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ORIGINAL RESEARCH ARTICLE

Assessing Herbaceous Vascular Plants Diversity and Conservation Needs on Kir and Tala Mountains, Bauchi State, Nigeria

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ABSTRACT

Kir and Tala mountains in Bauchi State, Nigeria, are recognized for their rich biodiversity, yet there remains a gap in understanding the diversity of herbaceous vascular plants within these ecosystems. The study was conducted between 2019 and 2022 to comprehensively assess the diversity of herbaceous vascular plants and potential conservation implications. Through systematic field surveys, specimen collections, and data analysis, we hypothesize that mountains harbor a diverse array of herbaceous vascular plant species. We found several distinct herbaceous taxa including native and endemic species, dominate the Kir and Tala mountains—Sixty-nine herbaceous angiosperms found in caves, crevices, rockpools, and mountain galleries. On Kir Mountain, Shannon and Simpson's diversity index of herbs are 1.63 and 0.77, respectively, with species richness of 7. On Tala Mountain, Shannon and Simpson's diversity index of herbs is 1.65 and 0.75, respectively, with species richness of 9. These findings contribute to the checklist of endemic and understudied plant taxa, including taxa with rare or no *in-situ* published photographs, such as *Kinghamia angustifolia, Streptocarpus nobilis, Laportea mooreana* e.t.c. Conservation measures are needed due to the accelerated rate of habitat degradation, deforestation, and agricultural activities at lower altitudes, which affects the diversity of herbs in the mountains.

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Biodiversity, checklist, conservation, degradation, herbs, mountains

INTRODUCTION

There are rapid changes in species abundance, distribution, and diversity of plants, especially in tropical and subtropical regions of the world, including Africa, due to climate change, over-exploitation of plant resources, human population growth and settlement expansion (Anwadike, 2020). These activities lead to the deforestation of trees and shrubs for charcoal production, fuelwood collections, and infrastructural development (Ogwu *et al.,* 2016). These significantly impact the diversity of plant species and composition, especially native species. Indigenous knowledge of plants is needed for proper conservation and wise use of natural resources. Examining the current status of species diversity, abundance, and composition is essential because a healthy ecosystem depends on plant diversity. According to Ogwu *et al.* (2016), plants provide many ecological services, including provisional services such as food production, supporting, cultural service, species conservation and prevention of soil erosion, and aesthetic potentials.

Mountain ecosystems account for one-fifth of the land surface, and tropical mountain forest represents 11% of tropical forest land surface (Prince *et al.,* 2019). High mountain ecosystems are spots for plant diversity (Michele *et al.,* 2018); hence, mountain forests play an essential role in biodiversity conservation Munishi *et al.* (2004). Elevation and Topography affect species diversity and vegetational structure (Ayemian *et al.,* 2018); also elevation strongly influences the distribution of biodiversity of plants and regulates several abiotic factors that control observed vegetation patterns and ecology of mountain forests.

In previous studies on mountain ecosystems in Nigeria, authors reported many herbs combined with woody species, but the number of herbaceous plants they reported is less than number of herbs reported on Kir and Tala mountains in comparison, with no reports of endemic species by previous authors on mountains in Nigeria.

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This research paper aims to fill the knowledge gap regarding the diversity of herbaceous vascular plants in Kir and Tala mountains in Bauchi State with three specific objectives: (i) to document a checklist of herbaceous vascular plants in Kir and Tala mountains, (ii) to provide photo guide to some available herbaceous vascular plants species (iii) to determine the diversity of vascular herbaceous. These objectives were used to test the hypothesis that the Kir and Tala mountains harbor a high diversity of herbaceous vascular plant species.

MATERIALS AND METHODS

Study sites

The study was carried out between 2019 to 2021 in Bauchi, Zungur district, of Bauchi Local Government Area (Bauchi LGA), Bauchi State of Nigeria, which is situated in Sudan Savanna as shown in (Figure 1). The two study sites comprise mountainous terrain, Tala and Kir mountains. Tala mountain is about 3750m^2, while Kir mountain is about 3100m^2. Bauchi is located between latitude 10^0 22' north of the equator and longitude 9^0 42' east of the Greenwich Meridian at an average elevation of 607m above sea level. It has a land area of 3,687 km^2, with an annual rainfall. The mean average yearly rainfall is between 900-1000mm, which occurred mainly during May to September.

