica, Madhuca longifolia, Tamilnadia uliginosa*	0.07
Kumar and Saikia (2020) (Jharkhand)	*N* = 14 *Amaranthus spinosus, Amaranthus viridis, Antidesma ghaesembilla, Buchanania lanzan, Commelina benghalensis, Dillenia pentagyna, Ficus racemosa, Grewia asiatica, Hygrophila auriculata, Madhuca longifolia, Ouret lanata, Polygonum plebeium, Tamilnadia uliginosa, Trianthema portulacastrum*	0.11

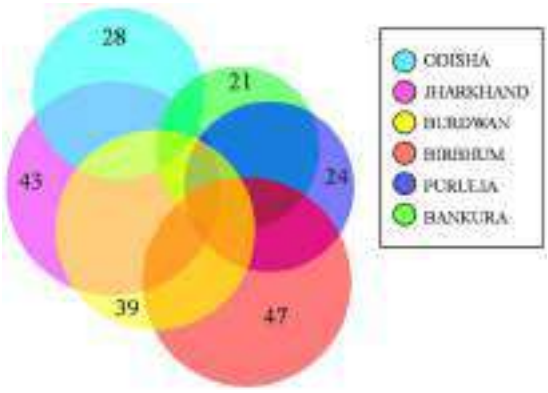

FIGURE 3
Area-Proportional Venn diagram showing the overlap of the commonly used wild edibles recorded from different areas of the laterite region in West Bengal and adjoining areas. Numbers presented within each circle are the unique numbers of wild edibles recorded from the respective areas.

toward urbanized culture. This may be a possible cause of reduced consumption of wild edibles and fading away associated traditional knowledge. Raising awareness among the community members is a long-term effective solution for sustenance of wild edibles in their natural habitat. Additionally collection of germplasm, raising them *in situ* or *ex situ* and formation of gene-bank are also crucial for conserving such treasure trove of our mother nature. Environmental conservationist, social activist, agriculturist, economist and other entrepreneurs can collaboratively step forward in this direction abide by the government laws and policies to protect the population of wild edibles and make fruitful utilization in benefit of the local tribes.

Conclusion

Phytodiversity, agricultural or harvesting practices, wild food gathering, ethnomedicine, nutrition and population health are inextricably linked with one another. Plants with food-medicinal importance play the central role in it. The formation of an inventory of 83 locally accessible wild edibles (WES) is an important step toward preventing malnutrition and ensuring food security for local inhabitants, especially the marginalized. It can also contribute to the eradication of poverty by generating alternate income sources through gathering and marketing popular wild vegetables, fruits and mushrooms. It probably helps with agricultural diversification as well by preserving some excellent traits of WES which can be exploited for developing new cross-breeding varieties.

The present study witnessed that the traditional knowledge of wild edibles still diffusely exists in the *Santal* community of that region. Conservation of this traditional knowledge and its associated natural resources is the best possible sustainable way to keep alive the persisting food heritage. For this, the foremost step should be taken to raise awareness among the wider consumers especially

the younger generation of the tribal community in the studied area regarding the utility of consuming wild edibles. Simultaneously to strengthen the local food use knowledge base, uniformity of ethnogastronomic knowledge should be maintained by creating an oblique knowledge transfer network among the stakeholders of the local food heritage through repetitive group discussions, workshops, and seminars. Additionally, sustainable collection, and use of local flora and macrofungi should be encouraged. As most of the traditional knowledge is related to the local natural resources, associated traditional knowledge will be sustained once the local biodiversity is conserved. Most of the cases culinary uses of wild edibles are very much localized which need proper promotion for diet diversification and intensification. Like other developing countries, India is also facing the conflicts between the population boom and the food availability. This challenge can be overcome through sustainable utilization of recorded inexpensive wild edibles. These wild edibles are lucrative natural source of essential minerals, phytochemicals, vitamins, and many other health benefits. They can be true alternative raw materials for food and nutraceutical industries and thus contribute in reducing the gap between food production and demand. Moreover, further research is needed to go beyond just their nutritional composition information; information on their functional properties is needed to include them in industrial processes. Toxicological studies are also needed to determine their acceptance as a food material. So, newly reported plants as well as plants with high CFSI value should be opted for their detail nutritional analysis, chemical profiling, toxicological studies, and bio-assay to start developing commercial products as well as promoting them as healthy food to overcome hidden hunger.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the ethnobiological study on human participants in accordance with the local legislation and institutional requirements. Written as well as oral informed consent to participate in this study was provided by the elder participants and minor participants' legal guardian/next of kin.

Author contributions

SKM and SatS designed the work, conducted the field survey, collected food-medicinal data, analyzed the data, and wrote the first draft of the manuscript. SarS created Venn diagram, and modified methodology, results and discussion accordingly. Finally, all authors critically revised the manuscript and finalized the draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1198187/full#supplementary-material

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ORIGINAL ARTICLE

Assessment of cytotoxic and genotoxic effects of *Colletotrichum gloeosporioides* and *C. capsici* toxins on tobacco BY-2 cells

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Abstract

Phytopathogenic fungi like *Colletotrichum spp.* produce toxins composed of an array of host-specific and non-specific compounds to execute their toxic effects on infected plants. Understanding how these toxins affect exposed plant cells is thus crucial for deciphering the molecular mechanism of plant-pathogen interaction. In the present study, cytotoxic and genotoxic potentials of different concentrations of toxins extracted from *Colletotrichum gloeosporioides* (CG-toxin) and *C. capsici* (CC-toxin) were tested on tobacco BY-2 cells. Both the toxins were found to be highly cytotoxic, causing decreased cell survival (cells treated with CG-toxin showing IC_{50} at 250 PPM and CC-toxin treated cells at 100 PPM). A significant increase ($P < 0.05$) in incidences of chromosomal aberrations were observed and abnormalities like sticky bridge formations, laggards, multipolarity, clumped metaphase, etc., along with extensive nuclear DNA damage assessed by COMET Assay indicated the potent genotoxic effect of the toxins. Interestingly, flow cytometric analyses depicted an increased accumulation of cells in G0/G1 phase and a consequent decrease in G2/M phase cells (in case of 500 PPM CC-toxin ~ 13.89% G2/M phase nuclei, while at 500 PPM CG-toxin ~ 16.81% G2/M phase nuclei) after toxin treatment, when compared with control cells (~ 55.75% G0/G1 phase and ~ 29.50% G2/M phase nuclei). The present study also recorded a reduction in nDNA content of the tobacco BY-2 cells treated with 250 PPM CC- and CG-toxins after 24 h exposure. These findings suggested that both the mycotoxins have potent cyto- and genotoxic effects on tobacco BY-2 cells, and, that CC-toxin was more toxic than CG-toxin.

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This article is dedicated to Prof. Arun Kumar Sharma in commemoration of his Birth Centenary.

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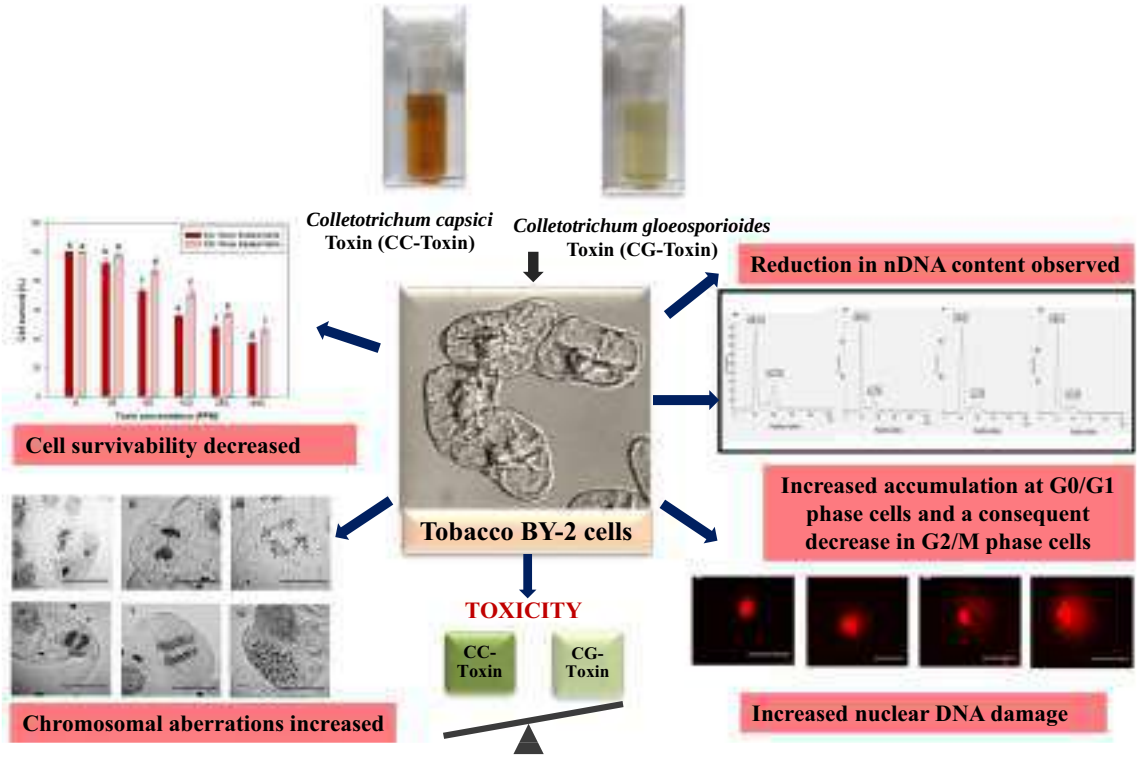
Graphical abstract



Keywords *Colletotrichum* toxin · Cytotoxicity genotoxicity · Cell cycle · Chromosomal aberration · Nuclear DNA content

Introduction

Different types of toxins produced by pathogenic fungi species have recently received greater scientific attention, due to their involvement in the development of plant diseases. One of the notable fungal diseases of several economically important crop plants pervasive globally is the anthracnose disease, caused by *Colletotrichum spp.* [7]. Primarily two important species, *C. gloeosporioides* and *C. capsici*, are responsible for this disease which is prevalent in several Asian countries [28, 30].

Colletotrichum is a hemi-biotrophic fungus with both biotrophic as well as necrotrophic stages in its life cycle. During biotrophic stages, members of *Colletotrichum* species develop primary hyphae and infection vesicles that ingress into host tissues, and, perturb activation of the host's defence, rather than killing the host cell. It has been suggested that the pathogen protects against degradation of the hyphal surface chitin by plant chitinase and avoids activation of defence response by deacetylating chitin [9]. However, during the necrotrophic stage, the pathogen prioritises on killing the host cell, which it does by producing different types of toxins [22]. A number of reports have suggested that different species of *Colletotrichum* secrete toxic metabolites which are capable of producing disease symptoms and are directly responsible for their pathogenicity [21]. Among the toxic metabolite-producing *Colletotrichum* species, *C. gloeosporioides, C. nicotianae, C. capsici, C. truncatum* and *C. lagenarium* are well studied [12].

Like most of the phytopathogenic fungi, *Colletotrichum* species secrete two types of toxins, viz., host specific and non-host specific toxins. Host specific toxins like glycoproteins are produced by *C. gloeosporioides* when infecting yam cv. Florido, mango and citrus and by *C. kahkwae* in coffee [2]. Among the non-host specific toxins produced by *Colletotrichum* species are colletotrichins produced by *C. nicotianae* [8] and *C. capsici* [12], colletopyrone produced by *C. nicotianae* [14], as well as, aspergillomarasmins and ferricrocin produced by *C. gloeosporioides* [12]. It is hypothesized that these toxins target and degrade host cell walls and membranes, and directly affect host protoplasm during disease manifestation [44].

Recent studies on *Colletotrichum* have focused on the characterization of their toxin secondary metabolites and unravelling their roles in the infection strategy, though

detailed studies on the genomic and molecular insights into the effects of these toxins on host cells is lacking [21]. Reports on cytotoxicity and genotoxicity of toxins produced by different *Colletotrichum* species on plants are very rare, although, studies have revealed significant cytotoxicity of several metabolites of other fungal strains, like, phytotoxic and cytotoxic activities of mycotoxins produced by *Fusarium* strains [1, 16]. Interestingly, metabolites produced by eight different fungus species (*Penicillium paneum, P. roqueforti, Monascus ruber, F. graminearum, F. avenaceum, Alternaria tenuissima, Aspergillus fumigatus* and *Byssochlamys nivea*) were reported to have cytotoxic activities on the human epithelial cell line Caco -2 [27].

Host cell death ushered by fungal toxins are believed to be key for successful infection and proliferation of necrotrophic fungal pathogens. While the plant pathologists are investigating different components of these fungal toxins to unravel their roles in inducing plant cell death, it is also necessary to understand how the host cell reacts on its exposure to fungal toxins. The present work was planned to explore how different concentrations of the toxins produced by *C. gloeosporoides and C. capsici* can induce DNA damage, and, affect cell survival and cell cycle progression in exposed host cells, using the classical toxicity assessment experimental plan of work. Outcomes of such studies involving investigation of cyto- and genotoxicity of the toxins produced by different *Colletotrichum* species are indispensable to draw up disease assessment and management strategies.

Material methods

Fungal strains and growth conditions

Two fungal strains (*Colletotrichum gloeosporioides* and *C. capsici*) were used in the present study. Active cultures of both the strains were obtained from Indian Agricultural Research Institute (IARI), New Delhi-110012, India. In our laboratory these cultures were grown and maintained on potato dextrose agar (PDA) medium at room temperature (25 ± 2 °C) [42].

Fungal toxin production

Richard's media was prepared for toxin production, which contained 5% sucrose,1% KNO_3, 0.5% KH_2PO_4, 0.25% $MgSO_4$ and 0.002% $FeCl_3$. A small block of mycelia growing for four weeks on PDA medium was inoculated in Erlenmeyer conical flasks containing liquid Richard's medium to elicit toxin production. The flasks were incubated at 25–28 °C for three weeks before toxin extraction [15].

Toxin extraction and purification

Fungal toxins were extracted and purified according to Slavovet et al. with some modifications [36]. The mycelial mat was separated after incubating for three weeks in Richard's medium and the culture filtrate was collected. Then 0.5% activated charcoal was added to the culture filtrate. After incubation, the mixture was filtered repeatedly and only the charcoal fraction was recovered. This fraction was washed repeatedly with 70% acetone and finally the charcoal fraction was discarded. The filtrate was collected and concentrated using a vacuum rotary evaporator. The pH of the filtrate was adjusted to 3, followed by addition of equal volume of ethyl acetate to extract the filtrate. Finally, the water phase was separated and the pH was set to 6 after which it was evaporated once more in a vacuum rotary evaporator. The residues were weighed and dissolved in distilled water to prepare solutions of different concentrations (parts per million or PPM) which were used for further assays.

Plant cell lines and treatment schedule

Wild type tobacco BY-2 cell lines were cultured according to Nagata et al. [23], with some modifications [33]. Every seven days, 2 ml of cell suspension was sub-cultured into 80 ml of fresh culture medium containing MS medium supplemented with 3% sucrose and 0.2 mg L^{-1} 2,4-D. The flasks were kept on 110 rpm rotation at 23 °C ± 2 °C in a dark room. Four-day old cells were harvested to perform all the experiments.

Tobacco BY-2 cells (50 mg ml^{-1}) were treated with two different fungal toxins, i.e., CC-toxin extracted from *C. capsici* and CG-toxin from *C. gloeosporoides,* at varying concentrations (0, 25, 50, 100, 250 and 500 PPM) for 24 h. At the end of each treatment period, the cells were harvested and processed for further analysis. A separate set of cells was cultured without the addition of the toxins, which acted as the negative control set. All the experiments were performed using three replicates and each experiment was repeated thrice.

Cell survivability assay

Cell survivability was tested using TTC assay, a colorimetric technique where a red formazan product formed by the reduction of 2,3,5-triphenyltetrazolium chloride or TTC indicated presence of viable cells. BY-2 cells were pelleted by centrifugation and incubated in 0.05 M TTC solution at 25 °C [32]. The red coloured formazan formed was extracted with 95% ethanol and optical density value

was recorded at 490 nm. Percentage viability of the treated cells was calculated according to Manna and Bandyopadhyay [19].

Cytological analysis

Tobacco BY-2 cells treated with fungal toxins were cytologically analysed using orcein squash technique [34], to observe chromosomal aberrations and the number of dividing cells per total number cells for each experimental set which was expressed as mitotic index (MI). Slides prepared from each treatment set were analysed under bright field microscope (Primostar, Carl Zeiss Microscope) using 1000× magnification. At least 500 cells were analysed from each treatment and every set was repeated thrice.

Flow cytometric analysis

Flow cytometry is one of the most popular techniques used to study cell cycle dynamics and nuclear DNA (nDNA) content estimation. The technique is based on the detection of relative fluorescence intensity of isolated nuclei stained with a DNA fluorochrome. In the present study, the flow cytometry technique was used to analyse both cell cycle progression and measure nDNA content of tobacco BY-2 cells after treatment with CC- and CG-toxins. For studying these parameters, nuclear suspension was prepared using MB01 buffer with some modifications [31]. Isolated nuclei suspensions were stained with propidium iodide (50 µg ml^{-1}) and analysed (minimum 10,000 events per experimental sets) using BD FACSVerse™ Flow Cytometer (Becton Dickison, Franklin Lakes, New Jersey, USA). For nDNA content estimation in absolute unit, a reference standard of known DNA content was required. Here, *Pisum sativum* cv. Citrad [2C = 9.09 pg DNA [39] kindly provided by J. Doležel was used as the reference standard. For the present experiment, flow cytometric analysis of each set was repeated three times.

DNA damage analysis

Alkaline comet assay was used to study DNA damage of fungal toxin treated cells and compare that to the control BY-2 cells according to the protocol proposed by Ghosh et al. [13] with some alterations [32]. The nuclei were isolated by chopping BY-2 cells with fresh razor blades in 300 µl chilled Tris buffer (400 mM, pH 7.5). Equal volume of 1% low melting point agar (LMPA) was added to the isolated nuclei and this mixture were spread on frosted end glass slide pre-coated with 1% normal melting point agar (NMPA). The slides were again coated with 0.5% LMPA after solidification of the previous layer, and were kept in an electrophoresis tank containing electrophoresis buffer (pH 13) prepared with 300 mM NaOH and 1 mM EDTA for DNA unwinding and electrophoresis. After electrophoresis, the neutralizing buffer (0.4 M Tris, pH 7.5) was applied to the slides and then washed off with water. The slides were visualized under fluorescence microscope. Komet 5.5 (Kinetic imaging, Andor Technology, Nottingham, UK) software was used to evaluate percentage of DNA damage.

Statistical analysis

All statistical analyses were done using Sigma Plot 12.0 software. The data presented here are the mean values of a triplicate set, and expressed as mean values ± standard deviation (SD), where the degree of significance is established at $P < 0.05$. To find out statistical correlation among acquired data, one-way analysis of variance (ANOVA) was performed, where all pair wise significant differences were tested using Holm-Sidak method.

Results

Cell viability decreased with increase in toxin concentration

TTC test was performed to analyse the percentage of metabolically active and inactive tobacco BY-2 cells after treatment with different concentrations of CC- toxin and CG-toxin for 24 h.

It was observed that both the toxins induced significant incidences of cell death in tobacco BY-2 cells at all the concentrations used, and the percentage cell viability of the toxin treated cells gradually declined in a dose dependent manner. An interesting observation noted was that, CC-toxin treated BY-2 cells showed IC_{50} (55.50 ± 2% cell death) at 100 PPM toxin concentration, while CG-toxin treated cells showed IC_{50} (57 ± 2% cell death) at a higher 250 PPM toxin concentration. Additionally, at the highest toxin concentration (500 PPM), CC-toxin treated BY-2 cells showed a 37 ± 2% cell survival rate whereas CG-toxin exposed cells showed 46 ± 2% cell survival rate. These results indicated that CC-toxins were more detrimental to BY-2 cell survival than CG-toxins at equivalent concentrations (Fig. 1).

Cell cycle progression was delayed by toxin treatment

The effect of CC-toxin and CG-toxin on cell cycle progression of tobacco BY-2 cells was studied using flow cytometry. The histogram of control experimental sets (without toxin exposure) displayed peaks corresponding to ~55.74% G0/G1 phase nuclei and ~ 29.50% G2/M phase nuclei (Fig. 2a).

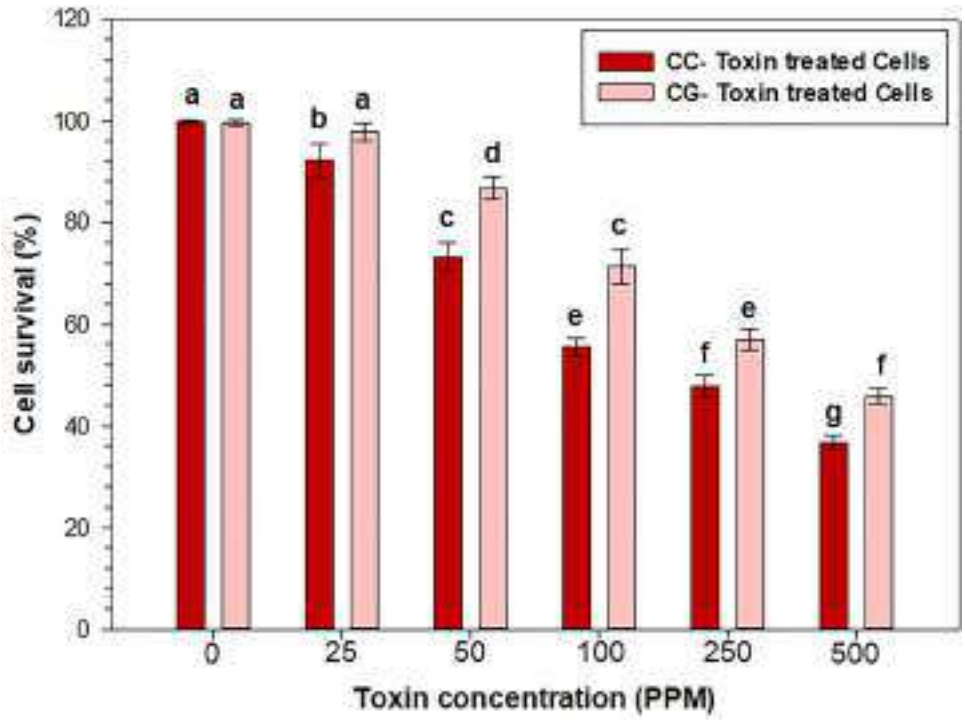


Fig. 1 Effects of different concentrations of CC- and CG-toxin on cell viability of tobacco BY-2 cells after 24 h exposure. Different alphabets indicate significant differences ($P < 0.05$) compared to control by Holm-Sidak multiple comparison test

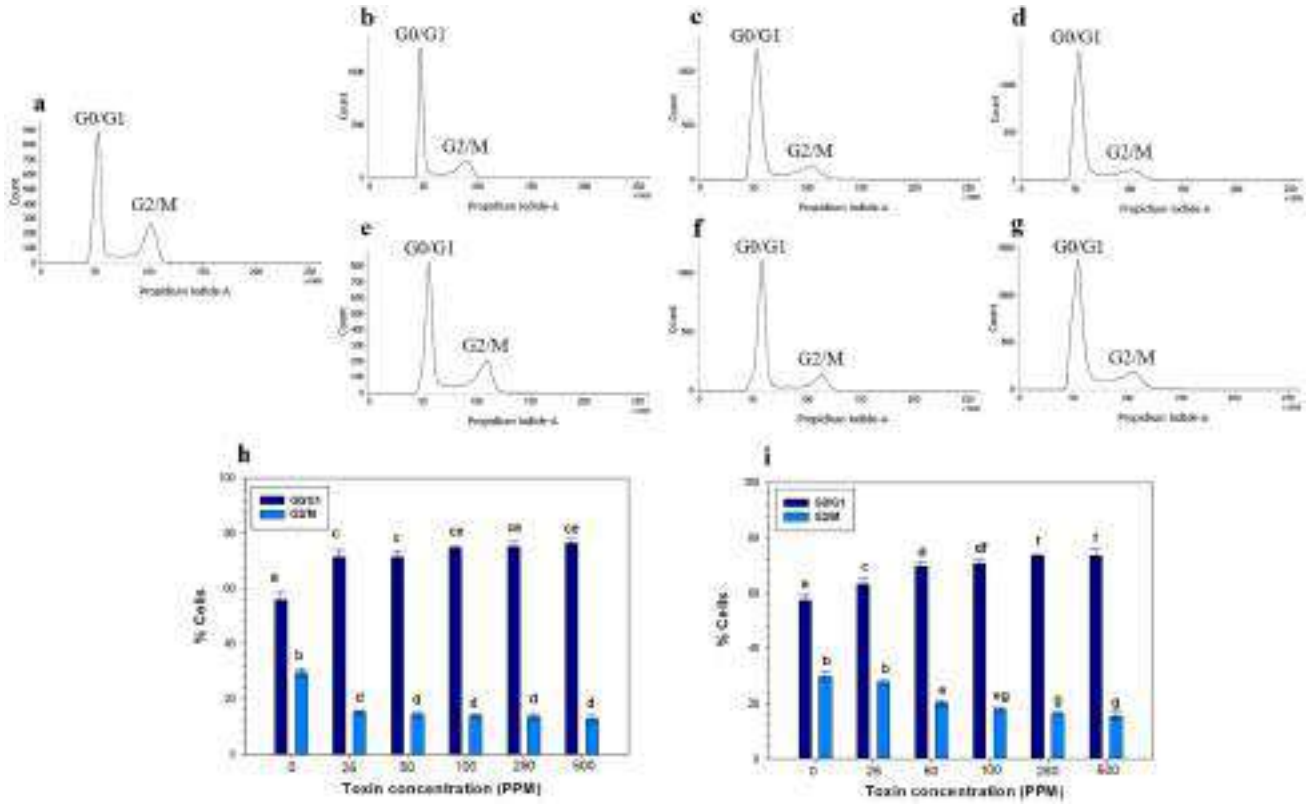


Fig. 2 Effect of CC- and CG-toxins on cell cycle progression in tobacco BY-2 cells: a-g represent flow cytometry histograms indicate distribution of cells in the G0/G1 and G2/M phases of cell cycle (**a**: control set; **b**–**d**:25,100 and 500 PPM CC-toxin treated sets; **e**–**g**: 25,100 and 500 PPM CG-toxin treated sets). **h** and **i** display graphical representation of percentage of cells in the G0/G1 and G2/M phases of cell cycle (**h** CC-toxin treated sets; **i** CG-toxin treated sets). Different alphabets indicate significant differences ($P < 0.05$) compared to control by Holm-Sidak multiple comparison test

A significant ($P < 0.05$) increase in G0/G1 peak values and corresponding decline in the G2/M peak was observed in both the CC-toxin and CG-toxin treated BY-2 cells when compared to the untreated control sets (Fig. 2h and i).

