International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133, Print ISSN: 2664-7125
Received: 03-05-2025, Accepted: 04-06-2025, Published: 18-06-2025
Volume 7, Issue 2, 2025, Page No. 69-75

Occurrence of a new fossil species of the genus *Grewia* Linn. (Malvaceae) in the Himalayan foot hills of Nepal and its phytogeographical implications

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Abstract
Investigation on the plant mega fossil (Leaf impressions) collected from Churia group (10-12Ma) of western Nepal revealed the presence of a new fossil species, *Grewia arjunkholaensis* showing its close affinity with phytogeographically important extant taxa, *Grewia microcos* Linn. (*Microcos paniculata* Linn.) of the family Malvaceae. The fossil leaf is characterized by asymmetrical, lanceolate shape, acute apex, obtuse base and acrodromous imperfect venation pattern. The analysis of present-day distribution of the comparable species indicates that the present extant species do not grow in the Himalayan foot hills of India and Nepal, but are presently distributed in the evergreen forests of other regions where there is more atmospheric precipitation. This suggests that after rise of Himalaya, drier condition was prevailed due to which such moist loving species could not survive there. Based on the present and past distribution of the comparable extant species of all the known fossils of genus *Grewia*, the phytogeography of the genus has been discussed.

Keywords: Plant mega fossils (Leaf impressions), *Grewia* Linn. morphotaxonomy, palaeoclimate, biogeography, churia formation, Himalayan foot hills, Arjun Khola area, western Nepal

Introduction

In the Himalayan foot hills of Nepal, the Churia group is delimited on the south by the Main Frontal Thrust (MFT) and on the north by Main Boundary Thrust (MBT). It consists of basically of fluvial deposits of Neogene age (23 million years to1.6 million years old). This extends all along the Himalaya forming the southernmost hill range with width of 8-50km (Fig1). Plant mega fossils including fossil woods, leaves, fruits and seed-impressions have been studied from different localities of western Nepal like, Koilabas, Surai Khola, Butwal, Arung Khola, Binai Khola and Seria Naka areas (Tripathi & Tiwari, 1983; Prasad & Prakash, 1984; Prasad, 1990a,b, 1994; Awasthi & Prasad, 1990; Prasad & Awasthi, 1996; Prasad *et al.*, 1997, 1999; Konomatsu & Awasthi, 1999; Dwivedi *et al.*, 2006a, b; Prasad & Dwivedi, 2007, 2008; Prasad, 2007, 2013; Prasad & Pandey, 2008; Prasad *et al*., 2013, 2016, 2019) [5, 11, 12, 17, 22, 23, 30, 28, 29, 25, 31, 36, 26, 43].

The study area, Arjun Khola falls in the Dang Section of western Nepal. Almost a complete and uninterrupted sequence of Churia group is well exposed all along the road from Arjun Khola to Ghorai ranging in age from Middle Miocene - Middle Pleistocene. The Arjun Khola sequences mostly consist of molasses sediments of the Lower and Middle Churia formation. A variety of plant mega fossils mainly leaf impressions have been collected from Lower and Middle Churia (Siwalik) sediments of Arjun Khola, western Nepal. Considering the thickness of sediments and amount of plant materials deposited therein, this is one of the best and richest plant fossils bearing locality among the known exposures of Churia Group in the whole Nepal.

In the present paper, a detail study on the fossil leaf resembling the genus, *Grewia* Linn. of the family Malvaceae (Grewioideae) collected from profile no. 3 of Arjun Khola area (Fig, 1A, B) is carried out and an attempt has also been made to interpret the palaeoclimate and biogeography of the area during Miocene times as well as on the basis of already recovered fossil species of *Grewia* Linn. of different Cenozoic horizons, the phytogeographical implications are also discussed herein.