Sampling methods and specimen collections

A mixed sampling method was used to collect and document vascular herbaceous plants. The first sampling method was the non-probability sampling method; herbs that live in caves, crevices, rock pools, and mountain galleries were deliberately sorted and collected. Information such as global positioning system (GPS) coordinates and elevations were recorded. Available *in-situ* photographs were captured for entire herbs, fruits, and flowers.

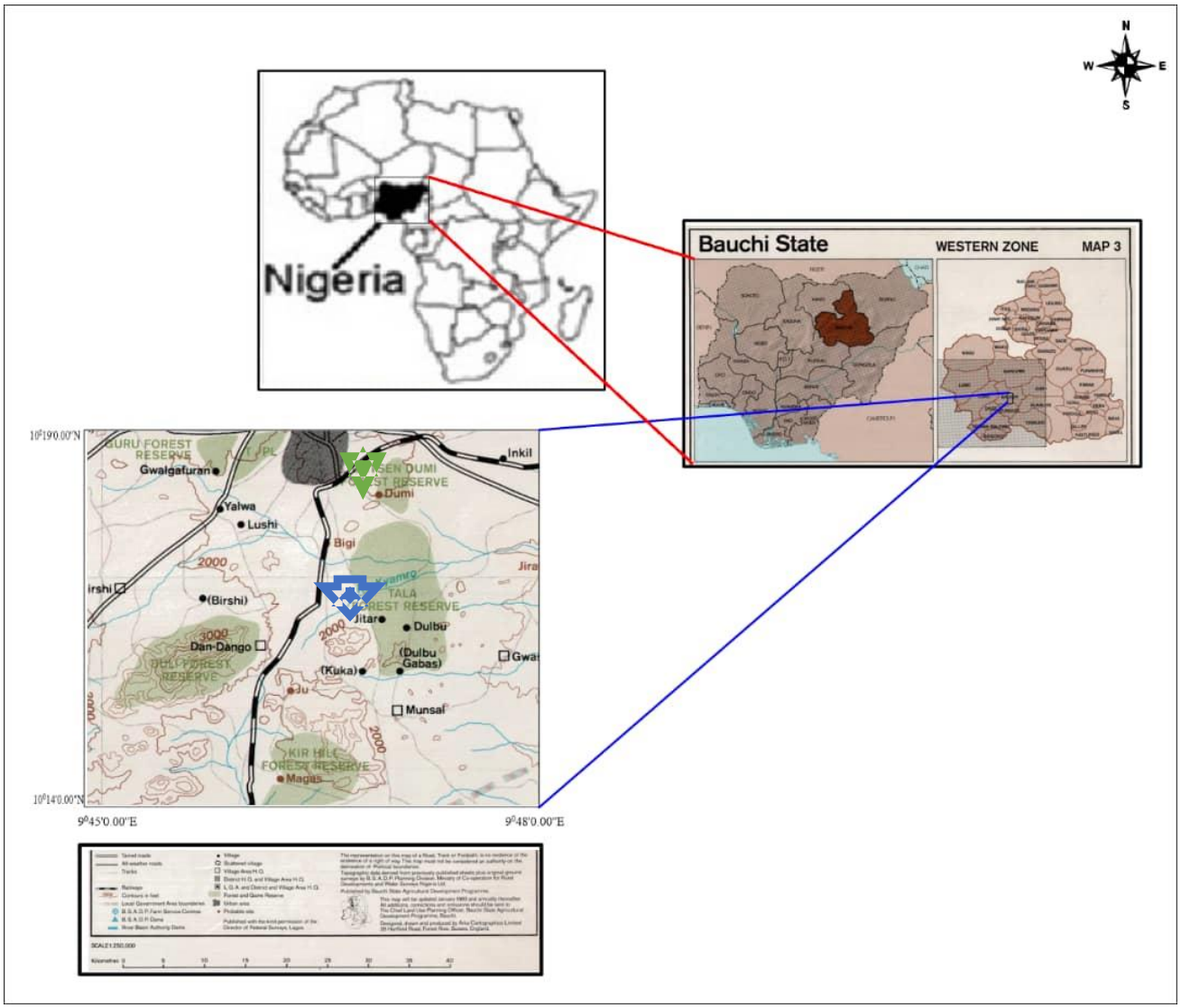

Figure 1: Map, green arrow showing the location of Tala Landscape and a blue arrow showing the location of Kir landscape in the part of the western zone of Bauchi State, Nigeria, and Africa.