Interestingly, while the G0/G1 peak increased consistently when the toxin concentrations increased from 25 to 100 PPM, cells treated with 250–500 PPM of either of the toxins did not register any increase of G0/G1 peak value over what was recorded at 100 PPM toxin concentration.

CC-toxin treated tobacco BY-2 cells showed a significant ($P < 0.05$) decline in G2/M peak values even after exposure to the lowest concentration of the toxin (~ 15.55% G2/M phase nuclei at 25 ppm), while the maximum decrease of the G2/M peak value was recorded when cells were exposed to 500 ppm CC-toxin (~ 13.89% G2/M phase nuclei). Likewise, tobacco BY-2 cells exposed to CG-toxin showed a concentration-dependant gradual decrease in G2/M peak value (~ 28.6% at 25 PPM, ~ 20.34% at 50 PPM, ~ 18.19% at 100 PPM, ~ 16.82% at 250 PPM and ~ 16.81% at 500 PPM). These results affirmed that a change had occurred in cell cycle dynamics in the cells exposed to different concentration of both the toxins. Selected histograms are represented as in Fig. 2 and the rest are submitted as supplementary Figure 1.

Mitotic index decreased with increase in toxin concentration

To study the potential toxicity of CC-toxin and CG-toxins on cell division in BY-2 cells, mitotic indices were evaluated after conventional orcein staining of the treated cells. Mitotic index (MI) of untreated control cells showed that ~ 19.2% cells were in dividing phase. In general, MI decreased significantly ($P < 0.05$) in both toxins treated sets in a concentration dependent manner. Cells treated with the highest CC-toxin concentration (500 PPM) showed a 4.84-fold decrease in MI, while after treatment with 500 PPM of CG-toxin BY-2 cells showed a 3.63-fold decrease in MI. Even at the lowest concentration (25 PPM) of toxin treated sets, MI was found to be significantly ($P < 0.05$) decreased when compared to the control sets, ranging from 1.34-fold decrease in CC-toxin treated sets to 1.14-fold decrease in CG-toxin treated sets. The MI results (Fig. 3) were strongly correlated with the cytotoxic (cell viability) results.

DNA damage was induced in BY-2 cells after treatment with different concentrations of toxins

To assess the genotoxic effect of the fungal toxins in terms of DNA damage, single-cell gel electrophoresis (SCGE) or comet assay was performed. Tobacco BY-2 cells exposed to CC-toxin exhibited a significant ($P < 0.05$) increase in % tail DNA content. Highest % tail DNA increase (~ 37.40%) was observed in cells treated with 500 PPM of CC-toxin. A similar trend was recorded for CG-toxin treated tobacco BY-2 cells, although, the extent of DNA damage induced by CC-toxins was remarkably higher than that induced by CG-toxins. Lowest DNA damage was observed in cells treated with 25 PPM of CG-toxin when compared to the control DNA. This result revealed a similarity with the cytotoxicity

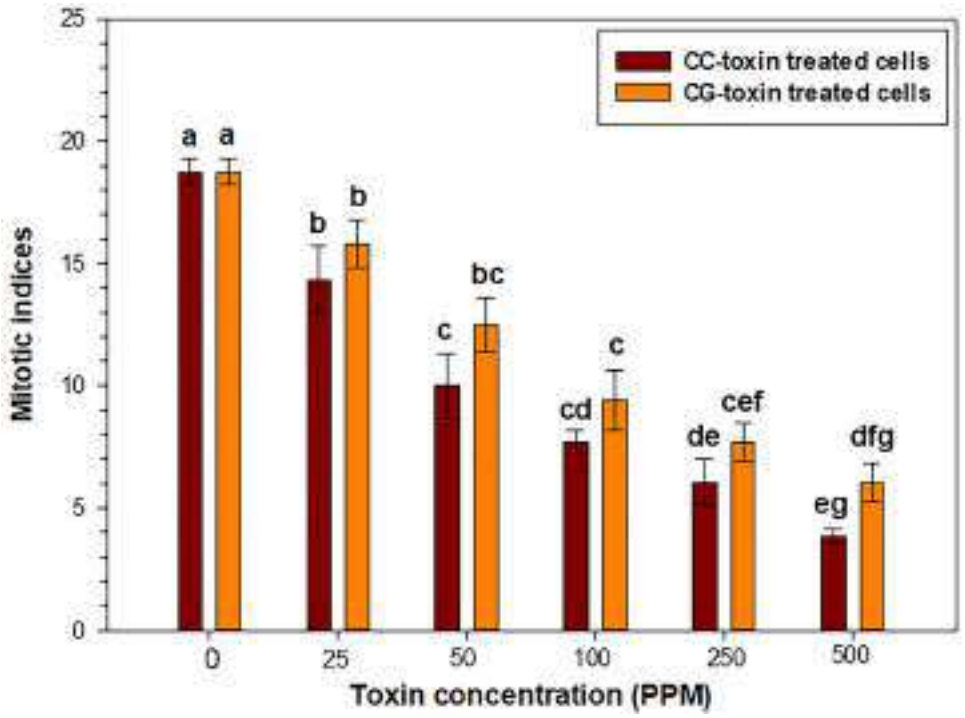


Fig. 3 Effect of CC- and CG-toxin on mitotic indices in treated tobacco BY-2 cells. Different alphabets indicate significant differences ($P < 0.05$) compared to control by Holm-Sidak multiple comparison test.

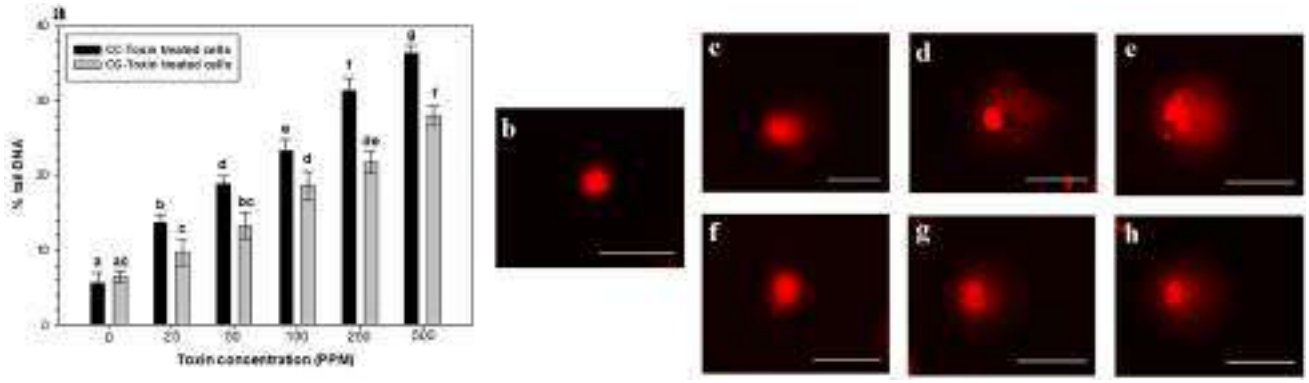


Fig. 4 Assessment of DNA damage in tobacco BY-2 cells treated with different concentrations of CC- and CG- toxin using comet assay. **a** Graphical representation of percent tail DNA representing DNA damage. Differentalphabets indicate significantdifferences ($P < 0.05$) comparedto control by Holm-Sidak multiplecomparison test. **b–h** Photographic representation of DNA damage **b**: control; **c–e**: 25,100 and 500 PPM CC-toxin treated cells respectively; **f–h**: 25, 100 and 500 PPM CG-toxin treated cells respectively). Scale bar represents 50 µm

data. Selected results are displayed in Fig. 4 and the rest of the images are complied as supplementary Figure 2.

CC- and CG-toxins altered nDNA content of the treated BY-2 cells

Nuclear DNA (nDNA) of treated tobacco BY-2 cells was estimated using flow cytometry technique. After 24 h exposure to both CC- and CG-toxins, there were no significant ($P < 0.05$) changes observed in the nDNA of the treated tobacco BY-2 cells as compared to untreated control cells (9.135 ± 0.039 pg/2C) in all the concentrations tested except at the 250 PPM concentration. At 250 PPM BY-2 cells treated with both the toxins recorded a decrease in nDNA content. Furthermore, to observe long term effect of toxin exposure, the nDNA content of tobacco BY-2 cells was measured after 48 h exposure to the toxins. After 48 h, CC-toxin treated tobacco BY-2 cells showed significant ($P < 0.05$) decrease in nDNA content after exposures to 50,100 and 250 PPM toxin, whereas in CG-toxin treated sets a significant reduction in nDNA content was observed only at 250 PPM. All results were tabulated in Table 1.

CC- and CG-toxins induced chromosomal aberrations in tobacco BY-2 cells

Apart from DNA damage and change in nDNA content, another parameter used to study genotoxicity is incidences of chromosomal aberrations, which was assayed in tobacco BY-2 cells exposed to different concentrations of the toxins. Different types of chromosomal aberrations like sticky bridge formation, laggards, multipolarity, clumped metaphase, early and late separation were observed.

Interestingly, in case of CC-toxin treated tobacco BY-2 cells, the frequency of chromosomal aberrations was high only at 50 and 100 PPM concentrations (6.78 and 7.62% at 50 and 100 PPM respectively) when compared with untreated cells (0.02%). Among the chromosomal

Table 1 Nuclear DNA (nDNA) content of tobacco BY-2 cells exposed to different concentration of CC and CG-toxin

Model System	Toxin	Concentration (PPM)	DNA content (pg/2C) at 24 h	DNA content (pg/2C) at 48 h
Tobacco BY-2 cells	CC-toxin	0	9.135 ± 0.039	9.135 ± 0.039
		50	9.125 ± 0.031	**8.756 ± 0.022***
		100	9.048 ± 0.023	**8.715 ± 0.091***
		250	**8.825 ± 0.048***	**8.470 ± 0.021***
	CG-toxin	0	9.135 ± 0.039	9.135 ± 0.039
		50	9.144 ± 0.049	9.054 ± 0.031
		100	9.283 ± 0.245	8.893 ± 0.082
		250	**8.867 ± 0.101***	**8.679 ± 0.088***

Results are represented as mean ± standard deviation of the mean (n = 3). *Significantly ($p < 0.05$) different to control

aberrations, anaphasic and telophasic sticky bridge formations were most predominant in CC-toxin exposed cells.

CG-toxin treated cells showed highest frequency of chromosomal aberrations at 100 and 250 PPM concentrations (5.53 and 6.59% at 100 and 250 PPM respectively), and, unlike CC-toxin treated cells, here chromosomal condensation and multipolarity were the most prevalent types of aberrations observed. This result indicated that both clastogenic (capacity to induce structural defect in chromosome) and/or aneugenic (ability to induce numerical aberration in chromosome number) modes of chromosomal instability were induced by CC- and CG-toxins in tobacco BY-2 cells. All results are displayed in Fig. 5.

Discussion

The hemibiotrophic lifestyle characteristic of many *Colletotrichum* species combines an initial short biotrophic phase, during which the host cell remains alive, followed by highly destructive necrotrophic development characterized by extended areas of killed host tissue, which occurs between 48 and 72 h post inoculation, depending on environmental conditions. During the necrotrophic phase, secondary hyphae are known to breach the plasma membrane, cause extensive degradation of plant cell walls and kill the host cells facilitating fungal ramification within the tissue [22]. *Colletotrichum* spp. are known to produce phytotoxic

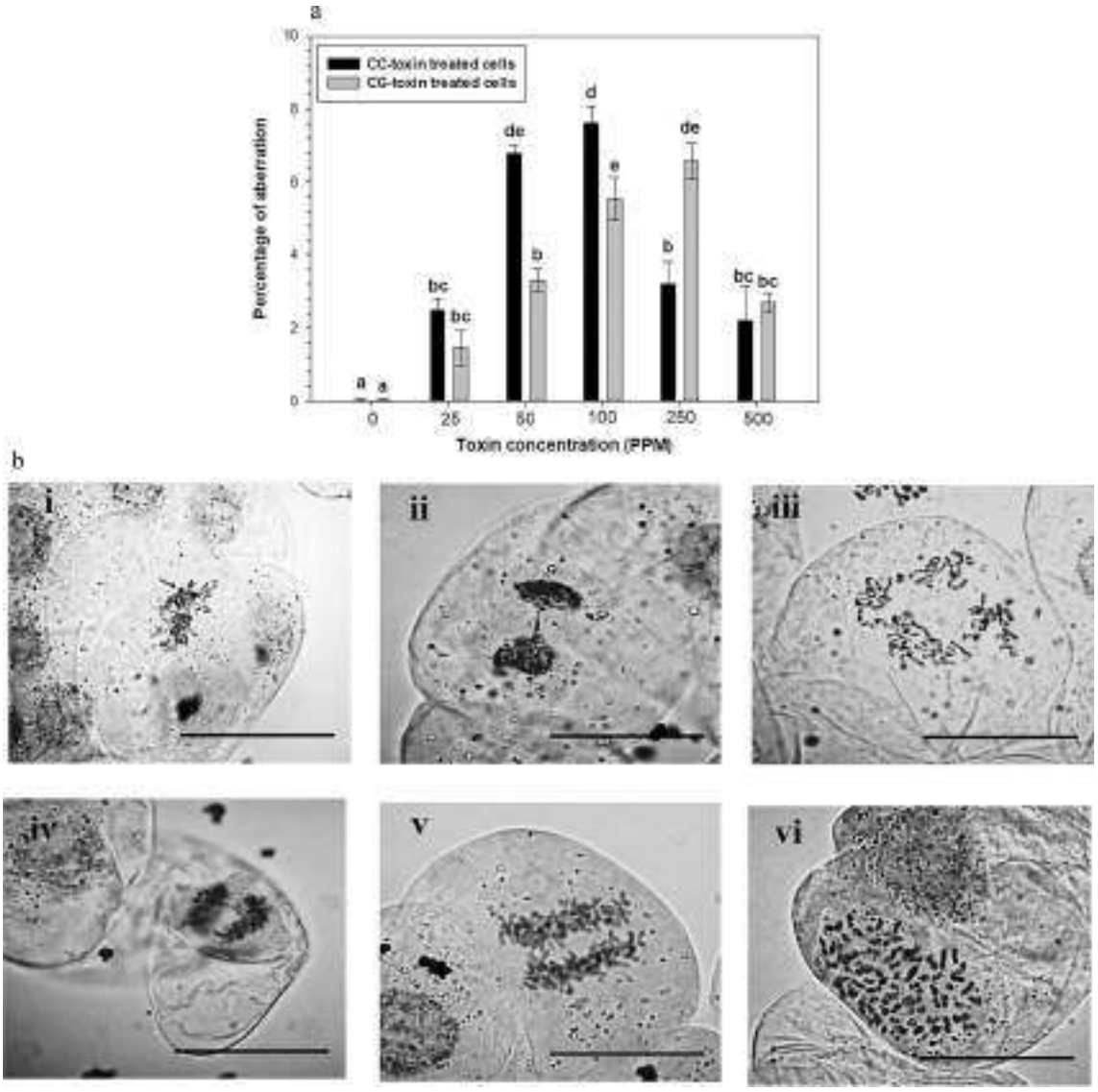


Fig. 5 Chromosomal aberrations induced by CC- and CG-toxins in tobacco BY-2 cells. **a** graphical representation of percentage of aberration; Different alphabets indicate significantdifferences ($P < 0.05$) compared to control by Holm-Sidak multiple comparison test **b** pictorial representation of different types of aberrations observed (i) clumped metaphase, (ii) telophase bridge, (iii) multipolarity, (iv) anaphase bridge, (v) early separation, (vi) aberrant chromosome condensation. Scale bar represents 50 µm

metabolites which when applied to host leaves induced symptoms, similar to those of the anthracnose caused by the fungus [21]. While these toxic concoctions have been shown to play a significant role in pathogenesis and infection mechanism, the exact cellular events that occur in the host cells upon exposure to these toxins are less explored. It is possible that these toxins primarily act as cytotoxic and genotoxic agents that physically damage cells and organelles, damage genomic DNA and eventually lead towards initiation of cell death cascades. In the present study, we assayed cytotoxic and genotoxic activities of different concentrations of CG- and CC-toxins extracted from *C. gloeosporioides* and *C. capsici* respectively, the causal organisms of the dreaded anthracnose disease, using tobacco BY-2 cells as a model system. This study is important to understand the effects of CC- and CG-toxins and draw a comparison between the potency of the toxins. Though it is not possible to estimate the exact amount of toxin that a particular host cell is exposed to during the process of infection, we attempted to simulate exposure concentrations by using a broad range of concentrations of the toxins.

A remarkable decrease in the viability of tobacco BY-2 cells was observed as the concentration of both toxins increased from 25 to 500 PPM, which indicated the cytotoxic potential of the CC- and CG-toxins. CC-toxin showed higher cytotoxic effect than CG-toxins in terms of cell viability; BY-2 cells exposed to CC-toxins reached an IC_{50} value at 100 PPM concentration, whereas CG- toxin treated cells showed IC_{50} value at 250 PPM. Such reduction in cell viability was previously reported in BY-2 cells treated with crude fungal toxins of *Alternaria alternata* [33]. It is noteworthy that in plant-fungi interactions, host cell death is a characteristic symptom, though the mode of cell death is a very complex process, which can arguably be either beneficial for the fungi to induce further infection or it can act as defensive strategy for the host cell [43]. Different types of programmed cell death mechanisms, such as, apoptosis, autophagy and necrotrophy, can be incited by different fungal pathogens. Further research is necessary to understand the exact sequence of induction of cell death cascades and also the factors affecting host cell viability for an exact insight into fungal pathogenicity.

Mitotic index (MI) is another important parameter used to assess the cyto- and genotoxic potential of compounds [37]. MI of tobacco BY-2 cells was found to be drastically reduced when they were exposed to CC- and CG-toxins, when compared to the unexposed cells. MI basically indicates rate of cell proliferation and measures the ratio of the number of cells undergoing mitosis and total number of cells in a population. Several workers have used this parameter to assess the effect of fungal toxins on proliferating tissues, and have found that MI declined in exposed cells [18, 25, 29]. In the present study, CC-toxin treated sets recorded comparatively lower MI when compared to CG-toxin treated sets at similar concentrations (~ 4.84- and 3.63-fold decrease in case of CC- and CG-toxin respectively at 500 PPM), even though, MI decreased significantly ($P < 0.05$) in both the toxin treated sets in a concentration dependent manner. Therefore, these results underlined cytotoxicity as well as genotoxicity of CC- and CG-toxins on tobacco BY-2 cells.

Decline in MI can also indicate an anomaly in the cell cycle progression, which might either be the result of arrest of dividing cells at the G2 phase of cell cycle or due to blockage in DNA synthesis [38]. In the present study, flow cytometric analyses revealed that the cell cycle phases was disrupted in cells treated with both the toxins. A dose dependent increased accumulation of cells in G0/G1 phase and concomitant decrease in G2/M phase cells recorded in the toxin treated cells when compared to untreated control cells clearly indicated arrest in cell cycle progression. Several cell cycle checkpoints such as G1/S, S-phase, and G2/M checkpoints are involved in the regulation of cell cycle. Moreover, several signalling pathways control these checkpoints [17]. In addition, regulation of these checkpoints has direct correlation with nuclear DNA damage. Results from the present study have suggested that the CC- and CG-toxin treated cells were arrested largely at the G1/S checkpoint which caused a decrease in the G2/M phase cell population. Since arrest at the G1/S phase is known to indicate an inhibition of damaged DNA replication and arrest at the G2/M phase in segregation of damaged chromosome during mitosis [24], the next set of experiments were designed to look into the extent of DNA damage and chromosomal aberrations in BY-2 cells due to toxin exposure.

In tobacco BY-2 cells, comet analysis revealed a gradual increase in DNA damage with CC- and CG- toxins doses, which confirmed the genotoxic potential of these toxins. However, the extent of DNA damage was remarkably higher in CC-toxin exposed cells than those cells that were exposed to CG-toxins. Several mycotoxins are reported as genotoxic agents, such as aflatoxins, ochratoxins, and some *Penicillium* toxins etc. [40]. Among these, Aflatoxin B_1 is deemed as most potent genotoxic agent capable of inducing DNA damage in experimental models [41]. Also, Ochratoxin A and B, a group of mycotoxins produced by some species of *Aspergillus* and *Penicillium* has been reported to induce DNA damage in rats and other animals [35].

Chromosomal aberration analysis is a parameter used for assessment of the genotoxicity as well as mode of action of the genotoxic compound [26]. It is obvious that stalling of the cell cycle essentially begins with hindrance in chromosome dynamics [4]. Thus, for clarity in comprehension of the possible causes behind the disruption of cell cycle observed after CC and CG-toxin treated tobacco BY-2 cells, it was essential to focus on the segregation of chromosomes during mitosis which exclusively depends on the mitotic spindle. The binding of spindle microtubules to centromeres and, depolymerization and polymerization of microtubules

actually controls the molecular mechanism of mitotic segregation. Therefore, any changes in the mitotic spindle and/or problem in faultless attachment to the chromosome can create several types of chromosomal aberrations [5, 11]. Interestingly, the present investigation showed that chromosomal aberration (CA) frequencies significantly increased as MI depression levels increased in CC- and CG- toxin treated BY-2 cells; highest rates of chromosomal aberrations were noted in 100 PPM and 250 PPM CC-toxin and CG-toxin treated BY-2 cells respectively, given that at the highest concentration of either toxin > 50–60% cells were unviable. Anaphasic and telophasic sticky bridges were most predominant in the CC-toxin exposed cells, which are known to happen in response to depolymerization, degradation or entanglement of inter-chromosomal chromatin fibres [6]. Such sticky bridge formations represent the clastogenic potential of CC-toxin [20]. On the other hand, pre-mature chromosomal condensation and multipolarity were most predominant in CG-toxin exposed cells. Multipolarity connotes inappropriate attachment of spindle fibre to the centromere of chromosomes [11] and represents the aneugenic potential of CG- toxin. Anomalies in chromosomal condensation indicated the changes of physiochemical structure of DNA and/or proteins, considered as one of the signature traits of toxicity [3, 10]. Even though, prevalence of sticky bridges was highest in CC-treated cells and anomalous chromosome condensation in CG-treated cells, all the types of chromosomal aberrations mentioned above were observed after both treatments, albeit at different frequencies. This indicated that CC- as well as CG-toxins can act as both clastogenic and aneugenic agents.