Geology of the Study Area

The area of present study falls in Dang section of western Nepal Himalaya. The Siwalik in Nepal is often called Churia Group which lies south of the Main Boundary Thrust. The detailed lithology and stratigraphy of the Siwalik (Churia) Group of Nepal have been given by Hagen (1959) [15], Bordet (1961) [6], Sharma (1977) [40], Tokuoka *et al*. (1986) [42], and Corvinus (1990) [9]. The Churia Group has often been classified into two formations: (i) Lower Churia Formation (Sandstone Facies), and (ii) Upper Churia Formation (Conglomerate Facies) by Hagen (1959) [15], Bordet (1961) [6] and Gleinnie and Ziegler (1964) [14]. However, a threefold lithostratigraphical classification of the formation in the western Nepal Himalaya has been suggested by Chaudhuri (1983) [8]. The Churia Group consists of basically of fluvial deposits of Neogene age (18 million years to 1.6 million years old). This extends all along the Himalaya forming the southernmost hill range with width of 8-50 km. A well developed Churia Sequence belonging to Lower and Middle Churia formation is exposed in Arjun Khola area all along the Arjun River and the road leading to Ghorai covering a distance of 15 km (Fig. 1 B). The sediments consist of clays, shales, sandstones and siltstones. The shale containing well preserved leaf and fruit impressions are generally thinly bedded and splintery in nature. Almost a complete and uninterrupted sequence of Churia Group is well exposed all along the road from Arjun Khola to Ghorai ranging in age from middle Miocene – middle Pleistocene. In this area, the Lower Churia Group is observed from Profile-1 to Profile-4 containing fine grained sandstone beds with variegated clay.

From Profile-5 to Profile 8 (Masot Khola) the rocks are of Middle Churia Group. Above the Middle Churia Group again lies the Lower Churia Group in Profile 9-14 which (Fig. 1B). There are number of fossiliferous beds of mainly shales, siltstones and few fine-grained types of sandstone yielded a variety of well-preserved leaf, fruit and flower impressions. The Lower Churia Group comprises alternation sandstone and mudstone beds of almost same thickness while in the Middle Churia Group the thickness of sandstone beds is greater than the mudstone beds.

Material and Method

The fossil locality, Arjun Khola (27º53'42.8"N:82º30'31.4"E) lies in the Dang District of Rapti Anchal, Nepal and is easily approachable by metalled road originating from Mahendra Highway about 3 km west of Lamhi (27º52'24.9"N:82º32'22.4"E), a famous town of Deokhuri Valley (Fig. 1A). The sections belonging to the Lower and Middle Siwalik (Churia) beds containing excellently preserved fossil leaf and fruit impressions are well exposed on both the sides of the road leading to Ghorai and also on both the banks of Arjun Khola river. The leaf-impressions are found on both grey as well as brown calcareous shale but they are more common and well preserved in the grey shale. A rich collection of well-preserved leaf impressions was made from Profile 3 of Arjun Khola Road section (Fig. 2).

The leaf impression, preserved in grey shale, was studied either with hand lens or low power microscope under reflected light. The identification of leaf impression has been done by the consulting a variety of herbarium sheets of dicotyledonous genera housed at Central National Herbarium (C.N.H), Sibpur, Howrah, West Bengal. The photographs of leaf-impressions showing various morphological characters were taken by Nikon SLR Camera. The photographs of comparable modern leaf showing similar features were also taken in the same magnification and displayed along with the fossil leaf. The fossil leaf has been named according to usual practice prevalent in the country and abroad. For naming the fossil specimen, generic name of extant taxa has been retained. For the description of leaf impressions, the terminology given by Hickey (1973) [16], Dilcher (1974) [10] and Ash *et al.,* (1999) [4] has been followed.

Systematic Palaeobotany Of Fossil Leaf

Order - **Malvales Juss**. ex Bercht. & J. Presl.
Family: **Malvaceae** Juss.
Sub-family - ***Grewioideae*** Hochreutiner
Genus - ***Grewia*** Linn.
Grewia arjunkholaensis *n.* sp.
(Figs. 3 A, D, F)

Material: This consists of single, almost complete fossil leaf specimens with satisfactory preservation.