The second sampling method was a series of continuous line transects established for data recording and collecting herbs. The transect was placed at 50m intervals between each transect, and herbaceous vascular plants that

intersect and torches the line transects were recorded. Available *in-situ* photographs were captured for entire herbs, fruits and flowers. Due to the nature of mountains, some collected herbaceous vascular plants were pressed at the collection point while some were pressed at a favourable place using a locally constructed wooden plant press. Leaves were pressed in abaxial and adaxial view; specimens were allowed to dry properly using adequate cross ventilation naturally**;** specimen**s** were mounted using herbarium sheets; glues were used while mounting processes; available seeds, fruits, and flowers were attached. Specimens were deposited in Abubakar Tafawa Balewa University Herbarium for final processing and storage.

Specimen identification and authentication

Collected specimens were identified with the help of constructed taxonomic keys, a book including Flora of West Tropical Africa by Hutchinson and Dalziel, available illustrations, and relevant literatures. Some specimens were verified and authenticated by comparison with available herbarium specimens from the local herbarium (Abubakar Tafawa Balewa University Bauchi), while some were verified by comparing with journal storage (JSTORE) online specimens and plants of the world online (POWO, 2023) and authenticated by Abubakar Tafawa Balewa University Curator.

Data recording and Data analysis

Results were presented in tables and plates. Shannon diversity index (H) and Sampson's diversity index were used to calculate herbaceous vascular plant diversity using data from line transect sampling.

Shannon diversity index (H) is defined in a given fraction below

$$\textit{Shannon-wiener index} \quad \boldsymbol{H = -\sum[(pi) \times log\ (Pi)]}$$

Where:

Pi = proportion of individuals of i-th species in the whole community, which is obtained as n/N where *n* = individual species

N = total number of individuals in a community,

log = is natural logarithm.

Simpson's diversity index (D) is define in the given fraction below

$$\textit{Simpson's diversity index} = 1\text{-}D = 1 - \left[\frac{\sum n_i(n_i\text{-}1)}{N(N\text{-}1)}\right]$$

Where Pi is propositional of individuals in the i-th species. Simpson index formular is D is:

$$\mathbf{D} = \frac{\sum n_i(n_i\text{-}1)}{N(N\text{-}1)}$$

Where n_i -- Number of individuals in the *i*-th species
N – Total number of individuals in the community

RESULTS

Non-probability and line transect sampling

The number of herbaceous vascular plants recorded on Kir and Tala mountains of Bauchi using both lines transect and non-probability sampling methods are presented in Table 1. On Kir Mountain, 7 species were recorded using line transects, while 37 species were recorded through non-probability sampling. 9 species were recorded using line transects on the Tala Mountains, and 49 species were recorded through non-probability sampling. These numbers indicate that the non-probability sampling method yielded more recorded species than the line transect method in both mountain ranges.

Table 1: Number of herbaceous plants recorded with non-probability and line transect sampling on Kir and Tala mountains of Bauchi

Mountain	Line transects	Non-probability
Kir	7	37
Tala	9	49

Table 2 presents the list of herbaceous vascular plants collected and identified from the Kir and Tala mountains along with their respective families and occurrence in each mountain and collection number. Several families, such as Fabaceae, Lamiaceae, Malvaceae, and Urticaceae, are represented by multiple species, indicating a diverse representation within these families. Some species, such as *Justicia insularis*, *Adiantum philippense*, and *Cucumis metuliferus*, were encountered in both the Kir and Tala Mountains, suggesting a broad distribution across the study area. Other species, such as *Laportea mooreana* and *Laportea aestuans,* were only encountered on Kir Mountain, indicating potential habitat preferences or restrictions. Notably, certain species like *Dioscorea bulbifera* and *Solenostemon monostachyus* were encountered in both mountains, suggesting their adaptability to diverse habitats within the region. However, species like Clematis hirsuta and Physalis angulata were only encountered in one of the mountains, indicating potential habitat specificity or limitations.