Finally, in addition to cytotoxic and genotoxic analysis of tobacco BY-2 cells upon exposure to CC and CG-toxin, the present study also assayed alteration of nDNA content that provided an insight into the genotoxicity of these fungal toxins. The outcome of this study revealed significant reduction in nDNA content upon exposure to both the toxins at specific concentrations and time points. A probable explanation is clastogenic DNA damage caused by both the toxins may have led to the loss of chromosome portions. Another probable explanation is that enhanced DNA condensation, as observed in CG-toxin treated BY-2 cells, lowered the binding affinity of Propidium iodide (fluorescent intercalating agent) to DNA structure which in turn lowered the estimation of nDNA content [8].

Conclusion

From the present experiments it is clear that both the toxins imparted cytotoxic as well as genotoxic effects on BY-2 cells, but CC-toxin was found to exhibit higher lethal effects on tobacco BY-2 cells than CG-toxin. The cells exposed to CG-toxin showed equivalent cytotoxic and genotoxic effects at comparatively higher concentrations than those exposed to the CC-toxin. Further studies on characterization of these toxins and understanding the molecular mechanisms of the observed cyto- and genotoxic effects would be useful in fully comprehending the roles of fungal toxins in plant-pathogen interactions, and devising plant protection strategies.

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Author contributions All authors have direct contribution to the work. SS designed the experiments, and prepared manuscripts, SS and SM conducted experiments, analysed data. MB checked the manuscripts and supervised the study.

Declarations

Conflict of interest The authors would like to declare that there is no conflict of interest. No commercial or industrial funding is involved in this study. MB is the member of the Editorial Board, but did not participate in decision making.

Ethical approval Not applicable.

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874. Assessment of Science PCK: A Review

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ABSTRACT

The introduction of "pedagogical content knowledge" (PCK) by Professor Lee S. Shulman in 1985 laid the foundation of worldwide research regarding the PCK conceptualization. These researches specified two distinct aspects of PCK, i.e., theoretical or cognitive and practical or enacting. The theoretical or cognitive aspect depicts PCK as a common or individual professional understanding or comprehension that can be shared among teachers or academicians (planning and reflection phase), whereas the practical or enacting aspect depicts its idiosyncratic nature during classroom actions, i.e., the teacher's execution or enactment of their PCK understanding in specific contexts in terms of classroom teaching (interactive phase) (Carlson & Daehler, 2019; Fenstermacher, 1994; Gess-Newsome, 2015; Park & Oliver, 2008a; Park & Suh, 2015; Schmelzing et al., 2013; Smith & Banilower, 2015). Therefore, to include the concept of PCK (theoretically and practically) in the formal teacher education system besides science PCK conceptualisation, a comprehensive framework regarding the assessment of science PCK needs to be addressed. The present study tried to find the answer regarding 'how to capture the theoretical and practical form of science PCK' in terms of significant findings and contributions through a critical and extensive review of several related studies, including research articles, book chapters, and theses from PCK's origin to present scenario.

Keywords: Pedagogical content knowledge (PCK), Theoretical & practical aspects of PCK, Assessment of science PCK

Prelude

Professor Lee S. Shulman's (1986) observation regarding the lack of research in the field of "how do teachers transform their understanding of it into instruction that their students can comprehend?" (p. 8), i.e., the "Missing Paradigm" (p. 7) in teacher education research laid the foundation of "pedagogical content knowledge" (PCK) during his presidential address to the American Educational Research Association (AERA) in 1985. After the introduction of PCK by Shulman, worldwide research has been conducted in conceptualising the science PCK (Roy & Bairagya, 2019) along with the first (2012) and second PCK Summit (2016), where the "consensus model" (CM) and "refined consensus model" (RCM) of PCK were developed respectively (Berry, Friedrichsen, & Loughran, 2015; Hume, Cooper, & Borowski, 2019).

In this process of PCK conceptualisation, researchers have specified two distinct aspects of PCK, i.e., theoretical or cognitive and practical or enacting. Various terminologies were used to portray it, as shown in Table 1. The theoretical or cognitive aspect depicts PCK as a common or individual professional understanding or comprehension that can be shared among teachers or academicians (planning and reflection phase), whereas the practical or enacting aspect depicts its idiosyncratic nature during classroom actions, i.e., the teacher's execution or enactment of his/her PCK understanding in specific contexts in terms of classroom teaching (interactive phase) (Carlson & Daehler, 2019; Fenstermacher, 1994; Gess-Newsome, 2015; Park & Oliver, 2008a; Park & Suh, 2015; Schmelzing et al., 2013; Smith & Banilower, 2015).

Table 1- Terminologies used to describe theoretical and practical aspects of PCK

Researcher	Theoretical aspect of PCK	Practical aspect of PCK
Tamir (1988)	Knowledge (knowing that)	Skill (knowing how)
Fenstermacher (1994)	Theoretical–formal PCK	Practical knowledge

Van Driel et al. (1998)	----------	Craft knowledge
Knight (2002)	Propositional PCK	----------
Park & Oliver (2008a)	PCK Understanding or PCK-on-action	PCK Enactment or PCK-in-action
Schmelzing et al. (2013)	Declarative PCK	Procedural PCK
Smith & Banilower (2015)	Canonical/Collective PCK	Personal PCK
Park & Suh (2015)	Indispensible PCK	Idiosyncratic PCK
Gess-Newsome (2015) (CM-2012)	Personal PCK	PCK & Skill
Berry, Depaepe, & Van Driel (2016)	Static Perspective of PCK	Dynamic Perspective of PCK
Carlson & Daehler (2019) (RCM-2017)	collective PCK" (cPCK) & personal PCK (pPCK)	enacted PCK (ePCK)

Now, the question comes of *how to capture these two forms of PCK*. The present study tried to find the answer through a critical review of several related studies from the origin of PCK to current scenario.

Rationale

As a teacher's unique professional knowledge base PCK acts as an essential determinant of effective science teaching (Mulhall, Berry, & Loughran, 2003; Ratcliffe, Harris, & McWhirter, 2004; Shulman, 1987; Smith & Neale, 1989), which make it a significant component of teacher preparation programmes (Anderson and Mitchener, 1994; Cochran, King & DeRuiter, 1991 & 1993; Shulman, 1986; Veal & MaKinster, 1999). Therefore, to include the concept of PCK (theoretically and practically) in the formal teacher education system besides science PCK conceptualisation, a comprehensive framework regarding the assessment of science PCK needs to be addressed.

Statement of the Problem

The present study is stated as: "Assessment of Science PCK: A Review''.

Objective of the Study

The prime focus of this study is to find the answer regarding *how to capture the theoretical and practical form of science PCK* and represent a comprehensive framework regarding the science PCK assessment.

Methodology

This study comprises of critical review of several related studies (more than fifty) that have been portrayed in chronological fashion starting from 1987 to 2019. Therefore, the present study is a qualitative enquiry through content analysis.

Chronological review regarding science PCK assessment

Hashweh (1987) in a study with six science teachers (three from Physics and three from Bio-science) utilised three different tasks completion (summarisation of a topic, concept maps drawing, and exam questions sorting) followed by a structured interview to assess their knowledge of content and general pedagogy in both Physics and Biology in the milieu of science PCK. He found teachers from Bio-sciences effectively identified and assessed those pre-and miss-conceptions of students regarding a particular Biology topic like the *Dark Phase of Photosynthesis* and knew how to deal with these, with appropriate instructional strategies and tools by advocating useful analogies, examples, models, and demonstrations but despite their teaching experience they possess general ideas regarding teaching difficult concepts of Physics. Similarly, Physics teachers were very good in arranging instructional strategies to effectively deal with students' difficulties regarding a particular Physics topic, but not in the case of specific Biological topics. These findings infer that content knowledge plays a crucial role in developing PCK and makes PCK subject specific knowledge.

Smith and Neale (1989 & 1991) focused on primary science teaching and studied ten teachers' PCK in the perspective of substantive content knowledge, science pedagogy and students' knowledge of the in-service teachers by building a programme around a "conceptual change model" of instruction (Smith & Neale, 1989, p. 2, & 1991, p. 187) concentrating upon the students' general misconceptions in a four week summer workshop with a follow up in the schools too. The application of this model revealed teachers' orientations regarding identifying students' difficulties and resolving their inconsistencies in different science concepts. Pre and during workshop video records of teachers' instructions, audio records of their interviews, and teachers written journal were analysed to document the changes. By transcribing and using independent raters' coding, Smith and Neale documented teachers' class room translation of substantive content in the aspect of science PCK, i.e., "knowledge of children's ideas in science", "teaching strategies", and "uses of metaphors, analogies, and examples in lessons" (Smith & Neale, 1989 p. 12). In this study they used following "orientations to teaching and learning science", i.e., "discovery", "processes", "didactic/content mastery", and "conceptual change" (Smith & Neale, 1989 p. 10).

Geddis (1993) used multiple choice questions along with a vignette of a set of pre-service secondary science teachers as they reflected on learners' misconceptions about the Physics topic "Electrical Current" to illustrate how inquiring into the way wherein learners would reasonably possessed such conceptions that can lead to content representations and instructional strategies with the ability for advancing the reasoned adoption of a logical view of "Electrical Current". He focused on "learning how to teach" (Geddis, 1993, p. 673), i.e., how the novice teachers' subject-matter knowledge transforms into a form that can be comprehended by particular learners. He concluded that pre-service teachers' simplistic view on teaching changed on the account of their real classroom exposure making them more aware in acquiring PCK, which is crucial in terms of "learning how to teach", i.e., transformation of subject-matter knowledge and reflections upon achieving it. He also suggested that teacher preparation programmes needed to be more focused on making pre-service teachers aware of the alternative conceptions of science topic possessed by learners even after instructions are being carried out.

Geddis et al. (1993) used case study method including a vignette, lesson planning, audio-recorded and transcribed interviews of two student teachers and their cooperating teachers and field notes of their teaching to explore the role of PCK in enunciating the approach of subject-matter transformation for teaching-learning, i.e., "learning to teach about isotopes" (p. 1). Their conclusion is quite similar to Geddis (1993), in addition they suggested adequate acquisitions of students' knowledge, knowledge of effective instructional strategies, and alternative representations along with curricular saliency of content that are crucial for a novice teacher to teach which make these PCK components essential part "for any teacher education methods curriculum" (p. 589).

Gess-Newsome and Lederman (1993) investigated 10 pre-service Biology teachers' content stability and knowledge, i.e., "subject matter structure" (p. 26) using open-ended qualitative approach in a multiple case study design through interviews. In this study the samples were asked to give their individual responses to open questions in two phases where liberty of concepts, ideas, and etc. selection was given to them to present their best views on subject matter representations, like first phase includes:

"1. What topics make up your primary teaching content area? If you were to use these topics to diagram your content area, what would it look like?" and

"2. Have you ever thought about your content area in the way you have been asked to do so above?" (pictorial representations approach) (p. 28).

Open questions were presented before them at four different times, i.e., first day of method course; again during mid-term (five week later); then at the end of the ten week term (2nd question replaced

with "Have your views changed? If so, how and why?", for the 2nd and 3rd administrations); and during internship (four months later), i.e., the second phase. Data were analysed qualitatively concerning to find out relational patterns among the ideas or concepts regarding subject-matter representations and changes in it over time of each of the cases. Initial data revealed lack of coherent knowledge and stability of subject matter structures among pre-service teachers regarding Biology content representations. But, analysis of fourth set of pictorial representations (accomplished during internship) to study pre-service teachers' PCK revealed that samples included scientific methods, problem solving, etc. in their representations (Figure 29). Gess-Newsorne and Lederman concluded that repeated exposures to pictorial representations of subject-matter helped pre-service teachers to develop a "coherent structure for their subject matter" (Gess-Newsorne & Lederman p. 43).

a) 1st phase's subject matter structure **b) 2nd phase's subject matter structure**

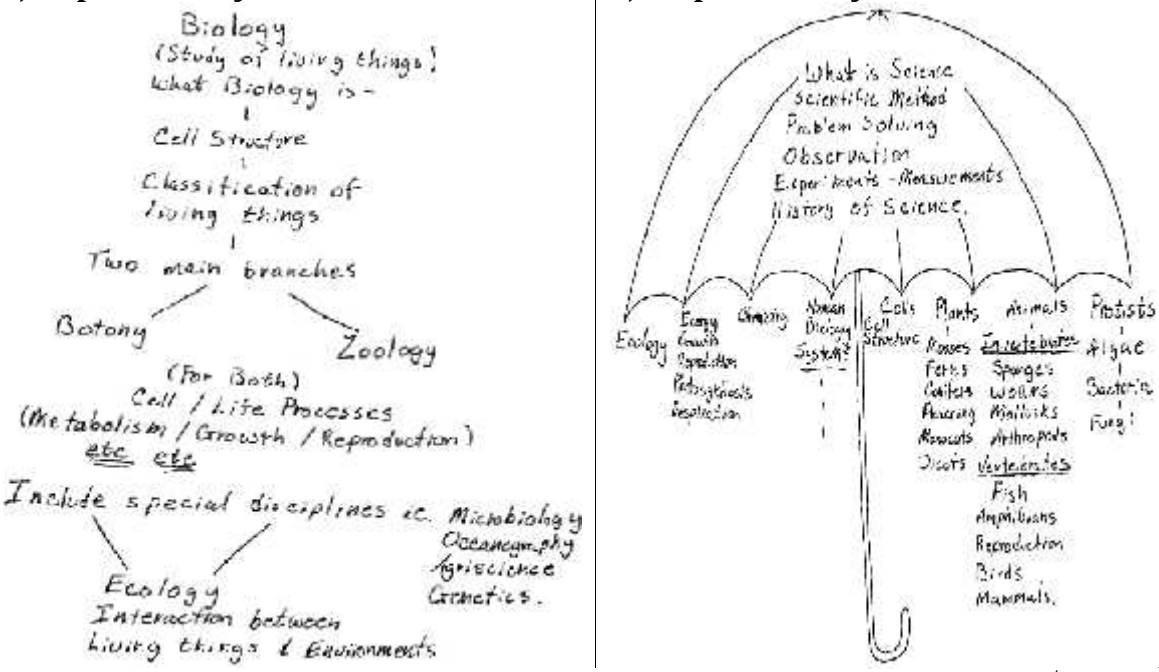


Figure 1: Comparison between pictorial representations of same individual between 1st and 2nd phase responses. (Gess-Newsorne & Lederman, 1993, p. 33 & 37)

Baxter and Lederman (1999) wrote a chapter on "Assessment and measurement of pedagogical content knowledge" in the very first edited book on science PCK, i.e., "Examining pedagogical content knowledge" (Kluwer Academic Publishers) (Gess-Newsome & Lederman, 1999). Here, they categorised the methods of PCK evaluation into three categories: (a) "convergent and inferential techniques"; (b) "concept mapping, card sorts, and pictorial representations"; and (c) "multi-method evaluations" (Baxter & Lederman, 1999, p. 149). "Convergent and inferential techniques" comprises Likert-type scales, multiple-choice items and short answer formats using "predetermined verbal descriptions" of required field to compare verbal responses of the pre- and in-service teachers (Baxter and Lederman, 1999, p. 149). Concept organisation of a teacher can be traced through "concept mapping" as it is a product of long term memory retrieval (Baxter & Lederman, 1999, p. 151 & 152). Card sorting is a flexible alternative of concept mapping used first by Shulman and his students where a set of "cards", each comprising a specific concept, idea, principle, etc. of a subject are supplied to the respondents and they have to organise these cards in such a meaningful way that best establishes the relationship among the contents of the cards by placing and arranging them appropriately (Baxter & Lederman, 1999, p. 152). In "pictorial representations" respondents are provided with freedom to choose any subject concept to give a diagrammatic representation of it in carrying out classroom

instructions. This method is first used by Gess-Newsome and Lederman in 1993 (Baxter & Lederman, 1999, p. 152). Multiple methods comprise data collections using a number of different techniques together like interviews, concept maps, video recording, etc. to infer a general outline regarding teachers' PCK (Baxter & Lederman, 1999, p. 154).

Van Driel, De Jong, and Verloop (2002) designed "a qualitative in-depth study" and used "multimethod" (p. 356) approach to investigate the PCK development within a group of 12 pre-service Chemistry teachers (all having M.Sc.) during one-year post-graduate teacher education course involving employing questionnaire regarding content knowledge and PCK followed by conducting workshop sessions with them (video recorded) followed by interviewing the samples along with their mentors and finally again followed by employing another set of similar questionnaire but this time concerning only on PCK. They found the pre-service teachers showed a marked PCK development during the course and the workshop sessions contributed significantly.

Loughran et al. (2004, 2008 & 2012) introduced and used *CoRe* and *PaP-eRs* as tools to "uncover, document, and portray science teachers' PCK" (Loughran et al., 2004, p. 373), i.e., scaffolds to support PCK development (Berry, Depaepe & Van Driel, 2016, p. 363). They came up with the idea that a science teacher's pedagogical reasoning through decision making makes PCK evident within the given teaching-learning context of specific topic, therefore, science teachers' PCK can be portrayed by combining *CoRe* ("which offers a holistic overview of particular science concepts"), and *PaP-eRs* ("which illustrate specific aspects of the content within the complexity of a science teaching/learning experience") to construct "resource folio of PCK" for a given content area (Loughran, et al., 2012, p. 21). Loughran et al. (2008) utilised a modified and well structured framework of *CoRe* and *PaP-eRs* through teacher education programme where prospective science teachers developed their own *CoRe* and *PaP-eRs* that resulted in gaining in-depth insights regarding conceptualising and understanding science teaching.

Miller (2007) analysed a number of researches on science PCK and like Baxter and Lederman (1999) classified the methodologies used in capturing PCK in to three categories: (a) "convergent and inferential techniques"; (b) "visualisation techniques"; and (c) "multiple-method evaluation/analysis" (Miller, 2007, p. 89 & 95). "Convergent and inferential techniques" entail pre-structured verbal expression of teachers' data relating to PCK by using Likert-scale survey, pre- and post-assessment, multiple choice responses and short-answer tasks (Miller, 2007, p. 91). "Visualisation techniques" comprise concept mapping, use of vignettes, and analogies construction entailing physical illustration of teachers' data, i.e., illustrating teachers' views on PCK (Miller, 2007, p. 92). "Multiple-method analysis" is most often used technique in PCK researches that features uniting of data from multiple sources using interviews, responses, observations, reflections and course materials with visualisations, and convergent and inferential techniques to assess teachers' perspective relating to PCK (Miller, 2007, p. 95).

Ozden (2008) advocated multiple methods like lesson planning, content knowledge tests, and semi-structured interviews upon 28 science student teachers and investigated the effect of the amount and quality of their content knowledge on PCK on the Chemistry topic "phases of matter". In this study each of them prepared a lesson plan on the topic within one hour for a two hour class period without any helping materials like books, etc., followed by a content knowledge test and semi-structured interviews to assess and determine their subject matter understanding, the difficulties faced during lesson preparations, knowledge of instructional strategies, learners' knowledge, and expected complexities in teaching. Ozden found that science student teachers possess basic comprehension, little misconceptions and insufficiencies at conceptual level of subject matter knowledge and inferred PCK is positively influenced by content knowledge.

Rollnick et al. (2008) carried out two case studies of Chemistry teaching and multiple sources of data collection to investigate the content knowledge on PCK of teachers. One case study focused on the content knowledge of "mole" of two high-school teachers and the other one focused on a lecturer's lessons on "chemical equilibrium" at tertiary level. Data collection included pre-and post-lesson interviews, 2 or more lesson observations (video and audio recorded), and analysis of various teachers' resources, in addition to these before the lessons delivery on "mole" teachers were exposed in a short workshop covering conceptual approaches regarding effective strategies to teach the concept. Teachers' subject-matter comprehension, planning regarding instructional strategies to be carried out, and the material resources utilised in the lesson preparations were explored through the pre-lesson interviews, whereas a "stimulated reflection on the lesson" (p. 1368) was included in the post-lesson interviews. They used "content representations" (*CoRes*) and "pedagogical and professional-experience repertoires" (*PaP-eRs*) (Loughran, Berry, & Mulhall, 2004 & 2012) as methodological tools for data analysis, i.e., capturing and portraying teachers' PCK.

Park and Oliver (2008a & b) focused on case study design taking three experienced high school science teachers and assessed their PCK through multiple sources comprising teaching observations in combination with semi-structured interviews to comprehend their actions and knowledge in executing the lesson plans prepared by them followed by their written reflections on their own teaching, along with work samples of students, and field notes of the researcher (1^{st} author) after each classroom observation. Collected data were analysed through (a) "constant comparative method" focusing upon the regularities or patterns identification; (b) "enumerative approach" focusing on individual teacher's PCK characteristics identification by reducing the subjective nature of qualitative coding through developing "PCK Evidence Reporting Table" (*PCK ERT*) using five PCK components with sub-categories from pentagon model (Figure 18) (Park & Oliver, 2008b, p. 815) and coding process with help of "Atlas.ti qualitative data analysis software"; and (c) "in-depth analysis of explicit PCK" to assess the PCK evidence from teaching observations by following three aspects, i.e., teacher's actions, justification of such actions, and what she knew (inter-rater reliability was 92%) (Park & Oliver, 2008a, p. 267 & 268). These data were combined together to ensure the credibility of their study and the findings of this study are already discussed above.

Rohaan, Taconis, and Jochems (2009) developed a time and labour-efficient standardised multiple-choice test to measure teachers' PCK in primary technology education named "Teaching of Technology Test" on a large scale basis via following seven phases: (1) *specification of the theoretical framework*; (2) *construct analysis*; (3) *specification of item characteristics*; (4) *production of items*; (5) *judgment of items*; (6) *construction of the instrument*; and (7) *validation of the instrument* (p. 327). Here, theoretical framework used as main guidance in instrument construction by forming working definition whereas construct analysis contains description of typical teaching-learning phenomena or situations in terms of item scenarios or contexts. Judgment of items were accomplished by the efforts of an expert team consisted of seven members and comparisons of the results with the experts' judgments provided the test validity. This test consists 19 items where each item contains four responses characterised as "high PCK" (best answer), "low PCK" (second best answer), exclusively pedagogical knowledge (third best answer) and exclusively content knowledge ("no PCK") (Figure 2) (Rohaan, Taconis, & Jochems, 2009, p. 334). This test got a satisfactory level of reliability as the test and re-test scores correlated significantly ($r = 0.641$, $p < 0.05$).

Two pupils together make a car out of cardboard (see pictures above), which can move due to a rotatable axle to which wheels made from bottle tops have been attached. The car can move forwards by winding up an elastic band attached to the axle and then letting go. The pupils test their car on a smooth table. However they are disappointed to discover that although the wheels rotate, the car scarcely moves forward. The pupils suspect that their car is too heavy but do not know a solution for this problem.

Which one of the following approaches can best be used to help these pupils?

a) You join in with pupils' line of thought and from this perspective you try to help them discover the relationship between friction, drive and weight.
b) You draw the pupils' attention to the elastic band and the weight of the car and make sure that they continue searching for a solution.
c) You let the pupils compare their car with those of the other pupils so that they can reach a solution.
d) You explain to the pupils that two smooth surfaces easily move over each other due to the lack of friction. You advise them to attach elastic bands to the wheels to give these more grip.