Diagnosis: Leaf asymmetrical, lanceolate; lamina length 11.6cm and width 3.8cm; apex acute; base obtuse, slightly asymmerical; margins almost entire; venation acrodromous, basal imperfect; primary veins three arising from the base; prominent; secondary veins about 6 pairs, alternate to sub-opposite with angle of divergence (about 60˚-70˚); tertiary veins with angle of origin AO-RR, percurrent, branched, oblique in relation to mid vein and close.

Description: Leaves simple, slightly asymmetrical, lanceolate; preserved size 11.6 x 3.8 cm; apex acute; base obtuse; asymmetrical; margin broken at some places, almost entire, slightly undulated; texture thick chartaceous; petiole 0.4 cm long, normal; venation acrodromous, basal, imperfect; primary vein (1°) three (one mid and 2 lateral) arising from the base; mid and lateral primaries giving off secondary veins; secondary veins from lateral primaries running towards the margins uniformly curving upwards, stout, straight, prominent; secondary veins (2°) more than 6 pairs, alternate to sub-opposite, unbranched, angle of divergence (about 60°-75°), wide acute angled intersecondary veins present, arise from primaries, simple; tertiary veins (3°) fine, opposite to alternate, close, angle of origin AO-RR, percurrent, branched, oblique in relation to mid vein.

Holotype*:* Arj/27/2018.
Locality: Profile 3 (27˚54'50.6" N: 82˚31'00.4" E), Arjun **Khola:** Ghorai Road Section, Arjun Khola area, Deokhuri **District**, Rapti Anchal, western Nepal.
Horizon and Age*:* Lower Churia formation, Middle Miocene.
Etymology*:* After the name of fossil locality, Arjun Khola.

Affinities with extant taxa: Morphological features exhibited by the present fossil leaves like slightly asymmetrical, lanceolate shape, acute apex, obtuse base, acrodromous imperfect venation, three primary veins, one mid primary arising at leaf base and two lateral primaries sending off secondaries towards the margins, wide acute angle of divergence of alternate to sub-opposite secondary veins, presence of intersecondary veins, AO-RR percurrent and branched tertiary veins, suggest its affinity with modern leaves of genus *Grewia* Linn. of family Malvaceae and sub-family Grewioideae.

A critical study of Herbarium sheets of different species of above genus showed that the leaves of *Grewia serrulata* (C.N.H. 124258), *Grewia scrabrida* (C.N.H. 61556) and *Grewia microcos* (C.N.H. 61932, 61996) have some common features but differ from the present fossil leaves in the nature of secondary veins while, the leaves of *Grewia microcos* (C.N.H. Herbarium Sheet No. 379; Figs. 3B,C,E,G) showed closest similarity with the present fossil leaves in shape, size and venation pattern.

Comparision with earlier known species of Grewia: Fossil leaves resembling the genus *Grewia* Linn. were reported from Cenozoic sediments of India and Nepal (Table 1). Two fossil leaves were reported from Siwalik sediments of Darjeeling District, West Bengal under the name *Grewia ghishia* Antal & Awasthi, 1993) [2] from Ghish River section (Antal & Awasthi, 1993) [2] and *Grewia tistaensis* (Antal & Prasad, 1998) [3] from Sevoke Road section near Tista Bridge. Both differ from the present fossil leaves in being of smaller size and showing marked serrations on the margins. A fossil leaf resembling extant *Grewia tiliaefolia* Vahl. reported from Late Cenozoic sediments of Mahuadanr, Palamau District, Jharkhand (Srivastava *et al*., 1992) [41] differs from the present fossil leaves especially in venation pattern. Fossil leaves like *Grewia mallotophylla* described from Siwalik of Arung Khola, west Nepal (Konomatsu & Awasthi, 1999) [17],

Grewia sahnii and *Grewia garoensis* from Tura Formation of Meghalaya, India (Mehrotra, 2000) [20] differ from the present fossil leaves in the nature of their secondary veins. A comparison of the present fossil with another species *Grewia kathgodamensis* (Prasad *et al*., 2004) [35] from Siwalik of Uttarakhand, India revealed that the two leaves were quite different as the latter was of small size and showed a different pattern of secondary veins

Table 1: Showing a list of fossil species of *Grewia* L. from the Cenozoic sediments of India and Nepal.