Both the Kir and Tala mountains sites exhibit moderate to high levels of species diversity, as indicated by their respective Shannon and Simpson diversity index values (Table 3). The Tala Mountain site shows a slightly higher Shannon diversity index (1.65) than the Kir Mountain site (1.63), suggesting slightly greater diversity or more equitable distribution of species abundances on Tala Mountain. Despite the differences in species richness between the two sites, the Shannon diversity index values indicate relatively comparable levels of overall diversity. The findings suggest that both the Kir and Tala Mountains of Bauchi support diverse herbaceous vascular plant communities, with the Tala Mountain site exhibiting slightly higher diversity based on the Shannon diversity index.

Table 2: Herbaceous vascular plants collected and identified from Kir and Tala mountains of Bauchi 2020-2021

Family	Collection No.	Species	Kir	Tala
Acanthaceae	UM/TAL/2020/007	*Pogonospermum ciliatum* (Jacq.) I.Darbysh. & Kiel	-	+
	UM/KIR/2020/011	*Justicia insularis* T. Anders.	+	+
	UM/KIR/2020/012	*Justicia landanoides* Lam.	+	-
	UM/TAL/2021/069	*Hygrophyla senegalensis* (Ness) T.Anderson	-	+
Adiantaceae	UM/KIR/2021/068	*Adiantum philippense* L.	+	+
Amaryllidaceae	UM/KIR/2019/015	*Crinum ornatum* (Aiton) Herb.	+	+
	UM/TAL/2021/067	*Scadoxus multiflorus* (Martyn) Raf.	-	+
Araceae	UM/TAL/2020/020	*Amorphophallus abyssinicus* (A. Rich.) N. E.	+	+
	UM/TAL/2019/008	*Pistia stratiotes* L.	-	+
	UM/TAL/2019/010	*Stylochaeton lancifolium* Kotschy & Peyr	+	+
Asphodelaceae	UM/TAL/2019/013	*Aloe schweinfurthii* Bak.	-	+
Asparagaceae	UM/TAL/2021/066	*Dipcardi viride* (L.) Monench	-	+
	UM/TAL/2021/065	*Albuca nigritana* (Baker) Troupin	-	+
Asteraceae	UM/TAL/2020/001	*Ageratum conyzoides* L	+	+
	UM/TAL/2020/002	*Aspilia africana* (Pers.) C.D.Adams	-	+
	UM/TAL/2019/003	*Aspilia bussei* O.Hffm. & Muschl.	+	+
	UM/TAL/2019/004	*Aspilia kotschyi* (Sch.Bip. ex Hochst) Oliv.	-	+
	UM/TAL/2020/009	*Chrysanthellum indicum* DC.	+	+
	UM/TAL/2020/014	*Kinghamia angustifolia* (Benth.) C.Jeffrey	-	+
Clomaceae	UM/TAL/2020/005	*Clome viscosa* L.	-	+
Colchicaceae	UM/TAL/2020/025	*Gloriosa superba* L.	-	+
Convolvulaceae	UM/KIR/2020/061	*Distimake aegyptius* (L.) A.R.Simoes & Staples	+	-
	UM/TAL/2020/039	*Merremia dissecta* (Jack.) Hall. F.	-	+
Commelinaceae	UM/TAL/2020/053	*Aneilema lanceolatum* Benth.	+	+
	UM/TAL/2020/023	*Cyanotis lanata* Benth.	+	+
Cucurbitaceae	UM/TAL/2020/043	*Cucumis metuliferus* E. Mey.	+	+
	UM/TAL/2020/026	*Cucumis maderaspatanus* L.	+	+
Cyperaceae	UM/TAL/2021/064	*Afrotrilepis Pilosa* (Boeckeler) J.Raynal	+	+
Dioscoreaceae	UM/KIR/2020/054	*Dioscorea bulbifera* L.	+	+
	UM/KIR/2020/040	*Dioscorea hirtiflora* Benth.	+	+
	UM/TAL/2021/063	*Tacca leontopetaloides* (L.) Kuntze	-	+
Euphorbiaceae	UM/KIR/2020/030	*Astraea lobata* (L.) Klotzsch	+	+
Fabaceae	UM/TAL2020/006	*Senna tora* (L.) Roxb.	+	+
	UM/TAL/2020/052	*Desmodium incanum* DC.	-	+
	UM/TAL/2020/016	*Indigofera hirsuta* L.	+	+
Gentianaceae	UM/TAL/2020/060	*Canscora diffusa* (Vahl) R.Br. ex Roem. & Schult.	-	+
	UM/TAL/2020/062	*Exacum oldenlandoides* (S.Moore) Klack.	-	+
Gesneriaceae	UM/KIR/2020/017	*Streptocarpus nobilis* C.B.Clarke	+	+
Lamiaceae	UM/TAL/2020/042	*Aeollathus suaveolens* Mart. Ex Spreng.	-	+
	UM/TAL/2020/018	*Hyptis suoveolens* Poit.	+	+
	UM/TAL/ 2020/047	*Leonotis nepetifolia* (L.) R.Br.	-	+
	UM/KIR/2020/056	*Solenostemon monostachyus* (P.Beauv.) Briq.	+	+
	UM/KIR/2020/057	*Solenostemon latifolius* (Hochst. ex Benth.) J.K.Mo	+	+
Loganiaceae	UM/TAL/2020/019	*Spigelia anthelmia* L.	-	+
Malvacea	UM/TAL/2020/021	*Corchorus tridens* L.	+	+
	UM/KIR/2020/027	*Hibiscus lobatus* (Murray) Kuntze	+	-
	UM/TAL/2020/022	*Hibiscus vitifolius* L.	+	+
	UM/TAL/2020/024	*Sida urens* L.	+	+
	UM/TAL/2020/028	*Wissadula amplissima* L.	+	+
Melastomataceae	UM/KIR/2020/036	*Nerophila senegambiensis* (G. & Per.) V-L & RD	+	-
Oleaceae	UM/TAL/2020/038	*Jasminum fluminense* Vell.	+	+
Orchidaceae	UM/KIR/2020/031	*Eulophia guineensis* Lindl.	+	-