Figure 2: Example of one test item where responses are characterised as (a) high PCK; (b) low PCK; (c) pedagogical knowledge; (d) content knowledge.
(Rohaan, Taconis, & Jochems, 2009, p. 334)

Park et al. (2011) studied the necessity of PCK for reformed science teaching by quantitatively correlating teacher's PCK with the degree of his/her classroom reform-orientation. They used "PCK rubric" that was derived from "pentagon model of PCK" (Park & Oliver, 2008b, p. 815) to measure teachers' science PCK level involving classroom teaching observations along with pre-/post-observation interviews. This rubric was designed by focusing upon the two PCK components from pentagon model: "knowledge of student understanding" (*KSU*) and "knowledge of instructional strategies and representations" (*KISR*) (Park & Chen, 2012, p. 925; Park & Suh, 2015, p. 111). The rubric was developed by a research team comprising faculty members, doctoral students, and experienced Bioscience teachers of high school comprising nine elements representing *KSU* and *KISR* at planning stage, implementation stage, and reflection of instructions as shown in Table 2.

Table 2- Elements of PCK rubrics (extracted from Park et al., 2011, p. 256 & 257)

Instruction stages	Elements
Planning	1. Understanding of prior knowledge including misconceptions 2. Instructional strategies to accommodate prior knowledge 3. Understanding of learning difficulties 4. Instructional strategies to accommodate learning difficulties

Implementation	5. Questioning to probe student understanding 6. Spontaneity to challenge misconceptions or resolve learning difficulties discovered 7. Rationale for instructional strategies and representations in connection with student understanding
Reflection	8. Focus on student understanding 9. Use of new understanding of student understanding to modify instructional strategies and representations

The draft rubric bearing specific elements of both *KSU* and *KISR* measures along with a four-point rating scale, i.e., 1="Limited" to 4="Exemplary" (for 9x4 = 36 possible total points) was tested by observing more than 45 video recorded classroom teaching and by interviewing 5 science teachers followed by revisions. Thus the final form comprises nine elements representing *KSU* and *KISR* at planning stage, implementation stage, and reflection of instructions. Reliability of the rubrics established by a high level of inter-rater reliability (i.e., $r = 0.958$, $p < 0.01$) and internal consistency (Cronbach's $\alpha = 0.73$) (Park et al., 2011, p. 251) and experts' views were taken for content related validity. In this study data were collected from 33 video recordings of classroom observations of 7 Bioscience teachers of high schools delivering lessons on either *Photosynthesis* or *Heredity* over two semesters along with pre-/post-observation teachers' interviews (Park et al., 2011, p. 251).

Hume and Berry (2011) in a study used *CoRes* construction method to observe the improvement in nine pre-service Chemistry teachers' PCK through a three hour workshop sequence, where samples were asked to identify and discuss Grade 11 students' possible preconceptions and misconceptions about the topic "atomic structure and bonding" with taking help of online resources followed by a small group (3 in each) work to discuss about the expected learning outcomes of Grade 11, 12 and 13 students (each group taking one grade) on the same topic through the analysis of relevant materials including national curriculum. They combined the teams' effort to find a general pattern "of how the sequence of concepts and skills evolved over the 3 years" (Hume & Berry, 2011, p. 347). After which the samples were provided with a vacant "CoRes template" to complete it for the topic of "redox reactions" (Hume & Berry, 2011, p. 354) along with registering "5-8 key ideas" in the template (Hume & Berry, 2011, p. 355), and after accomplishing it again samples in groups worked to explore different teaching-learning resources by identifying, assessing and registering potential teaching-learning experiences including identifying students' difficulties and any specific instructional strategies for recovery of the "key ideas" they had determined which was added to the *CoRe*. Finally each group presented and shared its template as a class discussion. Hume and Berry (2011) found that without real teaching experience these pre-service teachers developed a satisfactory level of pedagogical capacity as they showed awareness regarding identifying the general learning difficulties faced by students (misconceptions and preconceptions) as well as potential instructional strategies for effective classroom teaching. Thus, they stated:

However, if carefully scaffolded the CoRe design process enables student teachers to begin accessing and accumulating some of the knowledge of experienced science teachers in ways that can help to bolster feelings of confidence and competence when they come to organise that knowledge into their first model of PCK. (Hume & Berry, 2011, p. 354)

Nilsson and Loughran (2012) used *CoRes* approach and integrated a modified framework of *CoRes* into the elementary science method curriculum to promote PCK development and to construct PCK awareness among prospective science teachers for quality science teaching.

Mavhunga (2012), & Mavhunga and Rollnick, (2013) developed a tool to capture 16 pre-service Chemistry teachers' "topic specific PCK" (*TSPCK*) in the topic of "chemical equilibrium" by employing a case study design with mixed method approach for in-depth exploration. The tool

development process comprises the following steps: (i) *test items formulation*, (ii) *items judgment*, (iii) *instrument construction*, (iv) *pilot study* and (v) *validation of the instrument* (person reliability = 0.88, Item reliability = 0.92, and Cronbach's α = 0.89) (Mavhunga, 2012, p. 46 & 85; Mavhunga & Rollnick, 2013, p. 118 & 119). This tool is designed in accordance with five *TSPCK* components ("learners' prior knowledge including misconceptions"; "curricular saliency"; "what makes the topic easy or difficult to understand"; "representations including powerful examples and analogies"; and "conceptual teaching strategies") considering each component as a test item along with 2 to 4 sub-questions (5 items with 22 questions in total) (Mavhunga, 2012, p. 73; Mavhunga & Rollnick, 2013 p. 118). This tool comprises both open and semi-closed test items and similar to the Park et al. (2011) these responses (Figure 3) were captured and scored with the help of a rubric in correspondence with five *TSPCK* components with each being rated on a four point scale, i.e., 1="Limited" to 4="Exemplary" (Figure 4) (Mavhunga, 2012, p. 78; Mavhunga & Rollnick, 2013 p. 119). The first administration of the tool was followed by an intervention over 6 weeks (2 sessions per week, 100 minutes for each session) involving component wise theoretical understanding and explicit discussions on *TSPCK* in "chemical equilibrium". After this intervention the tool was again administered to the same participants. The analysis of participants' pre- and post-intervention data revealed that this intervention helped the pre-service teachers to improve their capability to reason about the teaching of the topic.

CATEGORY A: STUDENTS' PRIOR KNOWLEDGE

1. What comment would you write on a learner's script who writes:

A reaction reaches equilibrium when the concentrations of the products and reactants are equal.

Response A: No; when a reaction reaches equilibrium it does not mean the concentrations of the reactants and products are equal. The concentration of reactants and those of products are not equal at equilibrium. Sometimes the concentration of reactants is more than that of products and vice-versa. It depends on the type of reaction.

Response B: No; when a reaction reaches equilibrium the concentration of the products and the reactants are not equal. Equilibrium is reached when both reactions proceed at the same rate.

Response C: No; the concentration of reactants and products at equilibrium are not necessarily equal. Each reagent may have its own concentration which is different to the other. What ensures a reaction to be at equilibrium is the rate at which the forward and the reverse reaction occur. For equilibrium to occur this rate must be equal for both reactions.

Response D: None of the above

Choose your response, and use the space below to expand on your choice.

Figure 3: Example of test item from Mavhunga & Rollnick's TSPCK tool.
(Mavhunga, 2012, p. 78; Mavhunga & Rollnick, 2013, p. 118)

RUBRIC FOR QUANTIFYING PCK – based on components for Topic Specific PCK

TSPCK Components	Limited(1)	(2) Basic	(3) Developing	Exemplary (4)
Learner Prior Knowledge including misconceptions	No identification/No acknowledgement/No consideration of student prior knowledge (misconceptions, alternative conceptions and correct knowledge)	• Identifies misconcept on or prior knowledge • Provides standardized knowledge as definition • Repeats standard definit on with no expansion or with incorrect explanation	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrase explanat on correctly	• Identifies misconception or prior knowledge • Provides standardized knowledge as definition • Expands and re-phrases explanation correctly • Confronts misconceptions/confirms accurate understanding
Curriculum Saliency	• Identifies concepts are a mix of Big Ideas and subordinate ideas • Identifies subordinate ideas are a mix with those of other topics or no subordinates provided • Identifies pre-concepts are a mix with those to be taught in current topic • Sequencing no value due to mixed concepts • Reasons given for importance of topic limited to generic benefit of education	• Identifies at least 3 Big Ideas • Not all 3 Big ideas have subordinate concepts identified however those identified are correct • Sequencing has one or two illogical placing of main concepts (Big Ideas) • Identifies pre-concepts are far from the current topic, they refer to concepts basic to the subject. • Reasons given for importance of topic exclude conceptual considerations such as scaffolding or sequential development for other topics in the subject.	• Identifies at least 3 Big Ideas • Identifies correct subordinate ideas and shows (symbolic) links to Big ideas with no additional explanations • Provides logical sequence of concepts of all three Big Ideas • Identifies pre-concepts includes those needed for the current topic • Reasons given for importance of topic include reference to conceptual scaffolding/sequential development of understanding of other topics in the subject however without specifying the topics	• Identifies at least 3 Big Ideas • Identifies correct subordinate ideas and explains links to Big Ideas • Provides logical sequence of all three Big Ideas • Identifies pre-concepts include those needed in discussing the introductory definitions and those sequentially needed in the next Big Ideas of the current topic • Reasons given for importance of topic include conceptual scaffolding/sequential development of understanding for specified subsequent topics in the subject.

Figure 4: A sample extract from the TSPCK rubric.
(Mavhunga, 2012, p. 79; Mavhunga & Rollnick, 2013, p. 119)

Later, in **2014**, **Pitjeng-Mosabala** investigated 16 novice science teachers' *TSPCK* in topic of "particulate nature of matter" similar to Mavhunga and Rollnick (2012 & 2013) by using their *TSPCK rubric* under the supervision of Marissa Rollnick (Pitjeng-Mosabala, 2014). Again, in **2016**, following the similar pattern **Akinyemi** studied the development of 23 pre-service Physics teachers' *TSPCK* in the topic of "kinematics" under the supervision of Elizabeth Mavhunga (Akinyemi, 2016).

Schmelzing et al. (2013) developed a paper-and-pencil test to capture both pre-and in-service Biology teachers' "declarative knowledge" (Heller et al., 2004) of PCK (PCK understanding or theoretical/canonical/collective PCK as discussed earlier) on a large scale basis comprising two test scales, namely "PCK I" and "PCK II" measuring the two components of PCK, i.e., (a) "knowledge of student learning and conceptions"; and (b) "knowledge of representations and strategies" respectively on the topic of "cardiovascular system" (Figure 5) as conceptualised by them. They formulated this test as a power test with no limitations of score as because contrary to "procedural PCK" (teacher's actions, skill, enactment during a lesson, i.e., tactic knowledge) (also kwon as "knowing how"/teachers' practical or craft knowledge/"PCK-in-action") "declarative PCK" (also kwon as "knowing that"/"theoretical–formal PCK"/"propositional PCK"/"PCK-on-action") (Baumert, Blum, & Neubrand, 2004; Fenstermacher, 1994; Knight, 2002; Park & Oliver, 2008a, Van-Driel, Verloop, & De-Vos, 1998) can be easily captured through teachers' written reflections or expressions, such as reflections of teachers' factual knowledge regarding typical learners' difficulties (preconceptions and misconceptions).

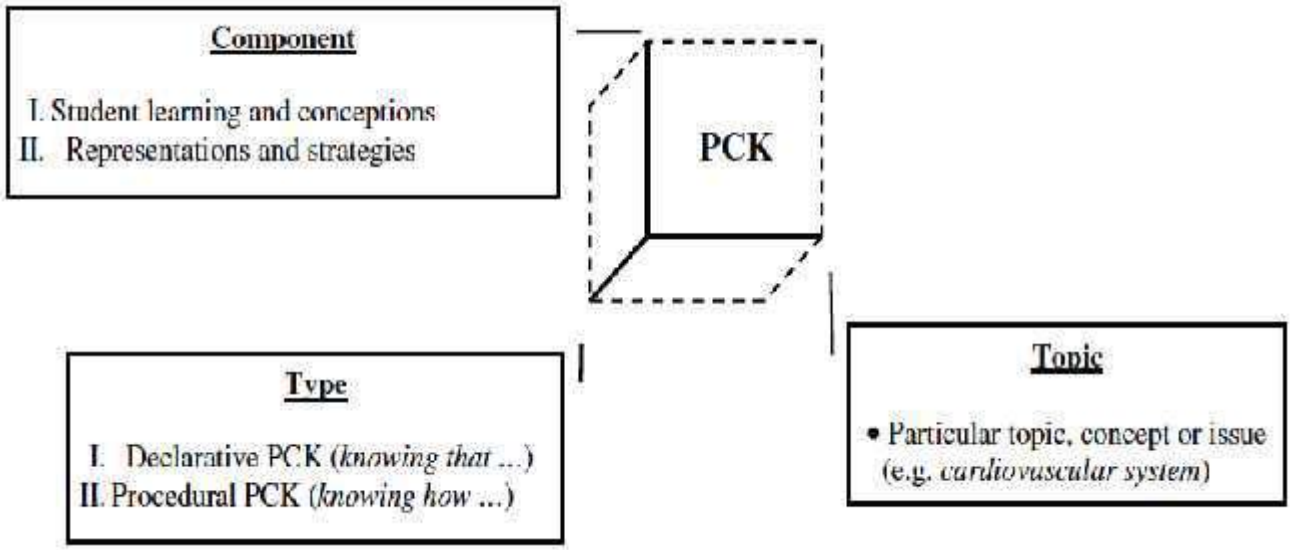


Figure 5: Schmelzing et al.'s conceptualisation of PCK.
(Schmelzing et al., 2013, p. 1373)

After completing a "theoretical-deductive conceptualisation" (literature review) (p. 1376) for the foundation of PCK test construction, 50 "cardiovascular system" lessons videos were analysed for item development followed by a pilot study, main study and validation study. They preferred open ended items where each item depicts a hypothetical teaching-learning scenario or "pedagogical context information" (p. 1378) and teacher has to give responses in written form and each valid response will carry one point (Figure 6 & 7). Written responses were judged by coding process by two independent raters. The final PCK test comprises total 15 items (5 in test scale PCK I and 10 in test scale PCK II). After final administration on 93 samples comprising both pre-and in-service teachers they found a satisfactory internal consistency (Cronbach's $\alpha = 0.85$).

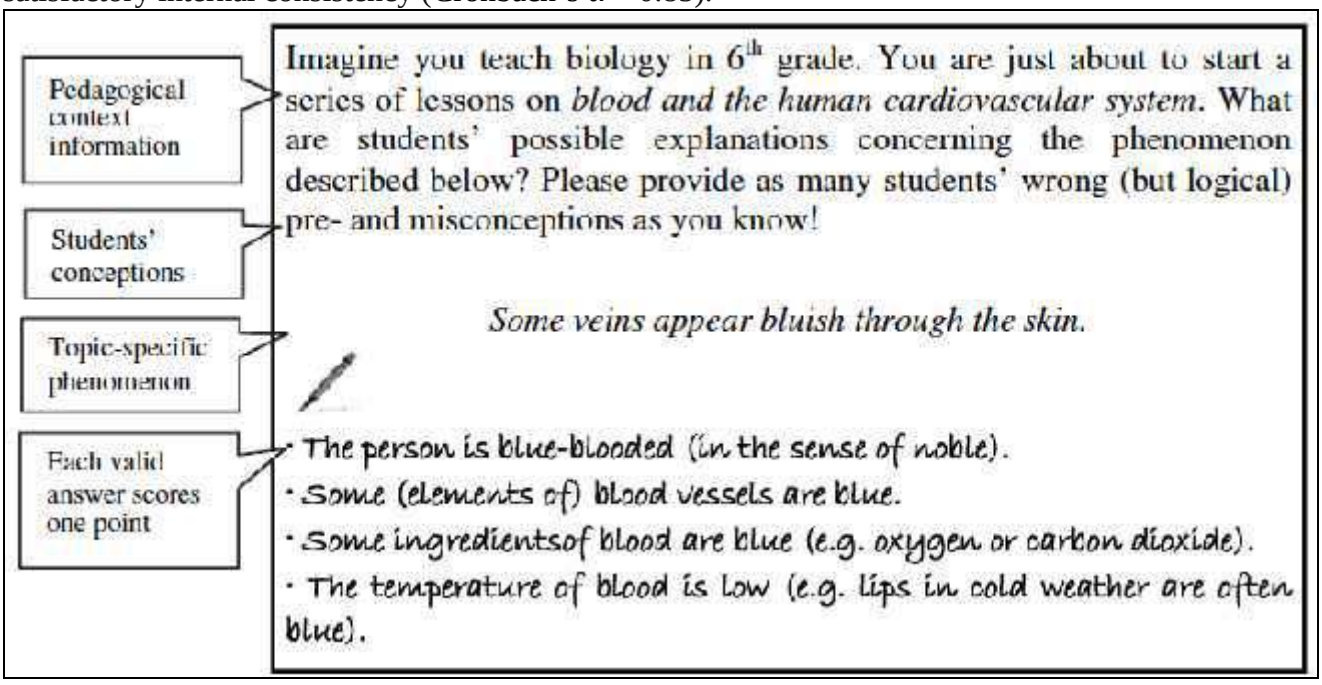


Figure 6: Example of test item of test scale PCK I. (Schmelzing et al., 2013, p. 1378)

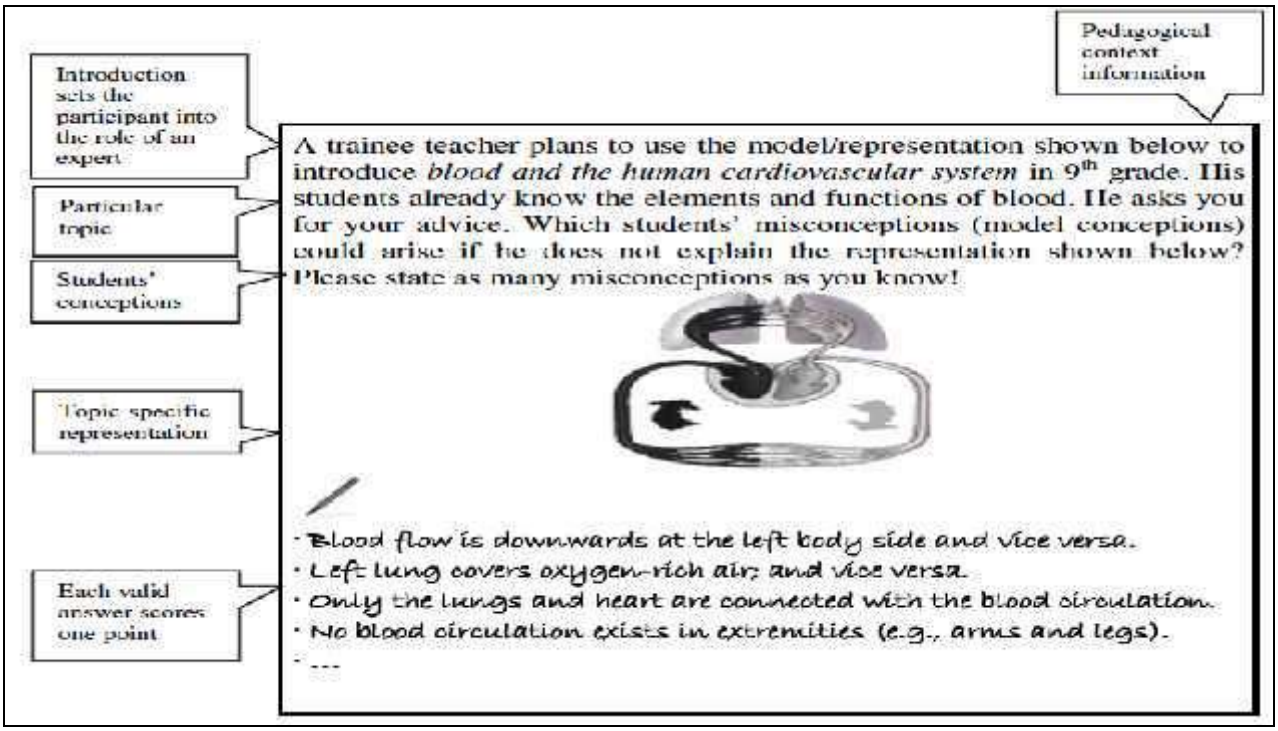


Figure 7: Example of test item of test scale PCK II. (Schmelzing et al., 2013, p. 1379)

Aksu, Metin, and Konyalioğlu (2014) developed a standardised five point rating scale (*PCK attitude Scale*) such as "strongly disagree", "disagree", "undecided", "agree" and "strongly agree" to determine pre-service teachers' PCK. The study involved 768 pre-service teachers from different grades and subject streams (science, math, social science) as samples followed five stages of scale development such as a literature review, an item pool construction, experts' opinions, scale administration, and reliability and validity computation. The final form of the scale consists of 38 items (Figure 8) having a good internal consistency (Cronbach's $\alpha = 0.967$).

Number of Items	
1	I have knowledge about the context of my lesson
2	I know the critical points of my lessons
3	I pursue the last improvement regarding teaching lessons
4	I want to participate in a seminar, symposium, workshop related to my scope
5	I pursue publication related to my scope
6	I can identify familiar national and international scientists
7	I can recognise lacking areas related to my lessons
8	I know the basic definitions in my lesson
9	I have knowledge about relation, rule and formula in my lessons
10	I know theory, axiom, theorems etc. in my lesson
11	I can realise and meet the difficulties of students during my lesson
12	I can determine that the students may be pressured in my lessons in advance
13	I can prepare an appropriate lesson plan in accordance with the point that students may be pressured in my lessons
14	I can notice misconceptions of students in the course of teaching a new topic
15	I can determine misconceptions of students while teaching new topics
16	I can select problems suitable for teaching contexts in my lesson
17	I use teaching methods and techniques suitable for the topic
18	I can contact among topics in the lesson
19	I can develop measurements and assessment tools suitable for the topics
20	I can contact between explaining the topic and other topics

Figure 8: Example of some draft items for PCK attitude scale.
(Extracted from Aksu, Metin, & Konyalioğlu, 2014, p. 1369)

Smith and Banilower (2015) specified two forms of PCK, i.e., "personal PCK" (individual teacher's ability to purposefully deliver a specific topic in a specific context developed during planning, teaching, and reflection) and "canonical PCK" (normative or collective PCK) (commonly agreed knowledge on expertises in purposefully teaching a specific topic in a specific context developed through research and/or collective wisdom of experts) (p. 90). They argued the latter one can be converted to personal one through planning to teach, executing the plan, and reflecting upon the teaching-learning process, i.e., via applications, and "personal PCK" may also develop as a distinct form through experiences related to teaching-learning, and adequate accumulations of teachers' "personal PCK" that makes it canonical or collective in nature (Figure 9) (Smith & Banilower, 2015, p. 90).