Species	Fossil Locality/ Period	Distinguishing Characters
Grewia tiliaefolia Vahl. Srivastava *et al*., 1992 [41]	Late Cenozoic, Mahuadanr, Jharkhand	
Grewia ghishia Antal & Awasthi, 1993 [2]	Lower-Middle Siwalik, Oodlabari, Darjeeling District, West Bengal, India	Size smaller (6.2 x 1.9 cm), narrowly elliptical shape and simple craspedodromous venation type.
Grewia tistaensis Antal & Prasad, 1998 [3]	Lower Siwalik, Oodlabari, Darjeeling District, West Bengal	Size 11.3 x 5.8 cm, widely elliptical shape, craspedodromous venation type.
Grewia sp. Mathur & Mathur, 1998 [19]	Neogene, (Mar Formation), Bikaner, Rajasthan	
Grewia mallotophylla Konomatsu & Awasthi, 1999, Prasad *et al*., 2017 [17, 27]	Arung Khola and Binai Khola formations of Churia Group (Siwalik), west central Nepal, Lower Siwalik of Tanakpur, Uttarakhand	Size 9.0 x 6.0 cm, ovate to elliptical shape, venation type acrodromous and two strongly developed secondary veins arising from a single point at the base. angle of divergence 45-°50°.
Grewia kathgodamensis Prasad *et al.*, 2004 [35]	Lower Siwalik, Middle Miocene, Gola River beds near Jamrani, Kathgodam, Nainital District, Uttarakhand	Size smaller (4.4 x 6.2 cm), elliptical to widely elliptic, craspedodromous venation type.
Grewia sahnii (Lakhanpal) Mehrotra, 2000 [20]	Tura Formation (Upper Paleocene) of Nangwalbibra, Garo Hills, Meghalaya, India	Size 9.0 x 4.0 cm, elliptical shape, basal imperfect acrodromous venation type.
Grewia garoensis (Lakhanpal) Mehrotra, 2000 [20]	Tura Formation (Upper Paleocene) of Nangwalbibra, Garo Hills, Meghalaya, India	Size 11.5 x 4.4 cm, asymmetrical, narrowly ovate shape.
Grewia miopaniculata Prasad, *et al*., 2016 [33]	Churia Formation, Arjun Khola, Western Nepal	Smaller in size 6.2x 2.1cm), Angle of divergence of Secondary veins is 50° and absence of intersecondary veins.
Grewia tanakpurensis Prasad *et al*, 2017 [27]	Lower Siwalik of Tanakpur area, Uttarakhand	Smaller size 4.2x 1.8cm, apex obtuse, venation simple craspedodromous, angle of divergence of secondary veins, 45°.
Grewia palaeodisperma Prasad *et al*, 2019 [34]	Churia Formation, Arjun Khola, Western Nepal	Symmetrical, elliptic, margin dentate, angle of divergence of secondary vein 40°-50°
Grewia nepalensis, Prasad, *et al*.,2019 [34]	Churia Formation, Arjun Khola, Western Nepal	Larger size, 14.0x3.8cm, symmetrical, margin finely dentate, 4 lateral primaries.

The detailed comparative study of all the above species revealed that the present fossil leaf was entirely different from leaves mentioned in Table 1. Therefore, a new species *Grewia arjunkholaensis* is being instituted for the present fossil leaf.