To be continued next page

Table 2 continued

Family	Collection No.	Species	Kir	Tala
Oxalidaceae	UM/TAL/2020/032	*Biophytum abyssinicum* Steud. ex A. Rich.	-	+
Plantaginaceae	UM/TAL/2020/041	*Dopatrium longidens* Skan.	-	+
Poaceae	UM/TAL/2020/029	*Andropogon gayanus* Kunth.	+	+
	UM/KIR/2020/033	*Cenchrus pedicellatus* (Trin.) Morrone	+	+
	UM/KIR /2020/034	*Cenchrus unisetus* (Nees) Morrone	+	-
	UM/KIR/2020/035	*Eragrostis multiflora* Trin	+	+
Pteridaceae	UM/TAL/2020/046	*Actiniopteris radiata* (Sw.) Link	-	+
	UM/TAL/2020/059	*Hemionitis dura* (Willd.) Christenh.	+	+
Ranunculaceae	UM/TAL/2020/058	*Clematis hirsuta* Guill. & Perr.	-	+
Solanaceae	UM/TAL/2020/037	*Physalis angulata* L.	-	+
	UM/KIR/2020/050	*Solanum lycopersicum* L.	+	-
Urticaceae	UM/KIR/2020/044	*Laportea mooreana* (Hiern) Chew	+	-
	UM/KIR/2020/045	*Laportea aestuans* (L.) Chew	+	+
	UM/KIR/2021/048	*Pilea angolensis* (Hiern) Rendle	+	-
	UM/TAL/2020/055	*Pouzolzia guineensis* Benth.	+	+
Vitaceae	UM/TAL/2020/049	*Vitis multistriata* Bak	+	+
Zingiberaceae	UM/TAL/2020/051	*Siphonochilus aethiopicus* (Schweinf.) B.L.Burtt	+	+