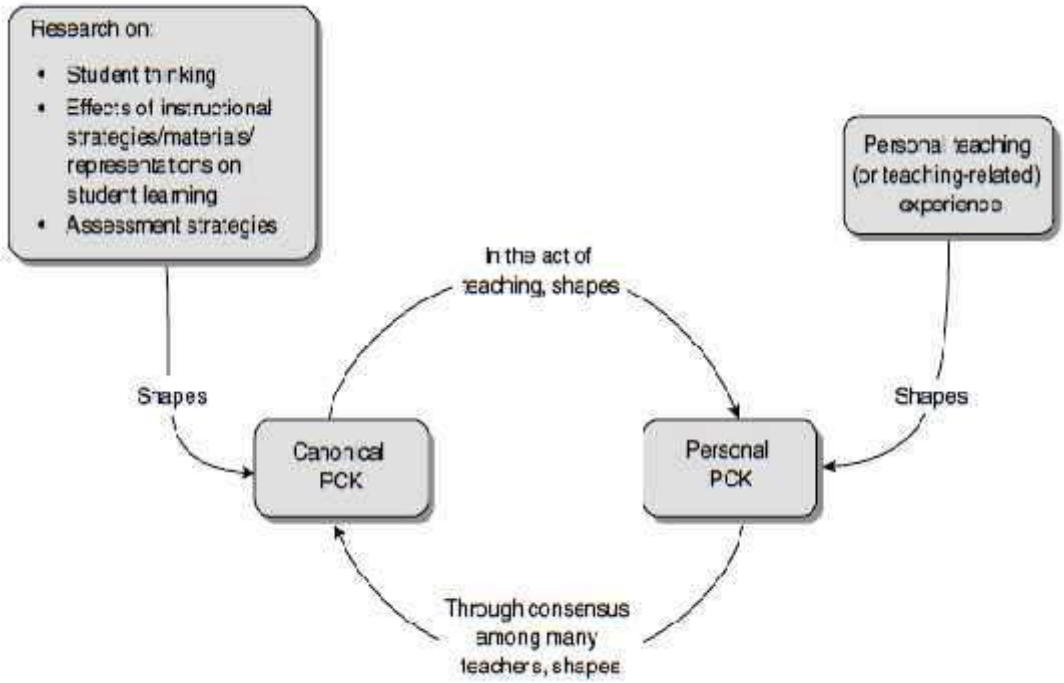
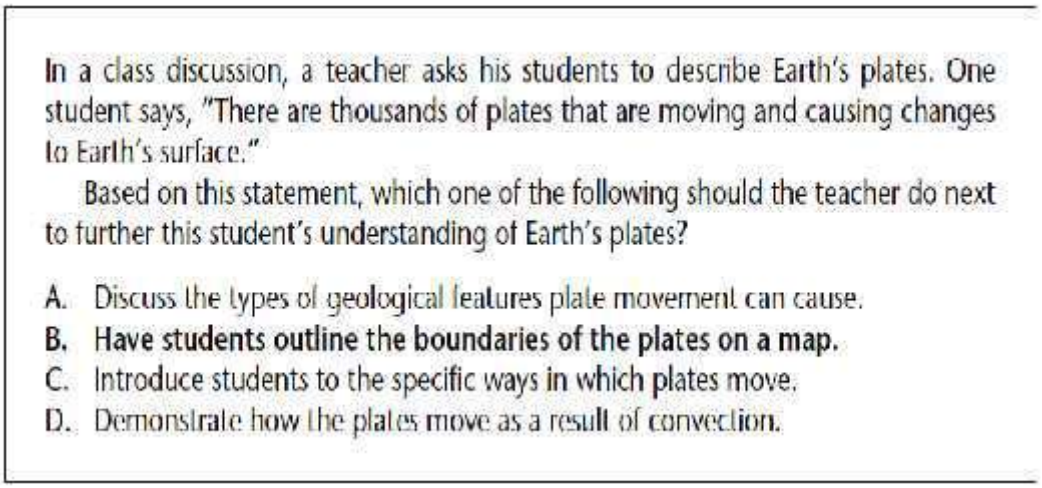


Figure 9: Smith and Banilower's model of PCK transformation.
(Smith & Banilower, 2015, p. 91)

Regarding PCK assessment like other forms of knowledge they considered PCK also as a "latent characteristic" that cannot be observed directly and only inferences can be drawn from observable behaviours through written feedbacks, interview responses, or teaching practices (Smith & Banilower, 2015, p. 92). And they designed a study to assess science PCK by opting three topics from *middle-grades science*, i.e., "flow of matter and energy in living systems"; "force and motion"; and "plate tectonics" (Smith & Banilower, 2015, p. 93). By unpacking these topics into distinct, assessable "sub-ideas", and then by taking100 *middle-grades science* teachers' feedbacks to open ended questions concerning learners' ideas and teaching regarding these topics, and with the help of literature review on learners' knowledge (mis/prior/alternative-conceptions) they developed a multiple-choice items test on science *canonical PCK* comprising items capturing knowledge regarding: students' subject-matter comprehension; topic-specific instructional approaches constructing learners' conceptual comprehension; and subject-matter for a large-scale research.



In a class discussion, a teacher asks his students to describe Earth's plates. One student says, "There are thousands of plates that are moving and causing changes to Earth's surface."

Based on this statement, which one of the following should the teacher do next to further this student's understanding of Earth's plates?

A. Discuss the types of geological features plate movement can cause.
B. **Have students outline the boundaries of the plates on a map.**
C. Introduce students to the specific ways in which plates move.
D. Demonstrate how the plates move as a result of convection.

Figure 10: Example of one item measuring teachers' instructional strategies.
(Smith & Banilower, 2015, p. 97)

They used different "instructional contexts" (Smith & Banilower, 2015, p. 95) in each item, where science teachers need to have a deep subject-matter understanding to respond appropriately by opting the correct option (Figure 10). In conclusion they suggested that it is better to elicit teachers' PCK than to assess it (Smith & Banilower, 2015, p. 98). Where the following approaches can be used such as, Loughran, Berry, and Mulhall's "CoRe" and "PaP-eRs" tools, (Mulhall, Berry, & Loughran, 2003, p. 6 & 9); teachers' interviews regarding their views on different "instructional scenario" by presenting hypothetical teaching-learning contexts before them to respond; or teachers can be presented with their own teaching video for self description of their instructional approaches and these all formats need precision in judging accuracy of a response (Smith & Banilower, 2015, p. 98).

Park and Suh (2015); & Park, Suh, and Seo (2017) conceptualised two dimensions of PCK: "teachers' understanding" and "enactment" (indispensable and idiosyncratic PCK) and advocated both cognitive and enacting aspects of PCK need to be assessed (Park & Suh, 2015, p. 107). Thus, they designed a survey based measure using paper-and-pencil technique, and a measure through "PCK rubric" based on observations and interviews (Park et al., 2011) to capture the PCK understanding and PCK enactment respectively centring upon "photosynthesis" as a specific topic, and supposed the sum of the both measures' scores will determine individual teacher's PCK (Park & Suh, 2015, p. 107 & 110) and they focused on two PCK components from pentagon model: "knowledge of student understanding" (*KSU*) and "knowledge of instructional strategies and representations" (*KISR*) (Park & Chen, 2012, p. 925; Park & Suh, 2015, p. 111). The survey consists of items bearing core concepts ("big ideas") of photosynthesis at Grades 9–10 levels drawn in classroom contexts that was conducted in two rounds for measuring and improving validity and reliability (internal consistency by Cronbach's α). They included 11 multiple-choice items from 50 draft items for the first round (Figure 11) and after modifications they increased the items to 30 with the inclusion of both dichotomous and open-ended items for second round, where 3 to 4 dichotomous items comprise specific classroom context to seek teachers' view on the learners' difficulties and misconceptions in that context followed by open-ended questions seeking for teachers to give rationale of their previous responses again followed by open-ended questions asking for effective instructional strategies to be carried out to deal with such learning difficulties with proper explanations of worth of such strategies (Figure 12) (Park & Suh, 2015, p. 112). The final survey was mailed upon 2,000 secondary science teachers and only 85 completed the whole survey and an acceptable level of internal consistency (Cronbach's $\alpha = 0.836$) was found and experts' view were taken for content related validity (p. 113). The "PCK rubric" was designed to

reveal teachers' PCK (enactment) as the observations of teaching practices reflected along with the justifications of their classroom actions captured through interviews (Park & Suh, 2015, p. 112). This rubric is the same one that had been validated and administered by Park et al., (2011) as discussed above (see Park et al., 2011).

Item 3 a-d) Mr. Benson was teaching a high school biology class about photosynthesis. He wanted to determine what students had learned about photosynthesis from their junior high school science courses taken some years earlier. He asked the students to explain why plants perform photosynthesis or cellular respiration. The following is a portion of that discussion.

April: Photosynthesis and respiration are to exchange gases.
Bill: I agree with April. The main product of photosynthesis is oxygen. Plants store up oxygen at night and release it during the day time.
Cindy: I disagree, Bill. Photosynthesis occurs when there is light. Therefore, plants cannot store up oxygen at night.
David: Yes. Photosynthesis captures light energy and uses it to make glucose. Plants respire when they cannot obtain enough energy from photosynthesis.

What would be Mr. Benson's interpretation of this discourse? The following is Mr. Benson's analysis of the discourse and lesson plan based on the analysis. Do you agree with his assessment? (Mark Agree, Disagree, or I'M NOT SURE for each item below. Please provide the reason in comments.)

		Agree	Disagree	I'm not sure
a)	April is likely to understand the purposes of photosynthesis and respiration. *Comments:*	1	2	3

Item 4 a-b) After listening to students' discussion represented in the previous question, Mr. Benson thought that there were some needs to help his students understand better of the purpose of photosynthesis and respiration. The followings are some teaching strategies which he may adopt in his science class. Do you agree with his strategies? (Mark AGREE, DISAGREE, or I'M NOT SURE for each item below. *Please describe your ideas below in detail*)

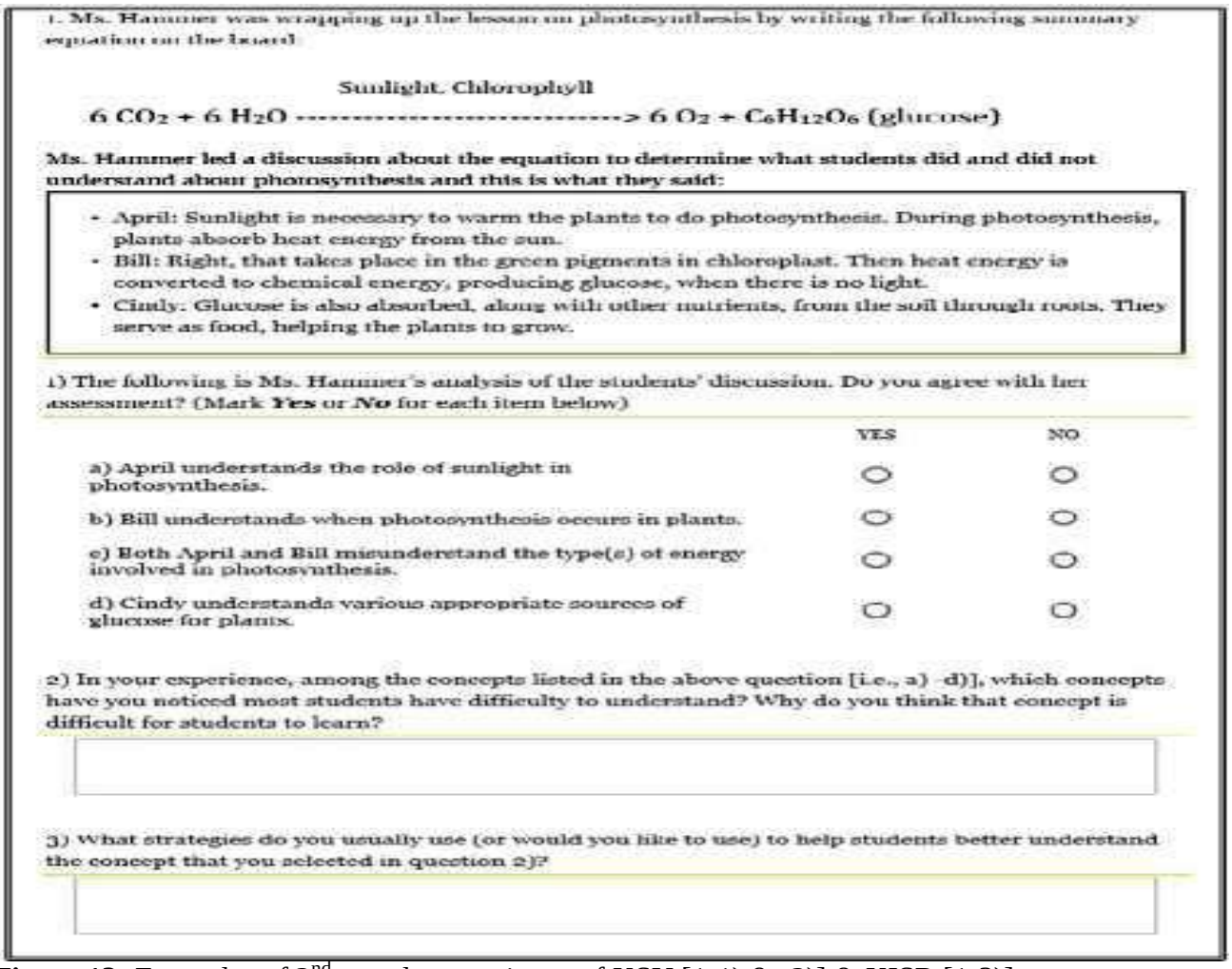
		Agree	Disagree	I'm not sure
a)	I will have them measure the number of oxygen bubbles of aquatic plant under different intensities of light.	1	2	3

If you agree, why do you think this strategy helps students' understanding of the purpose of photosynthesis and respiration?

If you disagree, how do you modify this activity or what other kinds of activity may be considerable?

If you are not sure, please describe your problem in decision making.

Figure 11: Examples of 1st round survey items of KSU & KISR respectively.
(Park, Suh, & Seo, 2017)



1. Ms. Hammer was wrapping up the lesson on photosynthesis by writing the following summary equation on the board

Sunlight, Chlorophyll

$6\ CO_2 + 6\ H_2O$ ----------> $6\ O_2 + C_6H_{12}O_6$ (glucose)

Ms. Hammer led a discussion about the equation to determine what students did and did not understand about phonosynthesis and this is what they said:

- **April: Sunlight is necessary to warm the plants to do photosynthesis. During photosynthesis, plants absorb heat energy from the sun.**
- **Bill: Right, that takes place in the green pigments in chloroplast. Then heat energy is converted to chemical energy, producing glucose, when there is no light.**
- **Cindy: Glucose is also absorbed, along with other nutrients, from the soil through roots. They serve as food, helping the plants to grow.**

1) The following is Ms. Hammer's analysis of the students' discussion. Do you agree with her assessment? (Mark *Yes* or *No* for each item below)

	YES	NO
a) April understands the role of sunlight in photosynthesis.	○	○
b) Bill understands when photosynthesis occurs in plants.	○	○
c) Both April and Bill misunderetand the type(s) of energy involved in photosynthesis.	○	○
d) Cindy understands various appropriate sources of glucose for plants.	○	○

2) In your experience, among the concepts listed in the above question [i.e., a) -d)], which concepts have you noticed most students have difficulty to understand? Why do you think that concept is difficult for students to learn?

3) What strategies do you usually use (or would you like to use) to help students better understand the concept that you selected in question 2)?

Figure 12: Examples of 2nd round survey items of KSU [1-1) &- 2)] & KISR [1-3)].
(Park, Suh, & Seo, 2017)

Aydeniz, and Gürçay (2018) in a study used Loughran et al.'s (2004 & 2012) *CoRes* to capture 16 pre-service Physics teachers' growth of PCK on "heat and temperature". With the help of "CoRes construction template" (Aydeniz, & Gürçay, 2018, p. 961) samples' PCK had been explored by asking them to identify "big ideas" regarding the topic and to transform those into learning materials for effective teaching, identifying possible students' difficulties in specific concept and to provide suggestions to tackle those with appropriate examples, analogies, and instructional strategies. At initial stage samples were asked to construct questions on "heat and temperature" targeting lower level, mid-level, and high-achieving students and then in subsequent weeks they were asked to answer these questions. After this the participants were provided with the empty *CoRes* template for completion followed by reflective peer discussions of the participants on basis of their initial responses to *CoRes* prompts. Finally, after three weeks from this peer-discussion the *post-CoRes* were administered. After analysing all pre and post *CoRes* answer sheets components wise (content knowledge, teaching orientation, knowledge of student understanding, instructional strategies, and assessment), they evaluated PCK in respect of "PCK sophistication levels" comprising level 1 to 3, i.e., least to most sophisticated level (Aydeniz, & Gürçay, 2018, p. 973).

Bayram-Jacobs et al. (2019) in a study used three validated and refined instruments, i.e., "lesson preparation" and "lesson reflection" forms [based upon Loughran, Mulhall, & Berry's (2004, & 2012) "CoRe", and Magnusson, Krajcik, & Borko's (1999) science PCK model] to capture science teachers'

PCK before and after action respectively along with Barendsen and Henze's (2015) "lesson observation table" to capture PCK during classroom action (Figure 13).

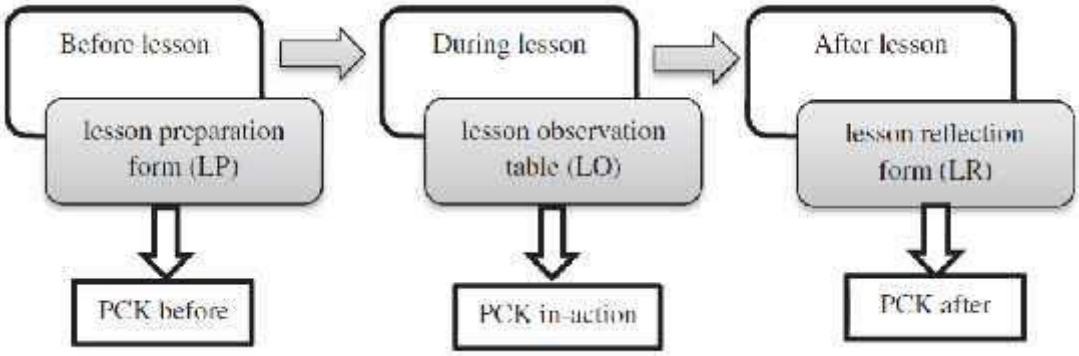


Figure 13: Bayram-Jacobs et al.'s research design.
(Bayram-Jacobs et al., 2019, p. 1216)

The "lesson preparation form" comprises topic and context specific questions concerning various data regarding teachers, class, students, lesson subject, instructional objectives, learners' potential difficulties and preconceptions, along with instructional and assessment approaches. The "lesson reflection form" comprises questions concerning the lesson's goals, achievement of learning objectives, learner's misconceptions, observed learners' difficulties, modifications in lesson plan, effectiveness of used activities, learners' engagement, etc. And, "lesson observation table" comprises three categories namely, "lesson content", "instructional method", and "assessment", (Bayram-Jacobs et al., 2019, p. 1216) thus data were collected by direct and structured classroom observations. Bayram-Jacobs et al. (2019) used coding method for data analysis with the help of "Atlas.ti qualitative data analysis software" by specifying certain categories such as "goals" (codes: "personal", & "learning objectives", "importance for the students", and "reason choosing the material"); "student understanding" (codes: "student difficulties with", and "misconceptions or beliefs"); "instructional strategies" (codes: "teaching approach", "adapting the activities", "teaching activities used", "difficulties teacher faced", "time management", and "further adaptation ideas"); "assessment" (codes: "ideas about what is a successful lesson", "ways of assessment used", and "further ideas for assessment"), etc. and 89% inter-rater agreement was found (p. 1217).

Inference

Along with the conceptualisation of science PCK, researchers also tried to capture both pre-and in-service science teachers' PCK. In the attempt to do so, they figured out various ways to assess science PCK, where some of them followed case study design and some followed survey design (large-scale research) utilising both qualitative and quantitative approaches (Akinyemi, 2016; Aksu, Metin, & Konyalioğlu, 2014; Aydeniz, & Gürçay, 2018; Bayram-Jacobs et al., 2019; Geddis, 1993; Geddis et al. 1993; Gess-Newsome & Lederrnan, 1993; Hashweh, 1987; Hume & Berry, 2011; Loughran et al., 2004, 2008 & 2012; Mavhunga & Rollnick, 2012 & 2013; Nilsson & Loughran, 2012; Ozden, 2008; Park et al., 2011; Park & Oliver, 2008a & b; Park, Suh, & Seo, 2015 & 2017; Pitjeng-Mosabala, 2014; Rohaan, Taconis, & Jochems, 2009; Rollnick et al., 2008; Schmelzing et al., 2013; Smith & Neale, 1989 & 1991; Smith & Banilower, (2015); Van Driel, De Jong, & Verloop, 2002). Baxter and Lederman (1999) and Miller (2007) summarised, categorised, and classified these methodologies into the following three categories: (a) "convergent and inferential techniques"; (b) "concept mapping, card sorts, and pictorial representations" or "visualisation techniques"; and (c) "multiple-method evaluations/analysis." These different approaches used in the assessment of science PCK have been summarized in Table 3.

Table 3- Methods used in assessing science PCK

Work done by	Methods used in assessing science PCK
Hashweh (1987)	Three different tasks completion, namely: summarisation of a topic, concept maps drawing, and exam questions sorting, followed by a structured interview were used for PCK assessment.
Geddis (1993)	Multiple choice questions along with a vignette were utilised to assess PCK
Geddis et al. (1993)	A vignette, lesson planning, audio-recorded and transcribed interviews were utilised to capture PCK
Gess-Newsome & Lederman (1993)	In a longitudinal study pictorial representations approach through open ended questions in two phases (at initial stages of the course and after internship) were administered in assessing PCK.
Van Driel, De Jong, & Verloop (2002)	In "a qualitative in-depth study" "multimethod" including analysis of pre and post workshop (video recorded) questionnaire followed by interviews were used for PCK assessment.
Loughran et al. (2004, 2008 & 2012)	*CoRes* and *PaP-eRs* & resource folio of PCK were conceptualised, developed and used to capture PCK as tools that scaffold PCK development.
Ozden (2008)	Multiple methods like lesson planning, content knowledge tests, and semi-structured interviews were applied to for PCK assessment.
Rollnick et al. (2008)	Pre-and post-lesson interviews, lesson observations (video and audio recorded), and analysis of various teachers' resources, along with a short workshop and were administered to assess PCK, and Loughran et al.'s (2004 & 2012) *CoRes* & *PaP-eRs* were used as methodological tools for data analysis.
Park & Oliver (2008a & b)	Multiple sources involving teaching observations in combination with semi-structured interviews to comprehend teachers' actions and knowledge in executing the lesson plans followed by teachers' written reflections on their own teaching, along with work samples of students, and field notes of the researcher were utilised to capture PCK, and data were analysed through (a) "constant comparative method" (regularities or patterns identification), (b) "enumerative approach" (individual teacher's PCK characteristics identification by qualitative coding process), and (c) "in-depth analysis of explicit PCK" to assess the PCK evidence from teaching observations.

Rohaan, Taconis, & Jochems (2009)	A time and labour-efficient standardised multiple-choice test named "Teaching of Technology Test" was developed to measure teachers' PCK in primary technology education on a large scale basis where responses are characterised as (a) "high PCK"; (b) "low PCK"; (c) pedagogical knowledge; (d) content knowledge.
Park et al. (2011)	Teaching observations along with by pre-/post-observation interviews were used and "PCK rubric" having a four-point rating scale, i.e., 1="Limited" to 4="Exemplary", was developed to measure teachers' level of science PCK.
Hume & Berry (2011)	*CoRes* construction method through a three hour workshop sequence was used to observe PCK improvement. Here students' possible preconceptions and misconceptions were given importance and completion of vacant *CoRe template* was advocated.
Nilsson & Loughran, (2012)	A modified framework of *CoRes* was integrated into the elementary science method curriculum to promote PCK development and PCK awareness among prospective science teachers.
Mavhunga & Rollnick (2012, & 2013)	A tool comprising both open and semi-closed test items was developed to capture "topic specific PCK" (TSPCK) and similar to the Park et al. (2011) responses were captured and scored with the help of a rubric (rated on a four point scale, i.e., 1="Limited" to 4="Exemplary").
Pitjeng-Mosabala (2014) and Akinyemi (2016)	Similar to Mavhunga and Rollnick (2012, & 2013) same method was followed.
Schmelzing et al. (2013)	A paper-and-pencil test (teachers' written reflections or expressions) comprising two test scales, namely "PCK I" and "PCK II" was developed to capture teachers' "declarative PCK" ("knowing that") on a large scale basis.
Aksu, Metin, & Konyalioğlu (2014)	A standardised five point rating scale (PCK attitude Scale) such as "strongly disagree", "disagree", "undecided", "agree" and "strongly agree" was developed to determine pre-service teachers' PCK.
Smith and Banilower (2015)	A multiple-choice items test on science canonical PCK (normative or collective PCK) was developed for a large-scale research.
Park, Suh, & Seo (2015 & 2017)	A survey based measure using paper-and-pencil

	technique, and a measure through "PCK rubric" based on observations and interview (Park et al., 2011) were designed to capture the PCK understanding and PCK enactment respectively.
Aydeniz, & Gürçay (2018)	"CoRes construction template" with help of Loughran et al.'s (2004 & 2012) *CoRes* (big ideas) technique was utilised and prospective science teachers' growth of PCK was evaluated in respect of "PCK sophistication levels" comprising level 1 to 3, i.e., least to most sophisticated level.
Bayram-Jacobs et al. (2019)	Three validated and refined instruments were used, i.e., "lesson preparation" and "lesson reflection" forms to capture science teachers' PCK before and after action respectively along with a Barendsen and Henze's (2015) "lesson observation table" to capture PCK during classroom action.