Present day Distribution: The genus *Grewia* Linn. consists of 150 species growing specifically in the Tropical region of Asia, Africa and Australia. The modern comparable species, *Grewia microcos* Linn. (*Microcos paniculata* Linn.) is distributed in South east Asian region and South china (Mabberley, 1997) [18].

Result and Discussion

The palaeobotanical study on fossil leaf impressions collected from Lower Churia (Siwalik) sediments of Arjun Khola area, western Nepal revealed the presence of a new species, *Grewia arjunkholaensis* of the family Malvaceae in the Siwalik flora of Indian subcontinents. *Grewia microcos* Linn. with which fossil leaf shows closest affinity is a small evergreen tree distributed in South east Asian region and South china. On the basis of the present-day distribution of extant comparable taxon, *Grewia microcos* Linn it can be surmised that there was a prevalence of a tropical warm humid climate with sufficient rainfall during Miocene Period which is suitable for a evergreen forest in the Arjun Khola and nearby area of western Nepal.

Grewia Linn. is a large genus of family Malvaceae with about 150 species. *G. subinaequalis* DC. is one of the well-known species which is widely cultivated in Indian subcontinents for the berries which are called Phalsa. *Grewia* Linn. is confined to the Tropical and sub-Tropical regions of the Old World, i.e. Africa, Madagascar, Arabia, India, Myanmar, Ceylon, Andaman-Nicobar, Malaya Peninsula, East Indies, Indo-China, extending to North Australia (Fig.4). The genus is fairly represented in India. About 34 species are found in the Indian sub-continent. *Grewia salvifolia* Heyne ex Roth another species of Arjunkhola area, is a shrub or small tree distributed in dry and arid regions of north-west India and the Deccan Plateau (Brandis, 1971; Gamble, 1972; Willis, 1973 [45]; Mabberley, 1997) [7, 13, 18]. Similarly, *Grewia disperma* Rottler ex Spreng. is a small tree growing in eastern and southern India from Nepal, Sikkim, Khasi Hills, Martaban, Tropical Africa, Malaya Island and Australia (Hooker, 1872; Mabberley, 1997) [18].

Both fossils laves and petrified woods resembling the genus *Grewia* Linn. have been reported from Cenozoic sediments of Indian subcontinents. The fossil leaves, *Grewia ghishia* Antal & Awasthi, 1993 [2] and *Grewia tistaensis Antal* & Prasad, 1998 [3] are reported from Siwalik (Miocene) sediments of Darjeeling District, West Bengal, India. *Grewia miopaniculata* Prasad, *et al*., 2016 [33]; *Grewia*

palaeodisperma Prasad *et al*, 2019 [34] and *Grewia nepalensis*, Prasad, *et al*., 2019 [34] and *Grewia mallotophylla* Konomatsu & Awasthi, 1999 [17] are reported from Churia formation (Upper Miocene) of western Nepal. *Grewia tanakpurensis* Prasad *et al*, 2017 [27] and *Grewia kathgodamensis* Prasad *et al*., 2004 [35] are described from Lower Siwalik (Middle Miocene) of Uttarakhand, India. *Grewia sahnii* Lakhanpal and *Grewia garoensis* Lakhanpal (Mehrotra, 2000) [20] are known from Palaeocene (Tura Formation) of Meghalaya, India. *Grewia* sp. Mathur & Mathur, 1998 [19] is reported from Mio-Pliocene of Rajasthan, western India. One more fossil leaf resembling the extant species, *Grewia tiliaefolia* Vahl is also reported from Plio-Pleistocene sediment of Jharkhand, India. However, the fossil woods, *Grewioxylon indicum* Prakas & Dayal, 1965; Khare *et al*., 2000; *Grewioxylon intertrappea* Sallom, 1963; *Grewioxylon maharzariense* Prakash & Dayal, 1963; *Grewioxylon canalisum* Bande & Srivastava, 1995; are reported from Deccan Intertrappean beds (Maestrichtian- Danian) of Central India and one more species, *Grewioxylon microcoides* Agarwal, 1991 [1] has also been reported from the Miocene of Neyveli Lignite Deposit of South India. Besides, four fossil woods are reported from outside of Indian subcontinents. Three species are from Neogene sediments of Europe and one from South-East Asia, These are *Grewioxylon neumaieri* Selmeier, *G. ortenvurgense*