DISCUSSION

The results highlight the diverse herbaceous vascular plants in the Kir and Tala Mountains of Bauchi. The differences in species composition between the two mountains and the variation in sampling methods underscore the importance of employing multiple sampling techniques for comprehensive biodiversity assessments. These findings provide valuable insights into these mountain ecosystems' ecological dynamics and conservation needs in concurrence. From both the two study sites, the species richness of herbaceous vascular plants recorded on both Tala and Kir Mountains is 69, using mixed sampling methods (non-probability and line transect sampling); this value obtained is higher than the values obtained by Azila *et al*. (2023) with 26 herbaceous vascular plants on Rhizha Mountain in Jos, Plateaus state which the sampling methods they used are quadrat. However, the vegetational zones are different. On Tala Mountain, species richness of 49 is higher than the number of herbaceous vascular plants recorded on Kir Mountain, with species richness of 37 due to less soil coverage, heavy rocks, and more rocky outcrops on the Kir Mountain gallery. In comparison between non-probability and line transect sampling, the species richness of herbaceous vascular plants is 60 using non-probability sampling, which is higher than the species richness of 9 herbs recorded using line transects sampling because some herbs live in caves, crevices, and under heavy rocks which is difficult for line transect sampling to pass through caves and crevices making impossible for some herbs to intersect and touch the line transect. Even using the quadrat sampling method has many limitations, especially on Kir Mountain, because of heaves rocks, rocky outcrops, caves, and crevices.

On Kir Mountain, rare families of vascular herbs that live in caves, crevices and under heavy rocks include Urticaceae, Melastomataceae, Gesneriaceae, and Orchidaceae. These families live on higher altitudes of Kir Mountain, where human accessibility is difficult. On Tala Mountain, rare families include Plantaginaceae on rock pools, and rare herbaceous species include *Kinghamia angustifolia.*

Shannon diversity index of herbs on Kir and Tala mountains is 1.63 and 1.65, respectively; the Simpson diversity index (1-D) of herbaceous vascular plants on Kir and Tala mountains is 0.77 and 0.75, respectively, and species richness is 7 and 9, respectively using line transect sampling method. Similar herbaceous plant diversity studies were carried out by Azila *et al.* (2023), where they recorded diversity of herbs with a value of 1.5 and species richness of 18; this value is higher than values obtained on Kir and Tala mountains because the sampling methods are different and soil and soil coverage. A similar diversity study from a non-mountainous area was conducted (Abba *et al.,* 2015) where they reported the Shannon diversity index and Simpson diversity index of herbaceous species in Kanawa Forest Reserve (KFR) as 4.57 and 0.998, respectively, these values are higher than the values obtained for herbaceous vascular plants diversity using line transect sampling on Kir and Tala mountains which are 1.63 and 1.65 respectively for Shannon diversity index and 0.77 and 0.75 respectively for Simpson diversity index, this is due soil coverage and area of study in Kanawa Forest Reserve is higher than that of Kir and Tala mountains. A similar study was conducted on herbaceous plants in Yankari National Park (Abdullahi, 2011), which reported the Simpson diversity index of herbs as 0.998; this value is higher than the values obtained on Kir and Tala mountains with 0.77 and 0.75, respectively, this is due to soil coverage and presence rocky outcrops on Kir and Tala mountains galleries.