Epilogue

An extensive in-depth analysis of the abovementioned related works of literature to PCK assessment revealed that the theoretical aspect of PCK can be captured on a large scale through paper-pencil tests, multiple-choice items tests, rating scales, i.e., "survey-type measures." In contrast, the practical/enacting aspect of PCK can be captured only through direct observation of classroom teaching, analysis of teachers' responses via interview, i.e., "rubric-type measure" (by using the coding technique) (Aksu, Metin, & Konyalioğlu, 2014, Park & Suh, 2015, Rohaan, Taconis, & Jochems, 2009; Schmelzing et al., 2013; Smith & Banilower, 2015).

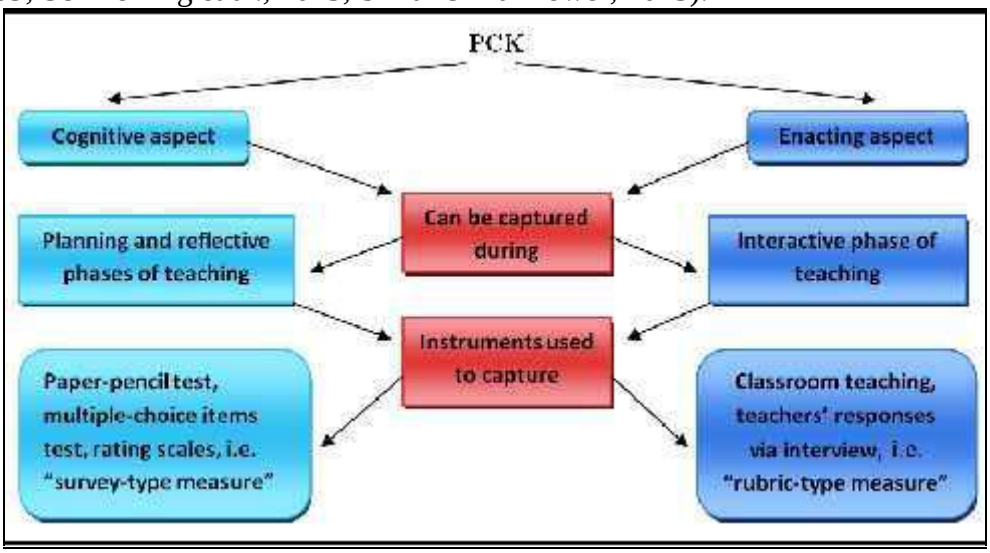


Figure 14: Conceptual framework for PCK assessment.

Based on these findings, a conceptual framework for PCK assessment has been developed (Figure 14).

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UNDERSTANDING THE BENGALI HOMELAND NARRATIVE A SAGA OF LOSS AND EVASIVE SOCIAL JUSTICE

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ABSTRACT

Terminologies like 'Dangababu' (The Riot Man), 'Handa na Gadha' (Fool or Donkey), etc. were part of the political diction of Mamata Banerjee to describe Narendra Modi in the run-up to the 2014 Lok Sabha elections as a reaction to Modi's statement of sending back illegal Bangladeshi refugees. Interestingly, Mamata's growing popularity seemed inversely proportional to her crossing the limits of democratic conduct. The underlining sentiment in this populist exercise is the notion of 'Bengaliness' which Mamata seemed to protect so vigorously. Growing Islamic fundamentalism in Bangladesh coupled with the populist politics of Mamata in West Bengal, forces one to relook at the underlining fundamentals of culture, language, and economy on which this idea of a 'Bengali' homeland is based. The paper argues that the present conditions are not such where 'homeland' discourses and practices can work. Though occasionally nationalistic poems, songs, images, etc. can act as referential points in this discourse but they fail in resisting the onslaught of populism and fundamentalism which seem to be making irreparable damage to this homeland discourse and thus denying social justice to its participants.

KEYWORDS: Homeland, Bengali, Narrative, Border, Political, Bhadralok, Justice

INTRODUCTION

'Home' has always been a concern of scholars exploring various issues relating to the ideas of intimacy, family, kinship, gender, ethnicity, relations of production and consumption, and many more (Mallet, 2004). Whenever one talks about the idea of homeland, the primary issue one needs to engage with is the notion of belief and its ability to mold our political, social, and moral systems. The question is how one engages with his or her alternative notion of a homeland, especially in a scenario where the political realities seem to be antithetical to this said belief. In addition to this one also encounters the basic question as to whether the idea of a transnational linguistic nationalism is more empowering and real for the lower strata of society as compared to the imposed idea of territorial nationalism. This piece examines various dimensions and ideas of the homeland category 'Bengal.' It argues that the fast-changing socio-political realities have made it very difficult to hold on to the idea of a Bengali homeland even at a philosophical level. It does not advocate the complete negation of this idea and instead looks at certain versions which seem to have passed the test of time. It is true that homeland categories are not fixed entities but rather are continuously evolving and acquiring new meanings.

The case of the Bengali homeland is a curious one especially because in this region that constitutes this homeland, a nation-state has been created based on ethno-linguistic identity. The independence of Bangladesh was the zenith of a popular narrative of a singular Bengali identity category that belonged in a single homeland of Bengal, irrespective of religious differences (Van Schendel, 2001). Bangladesh's independence heralded a new paradigm for defining "national identity" in South Asia … it was an ethnically defined nationalism that based its legitimacy on what was described as the common Bengali linguistic and cultural practices of the population, which transcended communal religious differences (Jones, 2011). This poses certain intriguing questions for this idea of Bengali homeland especially in terms of the relationship between place and identity. One of the primary questions is what does the term 'Bengal' mean in contemporary times and what relationship do the 'Bengalis' belonging to two separate political entities are supposed to share. Though not a political reality, the paper argues that common socio-cultural practices give the imagery of the Bengali homeland high levels of authenticity. The idea of a homeland provides the symbolic connection between an imagined community of people and a piece of land that is described as being the place from which the group emerged and the place to which that group belongs (Jones, 2011).

There have been two instances where the idea of Bengali homeland asserted itself and charted a political discourse in a significant manner and those are the Bengali Renaissance and the Swadeshi movement. This idea of 'home' was extended during the course of the nationalist movement unto the idea of the 'motherland' where Bengal became the name of the part of the world marked sacred by the habitation of the ancestors of the Bengali people (Chakrabarty, 1995). Rabindranath Tagore's song "Amar Sonar Bangla" written during the anti-partition movement in 1906 talked about a united Bengal. Interestingly the founding members of the nation-state of Bangladesh itself emphasize that very particular idea of a **united Bengal and a Bengali homeland**. The glaring example is the adoption of Tagore's song "Amar Sonar Bangla" (My Golden Bengal) as the national anthem which talked about a united Bengali homeland.

The partition in 1947 and the creation of Bangladesh in 1971 are perhaps two watershed moments in the process of imagination of a Bengali homeland when the idea underwent massive restructuring. The idea of a Bengali homeland had to renegotiate with the emerging political realities. In this context, the growing Islamization of Bangladesh in recent years has raised the larger question of disambiguation within the idea of a Bengali homeland. There are evolving demands for deciphering the ideas of Bengali, Bangladesh and finally Bengal from West Bengal instead of looking at them as mere constituent parts of a single entity. This practice of disambiguation has raised questions on the secular ethos of the Bengali identity. The critical question which needs to be asked is regarding the Bhadralok hegemony and level of accommodation of the customs and beliefs of the religious minorities dating back to the days of the Bengal Renaissance.

The troubled historical narrative

Many scholars have pointed out that Bengal as a territorial entity lacked a proper political history until the nineteenth century. This early construct of the homeland of Bengal was expansive and included a large portion of the Ganges delta in the northeast of British India (Sengupta, 2001). The famous song 'Vande Mataram' written by Bankim Chandra Chatterjee in 1870 is interesting in this regard as what was observed was that the level of inclusivity though on a geographical level was enormous but at a representational level there was growing dominance of the Hindu dominated bhadralok class. The song begins inclusively by describing the shared connection the population has with the land but ends by defining the boundaries of the true people of the Bengali nation as those that recognize the land as an embodiment of a Hindu mother goddess (Bose, 1997; Jones, 2006; Ramaswamy, 2001; 2002; 2008). The decimation of this practice was very limited during the days of the Bengal Renaissance but it got overtly showcased during the Swadeshi movement. Though Tagore's song "Amar Sonar Bangla" acted as an inspiring factor the dominance of the bhadralok section over the movement was clear by the fact that Bankim's 'Vande Mataram' acted as its prime inspiration. The inclusivity quotient in the Bengali homeland took a hit at the explicit representation of religious imagery. As a counter-reaction to this, an alternative religiously defined homeland narrative emerged.

Who is the real Bengali? The three competing narratives

Within this Bengali homeland discourse, three narratives are primarily emerging in the present times and force one to reimagine and reconceptualize the contours of the very idea.

The West Bengal Narrative

First, is the dominant version in West Bengal where it is claimed that a pure connection with the concept of 'Bangaliana' (Bengaliness) is still maintained by the people of this region by strictly adhering to the traditions and customs (primarily Hindu practices). This issue is sighted to both further the argument of a shift from secular Bengali nationalism to Islamization in Bangladesh and highlight a confirmation of the special bond which the Bengali Hindus share with the idea of Bengali homeland. These other narratives are then creating a division in West Bengal as the people of Bangladesh are described as disowning their connection to the land and culture of Bengal (Saikia, 2003). To this narrative of homeland, West Bengal is the real and eligible claimant to the idea of 'Bengal'.

The Bangladeshi Narrative

Interestingly a counter-narrative is presented by many in Bangladesh where they claim to hold on to the true spirit of Bengali(ness). The major reason showcased in this regard is their deep commitment towards their language where the language cum independence movement plays the part of an important alibi. Symbolic objects and sites of memory play an important role in creating and reiterating a homeland category in the collective memory of a population (Jones, 2011). The larger celebratory grandeur of the Language Martyr's Day as compared to that of Independence Day and Victory Day compels one to recognize their commitment towards the Bengali language even in the face of severe opposition from the fundamentalist Islamic forces. Even the famous Shaheed Minar (Martyrs' Monument) in Dhaka coupled with many more such smaller monuments at various places throughout the country shows the deep connection that the public psyche shares with the Bengali language. These monuments, performances, and events institutionalize the perception of a unique connection between Bangladesh, the Bengali language, and the land (Jones, 2011).

The Class Oriented Narrative

But within this contesting claims hinged on the ideas of adherence to traditions and commitment to language there emerges a third narrative. This narrative is largely a class-oriented one where the real custodians of the idea of a Bengali homeland seem to be the farmers and petty laborers of both halves whose commitment to the language remains much more robust as compared to the Bengali bhadraloks. The economic situations condition them to be more accommodative as far as religious sentiments are concerned. Even the fructification of a sense of Bengali camaraderie is observed in the work culture and pattern of this particular section that has to venture into each other's areas at designated times of the year and in some cases throughout the year. In this homeland narrative, the territory is represented as a symbolic home for the entire group that provides a sense of belonging, security, and a common purpose (Bishara, 2003; Mack, 1993; Yngvesson, 2003).

The border as a mere political arrangement

As far as the idea of a Bengali homeland is concerned the border is a mere political arrangement and is newer compared to the socio-economic arrangements which make much more sense to its participants. The idea of a homeland provides the symbolic connection between an imagined community of people and a piece of land that is described as being the place from which the group emerged and the place to which that group belongs (Anderson, 1991; Kaiser, 2002; 2009). In the present context, this sense of belonging is not limited to a mere philosophical arena but there are its practical dynamics of which the economic is most important. A careful look at the demography profile of many work sectors in the state like farming, cottage industry, handicrafts, etc. clearly shows that a lot of these are dominated by Bengali Muslims. Now interestingly many of these people belong to both sides of the border and work on both sides. Here the ecological condition is another great factor that contributes to this exchange of workforce. This narrative of the homeland also describes the territory as a functional political and economic unit. This argument has been put forward much earlier also by the supporters of the United Bengal Scheme, who included prominent Hindu leaders Sarat Bose and K.S. Roy. They had very clearly said that the region was a functional economic unit that would be devastated and substantially weakened if divided. The devastation which the jute industry underwent post-partition in West Bengal is a glaring example of this. The Bengali nation operates and thrives on a day-to-day scale and not at a symbolic diplomatic level championed by the governments of both countries. The political reality of nation-states coupled with their features (geographical border being one of them) acts as hurdles in this day-to-day imagination of a Bengali nation. This perception is reified by the new border fence that India has built around Bangladesh since 2002, which further inscribes the boundary into the landscape (Kabir, 2005). There is an effort to impose the concept of the border into the larger setting of Bengali homeland which though seems to fail to initiate separate and distinct homeland narratives.

The present complicated scenario

In recent times there have been enormous changes in the political, sociological, and mental landscape of both the geographical regions which constitute the idea of a Bengali homeland. This has had a tremendous impact on the perceptive lenses of many observers and participants of the Bengali homeland discourse.

The Distortions within the Bangladeshi Narrative of Homeland

As far as the idea of linguistic nationalism is concerned, Bangladesh is surely an exception. The Bangladeshi independence movement, which began primarily as an effort to gain greater autonomy within Pakistan, attempted to eschew communal politics and instead described the identity category Bengali as a post-communal grouping of everyone who spoke the Bengali language and lived in Bengal (Van Schendel, 2001). In the preceding years, there have been attempts by some political forces to change this fundamental understanding by replacing it with both Islamic fundamentalism and soft Islamisation. This though has been countered by movements like Shahbag. The larger fight here is about the mediation of the narrative of identity. The growing severance between the two ideas of Bengali and Bangladeshi in the political discourse has hurt the Bengali homeland narrative as the secular undertone coupled with the idea of linguistic nationalism is getting hampered.

The growing politics of the 'other' in West Bengal

This growth of hyper-religious nationalism in Bangladesh is giving rise to a reactive mechanism in the other half of the geographical entity of the Bengali homeland. There is a politics of aversion where a separate homeland narrative specific to West Bengal is carved out. Here the political entity of Bangladesh plays the role of the 'other.' At this juncture, the 'generational question' must be considered which dictates the level of resonance with any imaginary landscape and also the sense of belonging and identity. The reason why the idea of Bengali homeland does not resonate as strongly with the present generation as it does in most cases with the older generation has something to do with Alvis' words 'with pain and resultant wisdom'. Along with pain also comes wisdom, because exiles understand the importance of their homeland more fully than those who have never suffered its loss (Alvis, 2010). Largely the present generation of expellees has not directly experienced the trauma of partition and has not labored assiduously to assimilate into the society of present-day West Bengal as done by their earlier generations. The stimulation which drove the first generation of migrants is bound to be less for many members of the present generation. Moreover, the tremendous changes in the political landscape of the state in contemporary times have hurt the idea of a Bengali homeland. The emergence of the Bharatiya Janata Party (hereafter BJP) as the major political opponent of the Trinamool Congress (TMC) replacing the Left has given rise to a new sense of collective which is a religious undertone. What is under attack is a larger sense of linguistic camaraderie which has been the trademark of the state's societal canvas. The 'Rabindra and Nazrul' sandhas (evenings) are a good example of it where a Brahmo and a Muslim personality are being celebrated as representatives of a rich linguistic culture. The core philosophy of a Bengali homeland which is the acceptance of religious plurality coupled with a sense of linguistic unity and a sense of identity emerging from it is being challenged by political Hindutva.

Mamata's political stratagem

It is this politics of negation of the BJP that Mamata is trying to fight. Interestingly, her tactics are not one of adopting a typical 'secular' stand but instead by making religion a strong civil actor. In Mamata's politics, the narrative of a Bengali homeland is created through the process of identity recognition, where the unifying factor of language is unaffected by the explicit recognition of other identities. The relationship between Bengal and Bangladesh goes beyond borders ... we share a deep bond of culture, language, and a deep history of brotherhood (Mamata, 2016). The latest instance in this regard is the inauguration of the Bangladesh Bhavan within the Visva Bharati University campus which celebrates the rich cultural and literary tradition shared by the two regions. The fundamental question facing the Bengali homeland narrative in today's time is how will an independent Bengali identity tackle the Hindu-Muslim divide coupled with the nationality question and create an alternative space for itself. The Bengali movie Shankhachil (which interestingly is an India-Bangladesh joint venture) takes up this question beautifully and humanely. But these joint artistic projects and endeavors can act as referential points in this discourse on the Bengali homeland but cannot take forward the discourse beyond a certain point, especially with the onslaught of populism and fundamentalism.

CONCLUSION

The harsh reality remains that none of the narratives of "Aamar Sonar Bangla" (My Golden Bengal) are actual Bengals. 'Golden Bengal' is merely an emotional entity with historical betrayals, injustices, unimaginable trauma, rich culture, and an undying sense of belonging as its constituent parts. It is a ballgame where the emotional and sociological realities are in a constant tussle with the imposed political ones. It is a constant strive to achieve something imaginable but not achievable. It is this ability to imagine which gives all the participants in this exercise a sense of purpose and a sense of belonging that the politics of the land has failed to provide at times. In present times the biggest political battle is not about the detailing of the past events, but rather the structuring of the cognitive aspect of the participants in tandem with one's political goals and desires. It is a fight between history and memory. History seeks to explain the event, the memory of pain refuses the historical explanation and sees the event causing the pain as a monstrously irrational aberration (Chakrabarty, 1996). The political struggle is primarily here, where on the one hand the historical happenings (including partition) are portrayed as an exemplar of the ever-present incompatibility between the religious participants of this idea of Bengali homeland and on the other hand where partition is presented as a mere aberration in the otherwise imperishable linguistic camaraderie thereby surpassing all religious and nationalistic differences. Perhaps an unclear definition and an uncertain commitment to secularism which sadly has been the common political reality of the entire subcontinent acts as a major hurdle even in the philosophical realization of a Bengali homeland narrative with its rich syncretistic tradition.

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Impact of Intellectual Capital on Financial Performance in Indian Banking Sector

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Abstract:

The purpose of this study is to analyse the relationship between intellectual capital and bank financial performance of Indian banking sector. The intellectual capital performance of banks is measured through the value added intellectual coefficient (VAIC) methodology. The financial performance of banks has been measured with the help of return on assets (ROA), return on equity (ROE) and growth revenue (GR) of the firm. The results were based on the data taken from 10 topmost public sector banking companies, as per market capitalisation, listed on the National Stock Exchange in India for the last five years i.e. from 2017 to 2021. It was found that IC has a significant positive relationship with profitability measured by ROA and ROE but negative relationship with GR. The study revealed that the financial performance was positively and significantly associated with human capital efficiency and structural capital efficiency.

Keywords: Intellectual capital; Value added intellectual coefficient (VAIC); financial performance; Indian banking sector

1. Introduction:

Societies have experienced four different socio economic phases throughout history which include primitive society, agricultural society, industrial society, and information society in which we currently live (Ozkan and et al, 2017) . Prior to the information society, the focus was on traditional factors (labour, capital, natural resources and enterprises). Knowledge, information technologies, and intellectual capital factors took priority after the information society emerged (Yalama, 2013, Ozkan and et al, 2017). Now-a-days, most factors of production in developed countries are invisible assets or intangible assets which is also named as intellectual capital (IC) - brand, reputation, trademarks, software, research and development, patents, staff skills, strategy, process quality, supplier and customer relationships, etc.(OECD, 2006). Traditional accounting systems fail to reflect intangible assets creating value in enterprises (Canibao and et al, 2000; Lhaopadchan, 2010). Therefore, the economic value and wealth shown in the financial statement not only the products manufactured by enterprises but also their intangible assets, i.e. their intellectual capital (Goldfinger, 1997; Chen and et al, 2005). So, intellectual capital plays a greater role in creating value (Powell, 2003; Sardo & Serrasqueiro, 2017; Nassar, 2018). The potential competitive advantages and long term value of a firm highly depends on the efficient management of intellectual capital (IC) than in intangible assets (Alipour, 2012; Al-Musali & Ismail, 2014). This is mostly true in knowledge-based

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A Brief Sketch of Strategies and Planning for Plant Metabolic Pathway Moderation

***Abstract*: In order to improve metabolic engineering potentialities, new transformation mechanisms have been developed to allow for gene specific silencing strategies or stacking of multiple genes within the same region of the chromosome. Metabolic engineering of plant production systems are now developed using these resources and much more complex products are synthesized in engineered microbial hosts. Plant secondary metabolism has vital role in functioning various functionalities in the plant's life cycle including their response to different interactions with environments. Due to various internal qualities of secondary metabolites, scientists have become interested to work for development in the metabolic engineering and route changing of plant secondary metabolism pathway. Various researchers have identified various strategies and methodologies for pathway alteration. Gene encoding biosynthetic enzymes and gene encoding regulatory proteins are important examples in this regard. To uncover the hidden mystery within the plant is one of the great passion for researchers. The present article sketches the foundation of strategies and planning for engineering metabolic pathway. This article will stimulate researchers to correlate their work, direction, and motivation with their work in this field to make their prosperous idea successful for future world.**

Keywords: Plant metabolism, secondary metabolites, PNP, gene-coding, enzymatic pathway

Plant secondary metabolism plays vital role in various functionalities in the plant's life cycle. Due to these capacities plants can response for different interactions with environments. These interactions are Plant-plant, plant- microorganism, Plant-Environments and plant–insect interactions. Development of plant defense system through production of antifeedants, phytoalexin, phytoanticipin have also an important role of secondary metabolites. Other important role of secondary metabolism also found in the case of plant reproduction, food quality, pigments etc. Scientists have been continuously working for development in the metabolic engineering and alteration of routes of plant secondary metabolism. Various strategies and methodologies have been adopted for pathway alteration, using of gene encoding biosynthetic enzymes, sometimes, gene encoding regulatory proteins.

Basis of Plant Metabolism: Plant metabolism can be classified broadly into two stages: primary and secondary metabolism. The primary macromolecules such as carbohydrates, lipids, proteins, nucleic acids, and hormones are synthesized in the primary metabolism pathway whereas the secondary metabolites derived from primary metabolism through the evolutionary and biosynthetic pathway[1]. For the plant growth and development, primary metabolism take part in directly and it is the basic stage in complex molecules formation, while secondary metabolism plays vital role for formation of unique and more advanced phytochemical products[2,3]. The seed and plant vegetative organs are the main source of primary metabolites. They play an important role in plant growth, reproduction, development and signal transduction, protein synthesis, respiration, photosynthesis, assimilation of nutrients and solute transport - these are in primary metabolism process types[4,5]. The primary metabolites are originated in all types of plant kingdom whereas; the occurrences of certain secondary metabolites are limited only found in some specific plant species with the influence of biotic and abiotic factors and it is not directly influence in plant development but it plays an impotent role in plant adaptation, and their survivability, defense mechanism against the various types of bacteria, fungi, nematoda, and pathogenic microbes. It helps the plant from being eaten by herbivorous or mammals[1,6]. Secondary metabolites are found by extraction methods and compounds can be identified by various chemical and spectroscopic technique.

Root of Biosynthetic Pathway of Natural Products: Natural products (NPs) are derived from organisms of all kingdoms in nature. Nearly 300,000 identified natural products have been summarized in libraries[7] and Super

Natural II[8]. The generation of those major classes natural products and their hybrids have been possible due to four well-known biosynthetic pathways[9,10] which included:

(1) AA/MA (acetic acid and malonic acid) pathway which produces phenols, fatty acids, and polyketides;

(2) MVA/MEP (mevalonic acid or methylerythritol phosphate) pathway which generates steroids and terpenoids

(3) CA/SA (shikimic acid or cinnamic acid) pathway which produces flavonoids, phenylpropanoids, coumarins and lignans

(4) AAs (amino acids) pathway that is the key for construction of alkaloids.

Unfortunately, characterization and confirmation have been done only about 33,000 enzymatic reactions. Therefore, the overall biogenesis pathways and all intermediates involved in the process are not well established for a huge number of known natural products. Hence, it is most desirable to search on and reveal the biosynthetic pathway for various natural products.