Selmeier and *Grcwioxylon* sp, Se1rneier from Germany (Selmeier,1985) [38] and one *Grewioxylon fontanesii* Vozenin-Serra (1981) [44] from Vietnam. The above several fossil records of genus *Grewia* Linn indicate that this genus was widely distributed in the geological past of both Neogene and Palaeogene periods. It is also evident that the earliest record of *Grewia* Linn. goes back to Upper Cretaceous (Maestrichtian-Danian) which suggests that like most of the angiosperms it is also a Gondawanic origin.

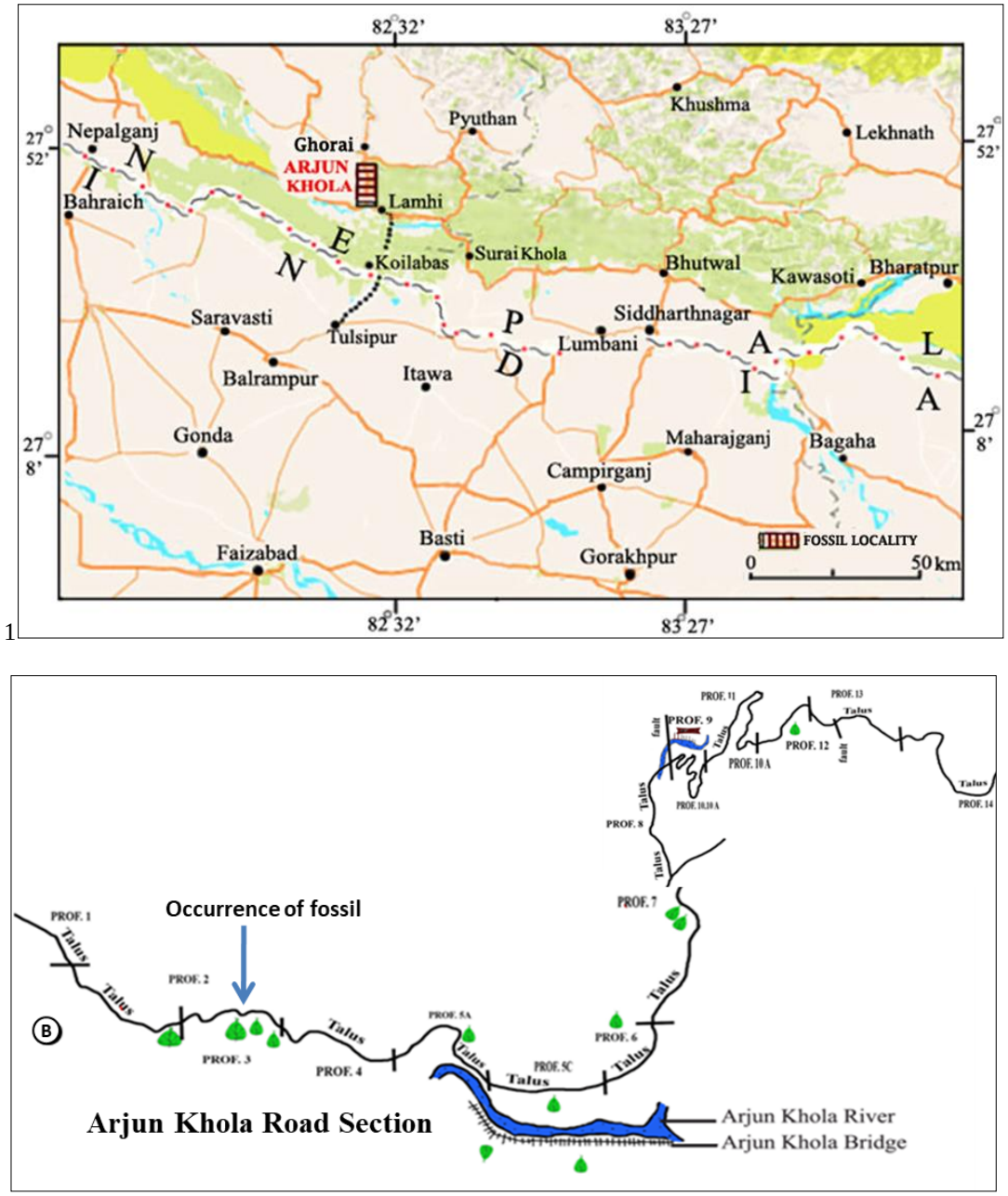

Fig 1: A. Google map showing physiography and location of study area, Arjun Khola, western Nepal. B. Arjun Khola Road Section showing 14 profiles with their fossil location

Fig 2: Field photograph of alternating sandstone and claystone beds in profile-3 of studied section in Arjun Khola area. western Nepal from where the fossil leaf, *Grewia arjunkholaensis* n. sp. is collected

Fig 3: *Grewia arjunkholaensis* n. sp. A. Fossil leaf showing shape, size and nature of apex, base and margin and presence of inter-secondary veins. B. Modern leaf of *Grewia microcos* Linn. showing similarity with the fossil in shape, size, margin and presence of inter-secondary veins. C. Another Modern leaf of *Grewia microcos* Linn. showing similarity with the fossil in nature and orientation of secondary veins. D. A part of fossil leaf magnified to show the obtuse nature of base and oblique arrangement of lateral primary veins. E. A part of modern leaf magnified to show similarity with base of fossil leaf and its lateral primaries. F. A part of fossil leaf magnified to show the details of venation pattern. G. A part of modern leaf magnified to show similar details of venation pattern. (Natural size Scale bar 2 cm.)

Conclusions

The present study on the plant fossils from Siwalik sediments of Arjun Khola area revealed the presence of new fossil leaf belonging to the genus, *Grewia* Linn. of the family Malvaceae which is important from phytogeographical point of view.