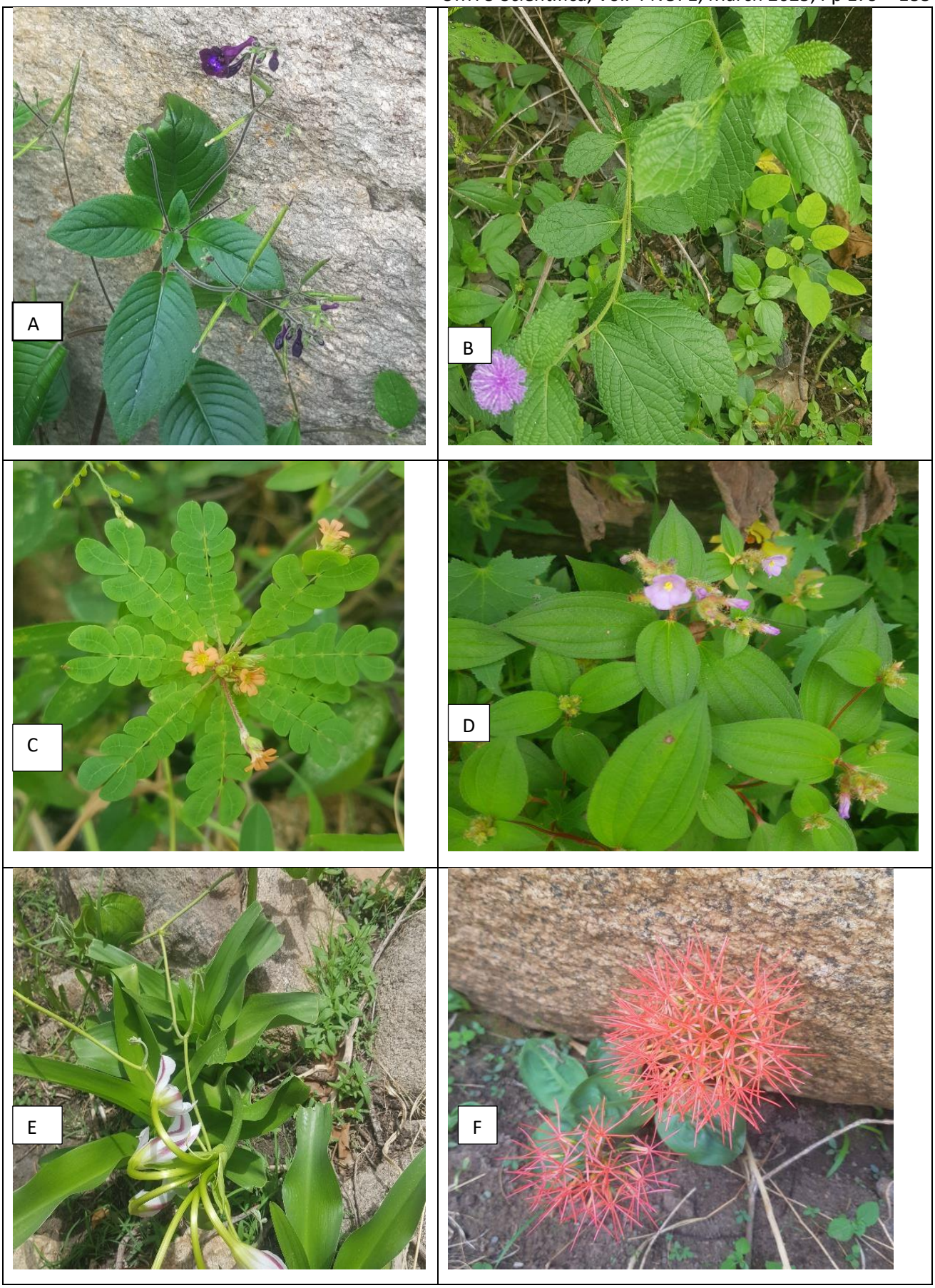

Figure 2: A. *Streptocarpus nobilis*, B. *Kinghamia angustifolia*, C. *Biophytum abyssinicum*, D. *Nerophila senegambiensis*, E. *Crinum ornatum*, F. *Scadoxus multiflorus*. Photos: A-F: Musa, U. (2021 & 2022)

Figure 3: A. *Pilea angolensis,* B. *Laportea mooreana,,*C. *Pistia stratiotes,* D. *Dopatrium longidens,* E. *Pellaea dura,* F. *Adiantum philipense*. Photos: A-F: Musa, U. (2021 & 2022)

Figure 4: A. *Albuca nigritana* B. *Afrotrilepis pilosa* C. *Cenchrus unisetus* D. *Distimake aegyptius* E. *Hygrophila senegalensis* F. *Canscora diffusa* Photos Musa, U. (2022 & 2023)

Table 3: Diversity index and species richness of herbs recorded using line transect sampling from Kir and Tala mountains of Bauchi

Study sites	Species Richness	Shannon diversity index	Simpson diversity index
Kir Mountain	7	1.63	0.77
Tala Mountain	9	1.65	0.75

CONCLUSION

Kir and Tala mountains are comprised of diverse herbaceous vascular plant taxa. Some herbs live in caves, crevices, and under heavy rocks; some live in rockpools and mountain galleries. Mix sampling methods should be employed for maximum collection and documentation of plant specimens. Some herbs, including *Laportea moreana* and *Pilea angolensis,* are endemic to Kir Mountain, while *Kinhamia angustifolia* is endemic to Tala Mountain based on local reports by locals of Kir Locality. Conservation (*in-situ* and *ex-situ*) measures and management are needed due to ongoing destructive human activities, including bush burning and deforestation for fuelwood, charcoal, illegal and bad agricultural practices in the Tala and Kir mountains.

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DISCLOSURE OF CONFLICT OF INTEREST

The authors have declared no competing interests.

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