Identification and Modification Through Engineering an Appropriate Host Organism: In order to fulfill various demands including industrial application, medicinal utility, agricultural purpose or scientific interest, a Plant Natural Products can be selected for target of metabolic engineering. Selection of an appropriate target host species for engineering the biosynthetic pathway is the primary step towards heterologus production. It has been proved that improvement of each host can be possible through adaptive evolution. In recent time, with the expanded journey of organism engineering afforded the various available methods, models, and tools for editing the host phenotypes. Improvements of the host organisms are made by a combination of a branch of operations like modification of the host, tuning, and optimizing unit operations. Utilization of pre developed strains which overproduce requisite metabolites can accelerate progress greatly.

Target Selection of Host Species for a Heterologous Plant Pathway: As there is a direct link of biochemical reactions happening within the host organism and heterologous pathways due to incorporation of foreign genes. Therefore, introduction of metabolic pathways into host organisms is an important strategy used for the greater productivity of valuable secondary metabolites. For that purpose selection of a host species is very important. Some properties such as ease of culture, cloning and suitability of host for compounds and enzymes are considered for selection of a host. Well known organism with good records in research specially in metabolic engineering and existence of developed technique for culturing, cloning, and make them for industrial scale-up which will make them most attractive choices. The plant cell for producing PNPs should be first choice as host where conservation of protein processing and specific sub-cellular compartments will be maintained[11]. On the other hand model plants like Nicotianabenthamiana are very useful during initial testing for transient expression of plant pathway enzymes, as enzyme functions, co-factors, and substrate pools are maintained in plant[12,13]. Microbial hosts are most preferable because it is comparable rapid process than genetic manipulation of plant.

Microorganisms like *Saccharomyces cerevisiae* and *Escherichia coli* have prosperity of well-established tools accessible for genetic manipulation, cultured easily and have a wide range of availability of advance platform strains. Other evolutionally well suited microorganisms are also employing for the said purposes. For the production of antibiotics, Streptomyces originated from Stretomyces species is also often used[14]. Use of *Corynebacterium glutamicum* is attributed for the production of amino acids[15]. For using lipid as substrate, *Yarrowialipolytica* is employed frequently[16]. Although it is true microbial hosts like *E. coli* or *S. cerevisiae* are generally used for production of PNP's. Hence, seeking of heterogeneous host whether to use *E. coli* or *S. cerevisiae* for the production of compounds is a great question in this regards. *S. cerevisiae* may get recommendation due to its high rate of homology and ease of genomic integration gives extra advantage.

Yeast harbors several organelles that are also present in plant cells. Several enzymes involved in the biosynthesis of para-nitrophenol (PNP), including cytochrome P450s, are characterized as transmembrane proteins that necessitate the presence of a suitable membrane, specifically the endoplasmic reticulum(ER), for their accurate anchorage and conformational folding. An obstacle during semi-synthetic Artemisini project was observed which had the potential to impede progress. This event served to highlight the challenges inherent in such endeavors. The project involved the modifications of *S. Saccharomyces cerevisiae* were genetically modified to generate elevated levels of artemisinic acid, a pivotal precursor in the production of the essential antimalerial compound, artemisinin. This project explores the implications of studying both *E. coliprotein* structure and function. *Escherichia Coli* and *salmonella enteric* are also

two bacterial species commonly studied in microbiology. *Saccharomyces cerevisiae* was evaluated as candidate host, and noteworthy titers of the intermediate. In the metabolic pathway involving *E. coli*[17], the ensuing stage is executed by P450AMO, a member of the plant cytochrome P450 family. *E. coli* failed to achieve high enzyme activity, requiring a switch to production. Using *S. cerevisiae* as a host for pathways with transmembrane proteins avoids extra modification work[18]. *S. cerevisiae* has micro compartments that mimic PNP biosynthesis in plants[19,20]. *E. coli* doubles faster than *S. cerevisiae*, by 3-4 times. *S. cerevisiae* is ideal for high enzyme expression and possesses unique metabolites. Using a native pathway, *E. coli* was engineered to produce taxadiene 2,400 times more efficiently than *S. cerevisiae* strains for taxol production. *S. cerevisiae* engineered for taxadiene[21].

When selecting a host organism for PNP biosynthesis, an alternative approach is to adopt a multi-organism co-culturing strategy, whereby constituents of a metabolic pathway are distributed among different organisms, either within the same species or across diverse species[22-25]. The advantages of this approach are manifold encompassing the amelioration of the load assigned to the host via the heterologous pathway, the enhanced potential to leverage the species that are optimally equipped to effectuate the expression of targeted enzymes within the pathway. As well as the modular nature of the process, this enables the combination of disparate pathways through the co-cultivation of distinct strains. In a specific instance, the chemical compounds known as benzyl-isoquinoline (BIAs) were synthesized within the context of an E. coli biochemical system. The bacteria *E. Coli* and Salmonala are commonly studied in microbiology due to their significant impact on human health and environment[24].

An additional illustration entails the attainment of elevated titers of an anthocyanin PNP via the dispersion of the metabolic load within four *Escherichia coli* cells. The *Escherichia coli* strains that underwent co-cultivation were evaluated[23]. The limitations associated with cultures are characterized by pathway specificity and encompass deficiencies pertaining to the transportation and diffusion of intermediate metabolites between cells within the co-culture. In addition, the co-culture also requires the imposition of a balanced growth of multiple hosts within a single culture, which may exhibit apparent differences in their preferred growth conditions and rates.

Decision taking for host strain choice of PNP precursors: Following choice of a host species, engineering the host to boom titers of main native metabolites that are biosynthetic precursors to the desired product can greatly accelerate downstream manufacturing of PNP molecules. The middle metabolic networks of version organisms are well-characterized and can be used to manual over expression and knockout changes for overproduction of critical metabolite precursors and to cope with not unusual challenges (e.g., comments inhibition or different metabolic law).

One of the blessings of biosynthesis over chemical synthesis is way of simple biosynthetic distribution. Once, a pressure has been engineered to produce a compound, researchers trying to extend on that paintings inside the destiny want now not repeat tedious syntheses of beginning fabric. Strains of *E. Coli* and *S. Cerevisiae* that overproduce alkaloids, fatty acids, terpenes, and other valuable compound training have been engineered. Producing more central metabolites or a heterologous secondary metabolite can both be beneficial. Central metabolites, such as geranyl pyrophosphate or amino acids, can lead to the production of a variety of PNP compounds. Secondary metabolites can make it easier to engineer biosynthesis of a specific PNP product.

A standard platform strain might be functional not only because it creates an indispensable initial material, but also for other factors like sustainability, inexpensive and easy handling by the researchers. The creation of an effective simultaneous saccharification and co-fermentation (SSCF) strain for bioethanol synthesis in *E. coli* that uses lignocellulosic biomass [26], a cheap waste product from agriculture and forestry, in place of pricy refined sugars, serves as a demonstration of this.Another illustration is the development of an enzyme that incorporates formate into the central metabolic process[27]. This enzyme may enable the manufacture of pharmaceuticals and common compounds from formate, which is anticipated to be readily accessible from the electrochemical reduction of CO_2.Last but not least, scientists created an *E. coli* strain that can photosynthesise CO_2 to make its own biomass[28]. The ability to engineer CO_2 fixation in well-researched, genetically tractable industrial microorganisms like E. coli and S. cerevisiae may be advantageous, despite the high interest in using naturally occurring photosynthesizing microorganisms (such as cyanobacteria) for the production of PNPs[29].

The other PNP-producing strains could potentially be integrated into these platforms, even though the aforementioned strains have not yet been used to make PNPs. The production of complex PNPs are allowed from agricultural waste, using renewable energy, or even directly from atmospheric CO_2. The engineering of E. coli to use the one-carbon fuel methanol and ultimately convert it into

the flavonoid naringenin[30] serves as a demonstration of this idea. Such approaches might help more environmentally friendly bioprocesses produce an expanding range of goods, including PNPs, on an industrial scale.

Host Metabolism Modification for Smooth PNP Biosynthesis: After choosing a host or pre-existing platform strain, alterations to the host, such as gene deletions, replacing indigenous enzymes with more active homologues, or overexpressing endogenous metabolic genes, may be made to increase the availability of biosynthetic precursors.

A recent masterstroke[31] integrated all of these methods to rewire the core metabolism of yeast to overproduce acetyl-CoA for the production of isoprenoid and fatty acids, which serves as the precursor for numerous PNPs, including the antimalarial artemisinin. A more advantageous reaction stoichiometry, which was described as having a reduced ATP need, reduced loss of carbon to side reactions, and better pathway redox balance, was found using yeast reaction stoichiometriesa model for acetyl-CoA, sugar, and redox cofactors.

By expressing four acetyl-CoA biosynthesis-related enzymes from other organisms to increase acetyl-CoA biosynthesis, the best acetyl-CoA stoichiometry was achieved. This allowed yeast to produce 25% more of the isoprenoid farnesene with an equal amount of sugar while using less oxygen, which is crucial for industrial fermentation settings with oxygen restrictions For instance, scientists developed yeast that produced 1.9 g/L of p-coumaric acid by combining six genetic changes to yeast's natural metabolism. These included eliminating competitive side routes, overexpressing enzymes near bottlenecks, and designing feedback-resistant enzymes[32]. Researchers watched biosynthetic intermediates in their designed route during work on the de novo synthesis of strictosidine, an alkaloid produced from plants, in order to spot competing side pathways[33].

Key Strategies for Planning and Engineering a Metabolic Pathway: An appropriate host can be selected, and a route can be planned to reach the desired PNP. In order to lay out a candidate pathway, a series of chemical intermediate first selected, leading to a host metabolism to target molecule, and then enzymes are chosen to perform each step necessary. In order to facilitate pathway engineering into a heterologous host, certain PNPs have detailed information of the native biosynthetic pathway that may be utilized to delineate all intermediates and enzymes in a pathway. Such in-depth knowledge, however, is frequently lacking or insufficient and can require years or even decades of devoted investigation in plant. The next sections go over the unique difficulties such as candidate pathway design, enzyme choice, and pathway testing provide under such circumstances.

Conclusion

The valuation of natural secondary metabolites insisted scientists to uncover the hidden mystery within the plants. The production of specific secondary metabolites in the plant species is of very limited amount. Hence, increasing the amount of production in various ways is the prime and important desire to the scientists. The present article analyzed, focused and summarized the basis of key strategies for engineering metabolic pathways. The present article will encourage the researchers in this field to create more and more successful and productive ideas to develop this field. ❐

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Exploration of Recent Progress of Plant Synthetic Biology for Plant Natural Products

***Abstract*: Plant natural products (PNPs) are Abundantly used in various fields which include health products, medicines, food additives, cosmetics, biofuels, flavors and other agriculture as well as industrial sectors and reservoirs of large number of compounds. With increase of the world population, it has become very difficult to satisfy our demands of daily life within the limited resources. Growing of specific plant in limited land, time and other obstacles made scientists and researchers to think an alternative way. Scientists have been continuously trying to construct infrequent plant natural products having complex structures at large scale by developing new strategies for creating cell factories artificially. Synthetic biology is a focus research area in recent trends for artificially alteration of possible biosynthetic pathway of the target molecule. Designing of synthetic biology cycle, construction of various strategies and methodology of different plant cells to modify biosynthetic pathway of secondary metabolite production is very important for synthetic biologists. This work will boost young researchers to work for betterment of the human society. The present article will discuss recent progress of synthetic biology in the field of Natural products, different strategies and methodologies of different plant species and their prospects.**

Keywords: Plant Natural products, Synthetic biology of Plant, designing way, reconstruction of metabolic pathway, strategies and methods for production of desired target products.

Plant natural products (PNPs) are reservoirs of immense number of phytochemicals which are widely used for various purposes like medicines, food additives, health products, cosmetics, renewable biofuels, flavors and other industrial sectors. Natural products having pharmacological activities are natural medicines. Source of these compounds are secondary metabolites of plants, animals and microorganisms[1-2]. Due to transformation and optimization in the journey of long evolution path, a good medicinal value has been developed[3-4]. A wide variety of chemical compounds are produced by plants which can be classified into primary (such as phytosterols, acyl lipids, nucleotides, amino acids, and organic acids) and secondary metabolites. The latter class compounds are known as natural products. The occurrences of secondary metabolites in plant kingdom are very limited but they have significant role for survivability of plants. The natural products derived from the plants have various important functionalities which include protection against pests, various diseases, UV-B damage, ecological, and other environmental stresses. These are backbones of pharmaceutical drugs, a large number of agrochemicals, food and drink industries, and other industrial biotechnology applications. It is true that plants are rich source of diversified and precious natural products. But identifying synthetic pathways for these compounds is more complicated than in microbes due to their larger and complex genomes. However, the existence of organized genes in many cases for natural products pathways is in operon-like clusters within the plant genomes. With the help of advance technology, accelerate the possibility to access the genes and enzymes of particular metabolism in plants smoothly. The plant synthetic biology may be useful for modifying the metabolic diversity of the plants and synthesizing the modified plant natural products. Extensive research on plants has become more attractive now a days for natural sources derived high value products in connection with various fields like medicines, foods, flavors, renewable fuels, cosmetics etc. But it is needless to mention that some challenges also exist. These challenges are basically very fundamental which include low abundance of secondary metabolites within plant, slow growth rate due to very complex metabolites. In addition to that, some plants are in danger of extinction, some chemical structures are so complex that they face difficulty to synthesis. Therefore, some alternative approachable needs are indeed to have high value natural products and fulfil our demands.

As it is very difficult to develop sufficient plants to satisfy our demand for these desirable compounds, researchers are seeking to manufacture those herbal products in their laboratories via expression in clean-to-subculture flowers, bacteria or yeast—so-referred to

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as heterologous hosts. For that purposes researchers are trying to develop cell factories that can produce greater than naturally made natural host. As plant natural products and their derivatives are vital resource for maturing the field of health products, medicines and food additives, synthetic biology techniques initiate new techniques for artificially construction and optimization of biosynthetic pathway of the target compounds within microbial cell at large scale.

Synthetic Biology in the Field of Natural Products: Now a day's investigation of plant natural products biosynthesis is very important for focusing on the compounds having economic significance for industrial purpose or of physiological importance (e.g., hormones). The studies have been developed from biochemical assays with cell-free extracts and isolation of the relevant enzymes to molecular biology based recombinant expression and analysis of plants genetically modified to over or under express the encoding genes. Various approach can be followed like making of artificial bio-system having unique properties[5], redesigning of system for desired purposes[6], and reconstruction for understanding biology[7]. The biosynthesis of very few plant natural products is very important. Identification of the relevant biosynthetic pathway enables access to the resulting natural product, via metabolic engineering for different classes of plant natural products like flavonoids, alkaloids, betalains, and glucosinolates and in the native plant or in microbial hosts. Emphasis should be given on microbial platforms as a highly useful tool for engineering these natural products with additional consideration given to microbial consortia. The potential to lifestyle sturdy assortments of microbes with various capability has dramatically elevated to permit a much wider scope of merchandise to be engineered in more and more green ways. These technological developments are persevering with increase at a fast tempo and coincide with new finding out concerning using plant natural products.

Synthetic Biology of Plant : The prime aims of synthetic biology are to design and modify natural systems or reconstruction of artificial biological devices and systems by applying engineering principles so that predictable behaviors are exhibited[8]. Development processes of this field can resemble automobile mechanics. For higher efficiency (top down), an older model can be tweaked or a new model can be made from scratch (bottom up). To make minimum size system, lesser number of parts and less complex structure, the top down system is applied in the existing plant. Whereas bottle up approach is applied to individual parts to form biological system artificially having potent properties[5]. Irrespective of said both approaches, ultimate aim of the synthetic biology is to redesign a desirable system for a target purpose[6] and by reconstruction to know biology greatly[7]. Biologists, engineers, scientists, and others work together for finding effective routes to combine various genetic architecture into purposeful products for real-life that are used every day. In some cases, main focus of the synthetic biologists more in engineering than biology. The prime focus of biology is on discovery of science and analysis while, focus of engineering on design, redesign and synthesis. Its extensive uses have been found in various fields like agriculture sustainability[9], improvement of human health and wellness[10], recent development of synthetic element of plant from single fraction to developed circuits, innovation of software, and incorporation of hardware tools within the engineering cycle[11]. It is different from conventional plant biotechnology that mainly relies on recombinant DNA technology and its focuses observed on recombination of preexisting heterologous genes and promoters whereas plant synthetic biology aims to combine the modules of nature differently with new innovative ways and to make new modules. It is similar to systems biology, focus of synthetic biology goes on the interactions and active behaviors of a natural or artificial system's parts[12]. Systems biology deals with the investigation of complex mechanisms of biological systems by the treatment of knowledge on the behavior of proteins, genes, biochemical networks including physiological responses within a whole system[13].

Methods for Partial Synthetic Modification of Biosynthetic Pathway of PNP in Plant Cell : It is observed to have tremendous complex metabolic pathway of plants secondary metabolites and these can be arranged in 3 dimensional grid, linear or cyclical having diversified branch. Although there are some limitations of microbial chassis e.g. very weak expression of P450 Enzymes and lesser tolerance to active products nor yielding of minimum yield. One important advantage to perform modification of metabolic pathway of PNP is due to known partial or complete biosynthetic pathway of the target PNPs, Hence, implementation of pathway is possible by overexpression, or by blocking competing reactions. There are three major genetic systems of plants. These are nuclear, plastid and mitochondrial. Due to the plant homology, plant cells synthesize specific PNP.

Zhuet al[14] reported recent progress in the modification of biosynthesis and other synthetic biology application of Plant natural products in plant cell. There, recent progress of modified biosynthesis of PNP within Plant cell of different secondary metabolites and associated methods has been introduced in tabular form. Different strategies and methods used for modification of biosynthesis of Plant Natural products in plant Cell have been well presented there[14].

Designing Way of Synthetic Biology Cycle : There are five stages for ideal designing of synthetic biology cycle. These are: conceptualization, designing, model preparation, construction, and, lastly, exploration, test, and validation[15,16–18]. Conceptualization directs the grand goals (i.e., expected features and activities of a device) of networks of synthetic gene in response to inputs and desired outputs. The targets should be formulated rationally so that production and testing be unambiguously. Basic knowledge helps synthetic biologists to construct nature's principles and modules with the help of biomimetic. After the specification of an objective, it is important to select genetic parts and strategy constructions for the actualization of the objective. In this context, use of Computer-Aided Design (CAD) helps for determination and optimization of kinetic parameters, network hierarchies, and parts selection[15]. It helps also modeling for the network analysis behaviors, sensitivity, and the promising design selection for implementation. Construction involves the fabrication, assembly of synthetic circuits and also their integration in a plant host[19]. A combination of trial-error approach with fine-tuning is needed for testing, experimental probing, and justification. Furthermore, multiple repetitions might be required to form a series of upgraded approximate solutions to eventually procure the convenient functions and properties[15]. Empowering tools to satisfy the design of plant synthetic biology cycle include various principles related to engineering for design, parts selection of component, and design and modeling of plant computational tools[19]. Standardization parts are very dependent on modularity and orthogonality and allow parts to be combined to form a complex system. The decomposition and simplification of a technical process by abstraction, decoupling, and standardization can lead to reduction of effort in the design cycle.

Conclusion

Since the historical period, secondary metabolites of plant have been used as origin of medicine. To fulfill demand in a large scale, it is needed to set up sustainable routes for availing secondary metabolites. For synthesizing PNPs within the cell of plant a perfect host is necessary where genetic transformation and metabolic process will be carried on. It is true that more than 500,000 natural products are known but their biosynthetic pathway have not yet been identified[20]. Hence, searching of these biosynthetic pathway and analysis should bring under the consideration. It is our belief that various strategies and methods will be matured for the next generation such as sequencing technology, genetic engineering technology, bioinformatics analysis, and other synthetic biology technologies. Interpretation of diversified biosynthetic pathways will be possible in the studies on medicinal plants. Although it is true that there is still a long journey to overcome the gridlock in the plant synthetic biology development, use of plant cells can be utilized as an excellent substitute for PNP production and provide a huge opportunity for future agriculture and industry. The present work will help the researchers to bring into their notice regarding way of thinking. ❐

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Synthetic Communications Reviews

Recent developments of nanocatalysts for Stille coupling reaction

Sasadhar Majhi & Shyamal K. Jash

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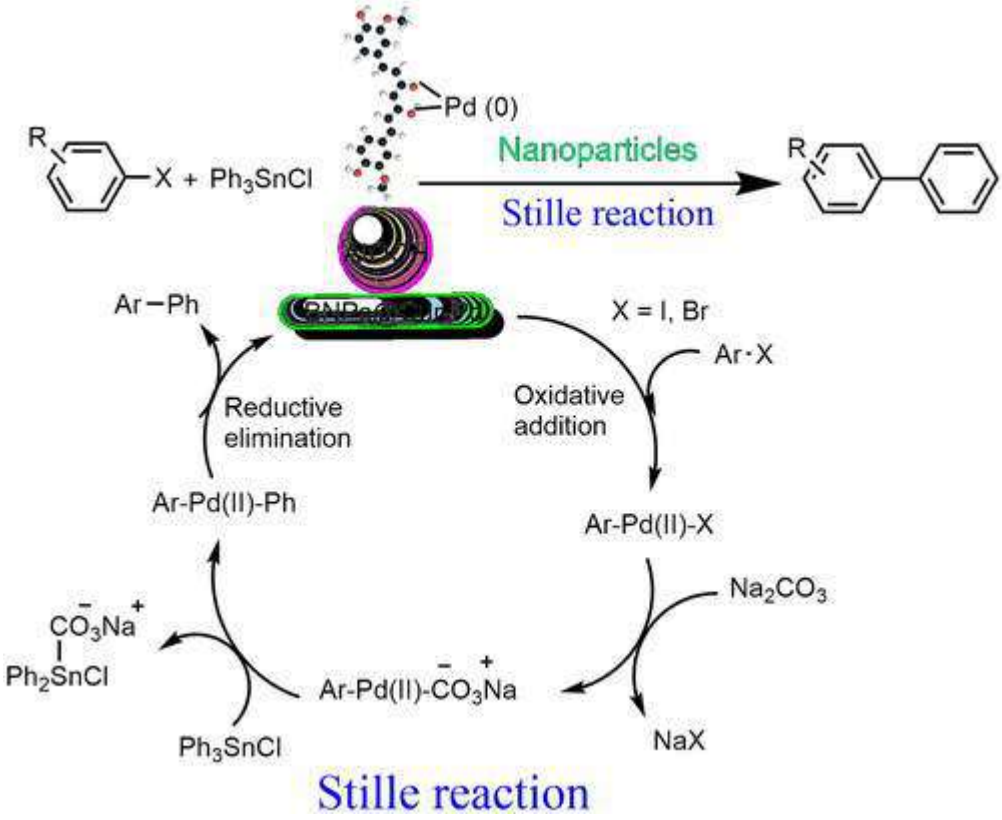
Abstract

In organic synthesis, the Stille reaction is one of the most general, effective, and selective Pd-catalyzed cross-coupling reactions for the formation of C–C bonds. It is based on organotin compounds using catalytic amounts of Pd complexes under mild reaction conditions normally. The stability toward moisture and air of organotin mediators provides superiority to the Stille reaction over other Pd-catalyzed cross-coupling transformations. The Stille reaction is effective in preparing promising organic molecules and is generally superior for synthesizing complex molecules including natural products. Currently, metal nanoparticles are more fascinating tools

for catalysis due to their high surface-area-to-volume ratio. Besides, magnetic nanoparticles have been the focus of more attraction during the last two decades as they can be easily separated from the reaction mixture. Hence, this review aims to focus on the applications of nanoparticles as an efficient catalyst in Stille coupling elegantly for the first time.

Graphical Abstract



Keywords: Stille reaction | nanoparticles | sustainable chemistry | C–C cross-coupling reactions | organic synthesis

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Disclosure statement

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Effect of channel morphological changes on wetland transformation

Swades Pal [a], Sandipta Debanshi [b], Pankaj Singha [a], Ripan Ghosh [a], Susmita Ghosh [a], Sutapa Mukhopadhyay [b], Abhishek Bhattacharaya [c], Surajit Let [d], Priyanka Das [e], Manabendra Let [a,*]

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HIGHLIGHTS

- About 57 % wetland area was lost along with lowering of water supply from rivers.
- Existing wetlands experienced hydrological, morphological and ecological distruption.
- Bottle neck channel, embankment, loss of drainage were major drivers of wetland loss.
- Channel morphological and flood ambiance change were detected to play vital role.