The presence of the evergreen species of *Grewia* Linn (Table 1) in the Himalayan foot hills of Nepal during Mio-Pliocene times indicates that the evergreen forest was flourishing there as compared to mixed deciduous type of forest at present.

The occurrence of *Grewia microcos* Linn. in Siwalik Sediments of Himalayan foot hills of Nepal suggests that most of the comparable

taxa of Siwalik fossils migrated from other region (South-east Asian) during early Miocene and later on became extinct due to prevailing of unfavorable condition most probably due to uplift of Himalaya.

The earliest fossil records suggest that the genus *Grewia* Linn. originated during Palaeocene in North east India.

The analysis of present-day distribution of the comparable species indicates that the present extant species do not grow in the Himalayan foot hills of India and Nepal, but is presently distributed in the evergreen forests of South-east Asian region where there are more atmospheric precipitation. This suggests that after rise of Himalaya, drier condition was prevailed due to which such moist loving species could not survive there.

Acknowledgments

The authors are thankful to the Director, Birbal Sahni Institute of Palaeosciences, Lucknow for providing the basic facilities. The authors express their gratitude to the authorities of Central National Herbarium, Sibpur, Howrah for providing permission to consult their Herbarium for the identification of the fossil leaf. Authors are grateful to Prof. Reena Pathak, Principal, Shiv Harsh Kisan P.G. College, Basti, Uttar Pradesh for providing basic facilities during the completion of research work. Thanks are due to Prof. G. J. Kushwaha, Head, Department of Botany, Shiv Harsh Kisan P.G. College, Basti giving valuable suggestion during the preparation of Manuscript.

Authors' contribution: All authors contributed equally**.**

Conflict of interest: The authors declare no conflict of interest.

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