GRAPHICAL ABSTRACT

ARTICLE INFO

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Keywords:
Floodplain wetland
Transformation
Channel morphological changes
Drainage modification
Wetland hydrology
Machine learning and ordinary least square regression

ABSTRACT

Keeping aside the traditional approaches to investigating floodplain wetland transformation, the current study investigated various aspects of it through changes in river channel morphology and drainage pattern. The study analyzed wetland transformation using satellite image-based machine learning and intensive fieldwork. Ordinary Least Square (OLS) regression was applied to identify dominant influencing factors among 24 contributing factors under six clusters to eight dependent phenomena of transformation. The result showed that 57 % of wetland area lost since 1991, and existing wetland has also experiencing hydrological scarcity. From 1991 to 2021, the area under low water depth (<1 m.) inflated from 18.55 % to 50.54 %, the hydro-period narrowed down, and the appearance of water becomes inconsistent. The OLS result showed that changes in channel morphology (bottle neck channel, embankment-driven carrying capacity enhancement, etc.), interruptions in river and wetland connecting channels (source closure, breaching the continuity, conversion in to agricultural

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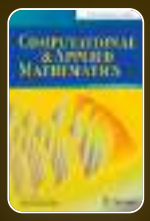
Unveiling the dynamics of canard cycles and global behaviour in a singularly perturbed predator–prey system with Allee effect in predator

| Published: 10 February 2024

| Volume 43, article number 86, (2024) Cite this article



Computational and Applied Mathematics

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Tapan Saha & Pallav Jyoti Pal

Abstract

In this article, we have considered a planar slow–fast modified Leslie–Gower predator–prey model with a weak Allee effect in the predator, based on the natural assumption that the prey reproduces far more quickly than the predator. We present a thorough mathematical analysis demonstrating the existence of homoclinic orbits, heteroclinic orbits, singular Hopf bifurcation, canard limit cycles, relaxation oscillations, birth of canard explosion by combining the normal form theory of slow–fast systems, Fenichel's theorem and blow-up technique near non-hyperbolic point. We have obtained very rich dynamical phenomena of the model, including the

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Allee effect and hunting-induced bifurcation inquisition and pattern formation in a modified Leslie–Gower interacting species system

Pallav Jyoti Pal [a] ✉, Gourav Mandal [b] ✉, Lakshmi Narayan Guin [b] ✉, Tapan Saha [c] ✉

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Highlights

- This article explores temporal and spatiotemporal dynamics of a modified LG system.
- Local stability, bifurcation and diffusion-driven pattern formation have been studied.
- Identified prey extinction, bistability, bubbling effect, limit cycle, homoclinic loop and cusp.
- Evolution of diffusion-driven patterns (spots, stripes, labyrinthines, etc) is demonstrated.
- Extensive numerical simulations are carried out.

Abstract

Singular Bautin bifurcation analysis of a slow–fast predator–prey system

| Original Paper | Published: 13 March 2024

| Volume 112, pages 7695–7713, (2024) Cite this article

Nonlinear Dynamics

Aims and scope →

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Tapan Saha, Pranali Roy Chowdhury, Pallav Jyoti Pal & Malay Banerjee

Abstract

Over the past few decades, the study of complex oscillations in slow–fast systems has been a focal point of research. Within the realm of slow–fast systems theory, the determination of the singular Hopf bifurcation and maximal canard locations relies on computing the first Lyapunov coefficient, based on the genericity condition that it is nonzero. This manuscript seeks to broaden these results to scenarios where the first Lyapunov coefficient becomes zero. To achieve this, the analytical expression of the second Lyapunov coefficient is derived, and an exploration of the normal form for codimension-2 singular Bautin bifurcation in a singularly perturbed Holling type-III predator–prey system with a weak Allee effect is conducted, explicitly identifying locally invertible parameter-dependent transformations. Utilizing geometric singular perturbation theory, the normal form theory of slow–fast systems, and the blow-up technique, this research

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ARTICLE

Sci. and Cult. 89 (11–12) : 411-414 (2023)

ARBITRARY *L*-STATE SOLUTION OF SHIFTED DENG-FAN POTENTIAL BY INTERPOLATING WAVELET COLLOCATION METHOD

M. K. SAHA

The Solution of D-Dimensional Radial Schrödinger Equation with Shifted Deng-Fan (sDF) Potential has been Investigated by Interpolating Wavelet Collocation Method. The Wavelet Based Interpolating Collocation Scheme Can Extract the Bound State Spectrum of sDF Potential Efficiently without any Pekeris Type of Approximation of the Centrifugal term and it gives most Accurate Results in Bound State Eigen Solution. As an Application, Bound State Eigen-Energies of some Diatomic Molecules (H_2, LiH, HCl, and CO*) are Presented in Low and High-Lying States for any Arbitrary Values of {l, n} and Compared with Existing best Results to show the Superiority of the Scheme.*

Introduction

In this study, the bound state solution of d -dimensional radial Schrödinger equation with sDF molecular potential has been considered, which is given as[1–5].

$$V(r) = D_1\left(1-\frac{b}{e^{\alpha r}-1}\right)^2 - D_2,\ b = e^{\alpha r_e}-1,\ r \in \mathbb{R}^+. \quad (1)$$

where D_1, D_2 represent the dissociation energy, α is the range of potential, r_e is equilibrium internuclear distance and r is internuclear distance. This potential is actually a modified form of originally Deng-Fan potential[6–10]. Various scientific phenomena in science like diatomic molecular energy spectra, interactions between nuclei, the motion of the nucleons, and electromagnetic transitions in diatomic molecules can be explained through sDF potential model. The bound-state solutions of the relativistic and non-relativistic wave equations have been investigated by number of authors by different type of approximation of centrifugal term due to their significance application in chemical physics, molecular spectroscopy, molecular physics, and related fields[1–5]. The focus of this study is to investigate the numerical bound solution of the *d*-dimensional radial Schrödinger equation with sDF molecular potential without any Pekeris type approximation of centrifugal term for any arbitrary *n,l* by using interpolating wavelet collocation scheme with high accuracy. The collocation scheme based on interpolating wavelets[11,12] generated by scale functions from the Daubechies family[13,14] has been developed here to obtain highly accurate solutions of the NR-Schrödinger equation in a semi-infinite domain R^+ containing sDF molecular potential. The energy eigenvalues for a set of homogeneous and heterogeneous diatomic molecules (H_2, *LiH, HCl and CO*) for some arbitrary values of quantum numbers n and l obtained by the proposed scheme are provided here.

The work is organized as follows: In Section 2, a short overview of the interpolating wavelet basis and expansion of function in this basis are provided, along with an estimation of errors. The solution of the Schrödinger equation by using the interpolating wavelet collocation method with arbitrary angular momentum quantum numbers involving sDF molecular potential is

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obtained in Section 3. The results obtained by the scheme proposed here are demonstrated in Section 4. Finally, Section 5. gives a conclusion of the study presented here.

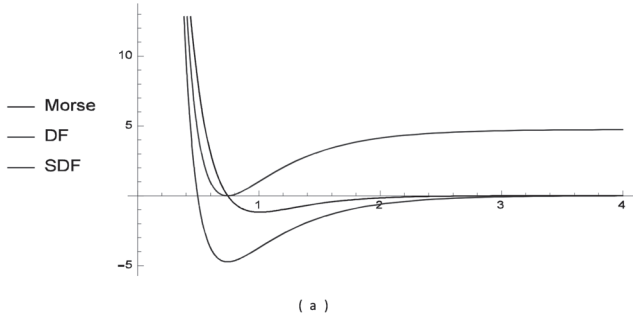

Fig. 1: Fig.(a)Variation of $V(r)$ with r of Morse, Deng–Fan(DF) and sDF potential for H_2 diatomic molecule.

Overview of Interpolating Wavelet

The fundamental theory of interpolating wavelets can be found in detail in literatures[15–18]. Here, some essential features of interpolating wavelet basis have been presented, as far as it is needed for our purpose.

1. The interpolating scale function $\Phi(x)$ and the wavelet $\Psi(x)$ [15,12] of compact support $(-2K+1, 2K-1)$, $K \in N$ are defined at different scales as

$$\Phi_{j,k}(x) = \Phi\left(2^j x - k\right),\ \Psi_{j,k}(x) = \Psi\left(2^j x - k\right) \quad (2)$$

2. Interpolating scale function, $\Phi(x)$ has vanishing moments for $i = 1, \cdots, 2K-1$, i.e.

$$\int_{\mathbb{R}} x^i \Phi(x)dx = 0, \quad i = 0, \ldots. 2K-1 \quad (3)$$

3. The interpolating wavelet function $\Psi(x)$ has vanishing moments for $i = 0, \cdots, 2K-1$, i.e.

$$\int_{\mathbb{R}} x^i \Psi(x)dx = 0 \quad i = 0, \ldots.. 2K-1 \quad (4)$$

4. Any smooth functions $f \in L^2(R)$ can be approximated by

$$f(x) \simeq f_i(x) = \sum_k f\left(\frac{k}{2^j}\right)\Phi_{j,k}(x) \quad (5)$$

The estimated error in the approximation in details given in *Proposition* 2.1 of [17] as

$$E_j^{Est}[f]\left(\frac{k}{2^j}\right) \approx \left|\left(P_j f\right)\left(\frac{k}{2^j}\right) - \left(P_{j+1} f\right)\left(\frac{k}{2^j}\right)\right|;$$

$$E_j^{Est}[f] = \sup_{k \in \Lambda_j} E_j^{Est}[f]\left(\frac{k}{2^j}\right) \quad (2.5)$$

where $\left(P_j f\right)(x) = \frac{1}{2^j}\int_{\mathbb{R}} f(y)\,\Phi\left(\frac{y-x}{2^j}\right)dy$ and and Ë$_j$ is an appropriate index set $\left(\Lambda_j = \left\{-2^{j+2}, \ldots, 2^{j+2}\right\}\right)$.

Formulation of Schrödinger Equation on The Interpolating Wavelet Basis

Let us consider the d-dimensional reduced radial Schrödinger equation

$$-\frac{\hbar^2}{2\mu}\frac{d^2u}{dr^2}(r) + \frac{\hbar^2}{2\mu}\frac{(2l+d-1)(2l+d-3)}{4r^2}u(r) + V(r)\,u(r) = Eu(r),\ r \in \mathbb{R}^+ \quad (3.1)$$

As there are some difficulties in the representation of unknown solution $u(r)$ directly in interpolating scale function basis $\left\{\Phi_{jk} k \in Z,\ j \in N\right\}$, a special type of transformation has been used here, which is given by

$$r = \Theta(y) = e^{\frac{\pi}{2}\sinh y}. \quad (3.2)$$

This transformation transforms the domain of the problem R^+ into R. The significance of this special transformation is that it acts as a contraction map that resolves the difficulties of partial support of the basis as well as counterbalance the singularities in the centrifugal term $1/r^2$. As a result, the scheme can effectively avoid Pekeris-type approximation.

Now, the approximation of the unknown solution $u(r)$ in Eq.(3.1) in the interpolating wavelet basis is given as

$$u_j^{Approx}(y) = \left(\phi_{jk}(y),\ k \in \Lambda_j^{(a,b)}\right).c_j \quad (3.3)$$

where $\Lambda_j^{(a,b)} = \left(2^j a, \ldots, 2^j b\right)$ being an index set depending on the resolution j as well as limits a,b of the truncated domain in R. Approximation $u^{Approx}{}_j(y)$ in (3.3) can now be used to transform this equation into a generalized matrix eigenvalue problem either by taking inner product of both sides with $\left(\phi_{jk}(y),\ k \in \Lambda_j^{(a,b)}\right)$ (Galerkin approach) or by evaluating both sides at nodes $\left\{\frac{k}{2^j}, k \in \Lambda_j^{(a,b)}\right\}$ (collocation method). The generalized matrix eigenvalue problem is obtained as

$$\mathcal{H}_j c_j = E^{Approx}\mathbb{Q}_j c_j \quad (3.4)$$

where the matrices H_j and Q_j are given by

$$\mathcal{H}_{j\,kl} = -2^{2j}\Phi''(1-k) + \left\{\frac{\pi}{2}\cosh\left(a+\frac{l}{2^j}\right) + \tanh\left(a+\frac{l}{2^j}\right)\right\}$$

$$\times 2^j\Phi'(1-k) + \frac{\pi^2}{4}\cosh^2\left(a+\frac{l}{2^j}\right)$$

$$\times\left\{\frac{(l+2d-1)\,(l+2d-3)}{4} + \Theta\left(a+\frac{l}{2^j}\right)^2\bar{V}\left(a+\frac{l}{2^j}\right)\right\}$$

$$\times\Phi(l-k)\;k,l=0,...,\,2^j(b-a)\,. \qquad (3.5)$$

and

$$\mathbb{Q}_{j\,l} = \frac{\pi^2}{4}\Theta\left(a+\frac{l}{2^j}\right)^2\cosh^2\left(a+\frac{l}{2^j}\right),$$

$$l=0,...,\,2^j(b-a) \qquad (3.6)$$

respectively. Then the eigen spectrum of the matrices (H_j, Q_j) can be obtained directly by using any efficient library function in a computational software, e.g., "Eigensystem" in MATHEMATICA.

Results and Discussion

Here, the efficiency of the scheme has been established by the estimated errors for states l = 0 with a homogeneous diatomic molecule H_2, where minimum accuracy is 12 decimal places {n = 5, l = 0} and maximum is upto 20 decimal places {n = 0, l = 0}. Then the energy spectrum of H_2, *LiH*, *CO*, and *HCl* diatomic molecules have been computed for any arbitrary l and n that are presented in Table-1. The potential parameters for this calculation are taken from [2] directly and the conversion factors Hartree energy = 27.21138*eV*., $\hbar c$ = 1973.269678.$eV\,A^0$ are given in NIST database 2018.

Conclusion

In this study, a highly accurate numerical solution of the Schrödinger equation has been obtained for the sDF potential by the use of an efficient interpolating wavelet collocation method without any Pekeries-type approximation of the centrifugal term. The method is found to be quite accurate for any high- and low-lying states as well as conventional choice of potential parameters. The estimated errors of H_2 diatomic molecules for l = 0, 1, 2 and numerical values of eigenenergies of (H_2, *LiH, HCl, and CO*) diatomic molecules with sDf potential for different angular momentum l are demonstrated here. The scheme developed here may be easily extended to solve a variety of molecular models involving Morse, Manning-Rosen, and Hulthen type molecular potentials in a non-relativistic and relativistic manner, where other numerical schemes often face difficulties due to approximation of the centrifugal term. Work in this direction is in progress and will be reported shortly.

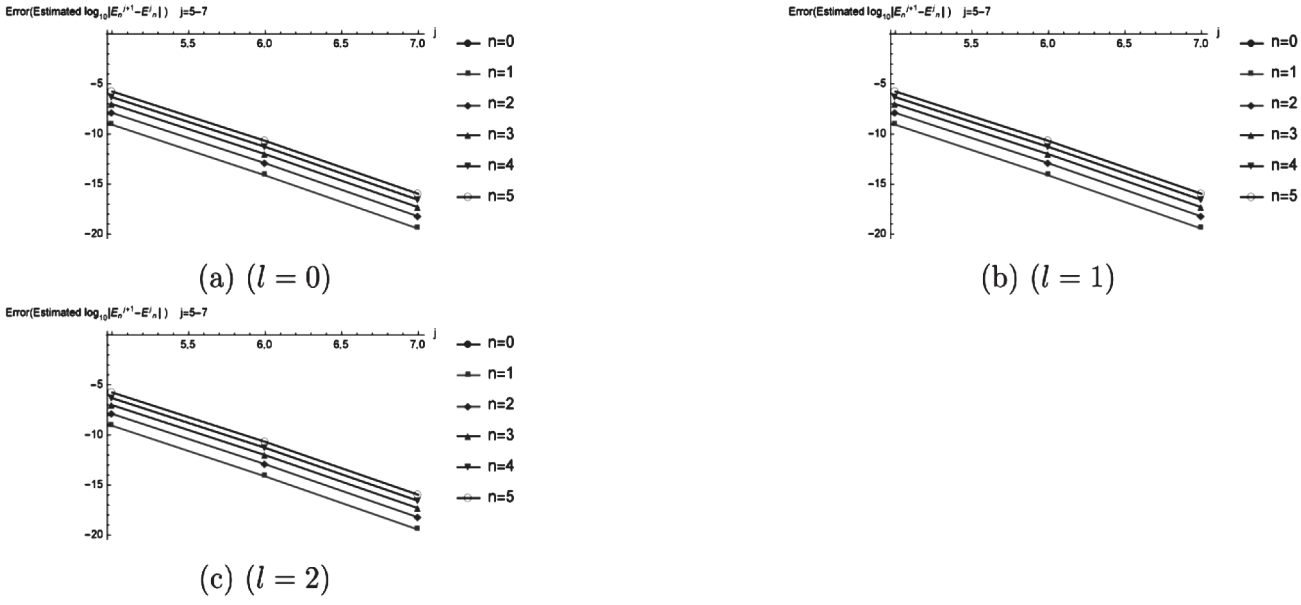

Fig. 2: Fig. (a-c) Plots of errors (Estimated errors in Log_{10} scale) in the approximation of energies of H_2 diatomic molecules for different states (n = 0,1, ⋯ ,5) with sDF potential for (l = 0, 1, 2) at different resolution (j = 5 " 7).

Table 1: Eigenenergies (– *E*) in *eV* of sDF potential for H_2, *LiH, HCl, and CO diatomic* molecules.

States		H_2	*LiH*	*HCl*	*CO*
n	*l*	Present method	*Present method*	Present method	Present method
0	0	4.394623310799	2.411933956692	4.417049456662	11.080751382006
	3	4.308382401676	2.400977626288	4.401589021819	11.077894131112
	5	4.180761369696	2.384582844386	4.378427613816	11.073608605396
	7	4.000047672053	2.360985447627	4.345034184642	11.067419144394
	0	2.640531716089	1.845674861914	4.417049456662	11.080751382006
3	3	2.574791289592	1.836030355411	2.574791289592	1.836030355411
	5	2.477651600636	1.821601208812	3.274610251843	10.226192734042
	7	2.340410962034	1.800838642038	3.244867541264	10.220188803972
	0	1.758473613071	1.516273362912	1.599511694466	9.688159630728
	3	1.704795431403	1.507467116153	3.295244368477	10.230349817504
5	5	1.625616875073	1.494294207386	2.634120212385	9.681373564509
	7	1.514049905437	1.475343787733	2.606794334310	9.675493259971

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DC conductivity mechanism in $La_{0.7}Sr_{0.3}MnO_3$ (LSMO)-ZnO nanocomposites

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$La_{0.7}Sr_{0.3}MnO_3$ (LSMO)-ZnO nanocomposites with varying concentrations of ZnO have been synthesized using the solution combustion method. A bimodal particle size distribution has been formed in all the samples. The crystallite size increases in the composites as compared to LSMO. The study on electrical resistivity reveals that LSMO exhibits a metal-to-insulator transition at 359 K, while the inclusion of ZnO suppresses the metallic behavior in the composites and increases the resistivity. Transport behavior of the samples in metallic and semiconducting regions has been explained with a known polynomial equation and a two-channel conduction model obeying the small polaron hopping mechanism, respectively. A very low activation energy in the range of 10–12 meV is observed due to smaller-sized particles. The presence of ZnO drives the hopping mechanism from adiabatic in LSMO to become non-adiabatic in the composites and enhances the maximum temperature coefficient of resistance. 80% LSMO-20% ZnO (by weight ratio) composite shows a maximum TCR of −29.81%/K at 248 K, which makes it a potential candidate for several applications in sensing devices. The Curie temperature of the material decreases with the increase in ZnO content in the sample. The results of this study also confirm the existence of correlation between the electrical and magnetic properties of LSMO.

Topics

Electrical conductivity, **Electrical resistivity**, **Phase transitions**, **Phonons**, **Polarons**, **X-ray diffraction**, **Nanocomposites**

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A QUEST FOR FEMALE IDENTITY IN THE POETRY OF ANNE BRADSTREET

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Abstract: This paper tries to focus on the quest for female identity in the poetry of Anne Bradstreet. It also strives to articulate the feminine sensibility in the selected writings of the poetess. The beginning of seventeenth century in America witnessed the birth of a revolutionary movement called feminism with raid development and progression even in the puritan male dominated society. At this century the emergence of women writers in America were very few. In such circumstances a poetess named Anne Bradstreet who was considered to be the most prominent of early English poets of North America and first writer in England's North American colonies, was born in the beginning of seventeenth century in America. She was one of the most radical poets of the century that she had exposed the brutal truth about women's life in early American puritan society. In her poetry she has brought to light how women' voices have been suppressed and dominated in the patriarchal puritan society. She also talked about gender discrimination in the society and expressed how women had to struggle in her time to establish her own identity in the society. She felt that women need an intellectual space in the society to fulfill their wishes and goals. But the male society always confined them in the boundaries of their home. This society compels them to do their household duties and ignores their dreams .This article brings out the struggle of being woman who resisted the suppression and oppression of patriarchy and eventually succeeded to find her own identity in a male dominated puritan society.

Keywords: Feminism, Identity,Gender Inequality, Domination, oppression, Poetry, Patriarchal Society, Intellectual space.

Introduction

Anne Bradstreet is considered to be the first poetess in England's North American colonies to be published. She has been a long lasting leading figure in American literature who struggled through out her life for her own identity . She was born in 1612 in Northampton of England and was the first puritan female writer who humbly raised the issues of feminism in her works criticising the puritan Patriarchal society. Her Poetry had a unique style through which she wanted to tell the readers about her role as a mother ,her struggles , sufferings of her life and her puritan faith towards the society. Women's role in the society in those days is the prominent theme found in her works. She did not believe that women have a fixed role to play in the society. Actually she did not agree with the stereotypical idea that women are incapable of doing some specific works in comparison with men. All these indirectly points out her attitude towards the society and makes her a feminist poet.

Feminism is basically a socio political, cultural and economic movement in the society. It demands equality of sexes. It deals with equal opportunities and scope for all. Women's rights, fighting against gender stereotypes, political, economic, social inequalities and gender discrimination in the male dominated society are the recurrent themes of feminism. In Anny Bradstreet's time these issues are very prominent in that puritan society. She is regarded as the pioneer of feminism in England's North American colonies. She was the first well-known poet who humbly protested against these issues of society. Nowadays, although women's rights are very strong, still women are fighting for equality everywhere and every day. But in days of Anne Bradstreet's time , women had been suppressed and confined and were seen as inferior to men. The society was completely puritan. Anne Bradstreet was living among the puritans

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Identifying key drivers of extinction for Chitala populations: data-driven insights from an intraguild predation model using a Bayesian framework

Dipali Vasudev Mestry[1] · Md Aktar Ul Karim[1] · Joyita Mukherjee[2] · Amiya Ranjan Bhowmick[1]

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Abstract

The fish species *N. chitala* is a freshwater fish that is widely distributed in African and Asian countries, including India, Pakistan, Bangladesh, Sri Lanka, Nepal, Thailand, and Indonesia. This species has been categorized as endangered (EN) in the Conservation Assessment and Management Plan. The study aims to investigate the cause of the species' decline in their natural habitat. Using mathematical models supported by empirical data analysis, we explore the interaction of the species with other tropic levels and discover important parameters that may be attributed to the rapid decline. Based on the literature, we considered an intraguild predation (IGP) system consisting of three species, namely Chitala (IG predator), *Mugil* (IG prey), and shrimp (resource). Two variants of IGP models governed by three coupled differential equations are considered for data modeling purposes. Chitala depends only on *Mugil* and shrimp in one model. An alternative food source is available to Chitala in the second model. The models are estimated using the Bayesian modeling framework. Posterior estimates of the parameters for each model were obtained using the Gibbs algorithm, and the reversible-jump Markov chain Monte Carlo method has been utilized for posterior model inference. Our findings suggest that the primary reason for the decline in Chitala is due to the reduced nutritional gain from the *Mugil* and reduced predation efficiency in acquiring shrimp as a food source in the unavailability of *Mugil*. This study may be useful to develop management strategies for Chitala conservation by emphasizing the regeneration of *Mugil* populations.

Keywords Fisheries management · Food chain · Multi-model inference · Posterior model probability · Sensitivity analysis

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