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Fossil leaf and fruit of the genus *Harpullia* Roxb. from Upper Miocene (Siwalik) sediments in the Sub-Himalayan zone of West Bengal and its biogeographic and palaeoclimatic significance

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Fossil leaf and fruit resembling the extant taxa, *Harpullia arborea* (Blanco.) Radlk. of the family Sapindaceae have been reported for the first time from the Upper Miocene sediments of Darjeeling district, West Bengal, India. The fossil leaf is characterized by an elliptic-lanceolate shape, oblique base, entire margin, and eucamptodromous type of venation and the fruit is a two-valved, inflated capsule having one or two seeds in a cell. The extant taxa is biogeographically important as presently distributed in the evergreen forests of the Indo-Malaysian region which suggests a tropical wet climate prevailed in the area during sedimentation.

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INTRODUCTION

The Sub- Himalayan zone has resulted from the tectonic processes that have been taking place in the Cenozoic era. During the Middle Miocene orogeny, the Siwalik Basin, which is part of the Sub-Himalayan zone, developed as a foredeep in front of the newly raised Himalaya and was the location of deposition of the Siwalik sediments. The Siwalik depositional System is 5-6 km. thick and is composed of several exposed lithological units e.g., sandstones, grits, and conglomerates. The Siwalik sequence of West Bengal has been broadly subdivided into three units - 1. Upper pebbly sandstones and conglomerate unit, 2. Middle sandstone unit, and 3. Lower claystone unit (Acharya, 1972, 1975). The lower claystone unit is best exposed in Ramthi River, Ghish River, Tista River, and the Sevok Road and is well developed and consists of claystone, siltstone, and fine-grained sandstone. The Middle sandstone unit is well exposed in Lish and Ghish Rivers and also in some tributaries of the Tista River. The latter two units are very rich in plant mega fossils, especially for the leaf and fruit impressions (Antal and Awasthi, 1993; Antal and Prasad, 1995, 1996a, b, 1997, 1998; Prasad *et al.*, 2015; Antal *et al.*, 1996; Khan and Bera, 2014).

The problems associated with the Siwalik (Mio-Pliocene) floras are regionalism, endemism, and migration/extinction in response to physical and climatic factors which need to be worked out in detail to unravel the history of the modern flora of India. The flora of the Siwalik Group of India has been subjected to numerous changes. Many genera which are recorded in India during Mio-Pliocene either migrated or faced extinction. The evolution of the Siwalik floras in the northern region has largely been influenced by the Himalayan orogeny. The Middle-Miocene orogeny of the Himalayas led to the proliferation of several gymnosperm groups and the appearance of several subtropical angiosperm taxa. Because of this, the authors visited several Siwalik localities in the Darjeeling area and made a good collection of well-preserved plant mega fossils comprising carbonized fossil woods and impressions of leaves and fruits from the Lower and Middle Siwalik sediments exposed near Oodlabari, Sevok, Tista Bridge, Kali Khola, and Bagrakot in the Darjeeling District. These megafossils have been studied in detail and out of them a fossil leaf and fruit have been identified showing their close resemblance with the extant taxa, *Harpullia arborea* (Blanco) Radlk. of the family Sapindaceae. Based on its fossil records and present-day distribution in different phytogeographical regions, the biogeography of the taxa and the climate that prevailed in the Sub-Himalayan zone of the Darjeeling area during the Upper Miocene have been discussed in the present communication. These trees grow in tropical regions and tolerate a small amount of forest. Well-growing mainly prefers fertile soils of clay, sand, or limestone.

GEOLOGICAL SETUP OF THE STUDY AREA

Darjeeling district lies between 26º 31´and 27º 13´ north latitude and between 87º 59´ and 88 º 53´ east longitudes, the northernmost district of West Bengal is located between

Table-1. Stratigraphy in the Darjiling District (Matin and Mukul, 2010)

Geologic Time	Group	Subgroup	Formation and Lithology
Late Miocene to Pliocene	Siwalik Group	Upper Siwalik	Murti Boulder bed (Crude immature conglomerate) Parbu Grit (pebbly sandstone and coarse - to-medium sandstone)
		Middle Siwalik	Geabdat sandstone (medium to coarse-grained sandstone and shale, pebble beds and marl)
Early –Middle Miocene		Lower Siwalik	Chunabati Formation (Fine to medium-grained sandstone, siltstone, mudstone, marl and conglomerate)
Upper Permian	Gondwana Group	Damuda	Sandstone, carbonaceous shale and coal
Lower Permian		Rangit pebble-Shale (Talchir?)	Diamictite, rythmite,Quartzite marl
Precambrian	Daling Group		Buxa Formation Reyang Formation Daling Formation
	Paro Group		(Parametamorphites with migmatitic and foliated granitic gneiss)
	Darjiling Gneiss		(Two-mica migmatitic gneiss)

Nepal and Bhutan and stretches from the plain of Bengal on the south to the state of Sikkim on the North. In this area, the rocks were subdivided by Mallet (1875) into five groups; the Darjeeling gneiss, the Daling series, the Buxa series, Gondwanas, and the Tertiary system. These outcroppings create a succession of bands that run roughly parallel to the overall Himalayan trend and descend one under the other into the slopes. The curious feature of the subdivision is the younger formation always appears to underlie the older (Table 1).

The order of superposition has been completely reversed by folding and faults. Gneiss varies from a foliated granitic rock, the exposures are composed of quartz, feldspar, and biotite to more or less pure mica schist and include partly intrusive granite and partly metamorphosed beds of sedimentary origin. The Daling series covers a large part of the northern and eastern parts of the district. It consists of phyllite, slate, and quartzite with some hornblende-schist and very subordinate bands of dolomite and crystalline limestone. Copper ore is frequently found disseminated through the slates and schist. The Buxa Series, which is mostly found in the Western Duars, is only found in the Darjeeling District's far eastern reaches. It is made up of quartz, dolomite, and slates, with the last rock serving as a distinguishing feature from the Daling series. The Gondwana beds, which span from Pankhabari to Dalingkot, are found towards the foot of the hills and form a small zone between the Daling and Tertiary systems. Gondwana chiefly consists of sandstone, shale, and coal, all of which have intensely crushed and faulted, and dip at high angles to the north-north-west. Tertiary beds run parallel to the older rocks almost to Dalingkot, from close to the Mechi east. They are chiefly composed of soft, massive, "pepper and salt" sandstones, containing mica and feldspar, with crunchy grey micaceous and calcareous beds containing a few subordinate layers of limestone. The sandstone frequently contains lignite, which, however, has not been found in sufficient quantity to be of economic value.

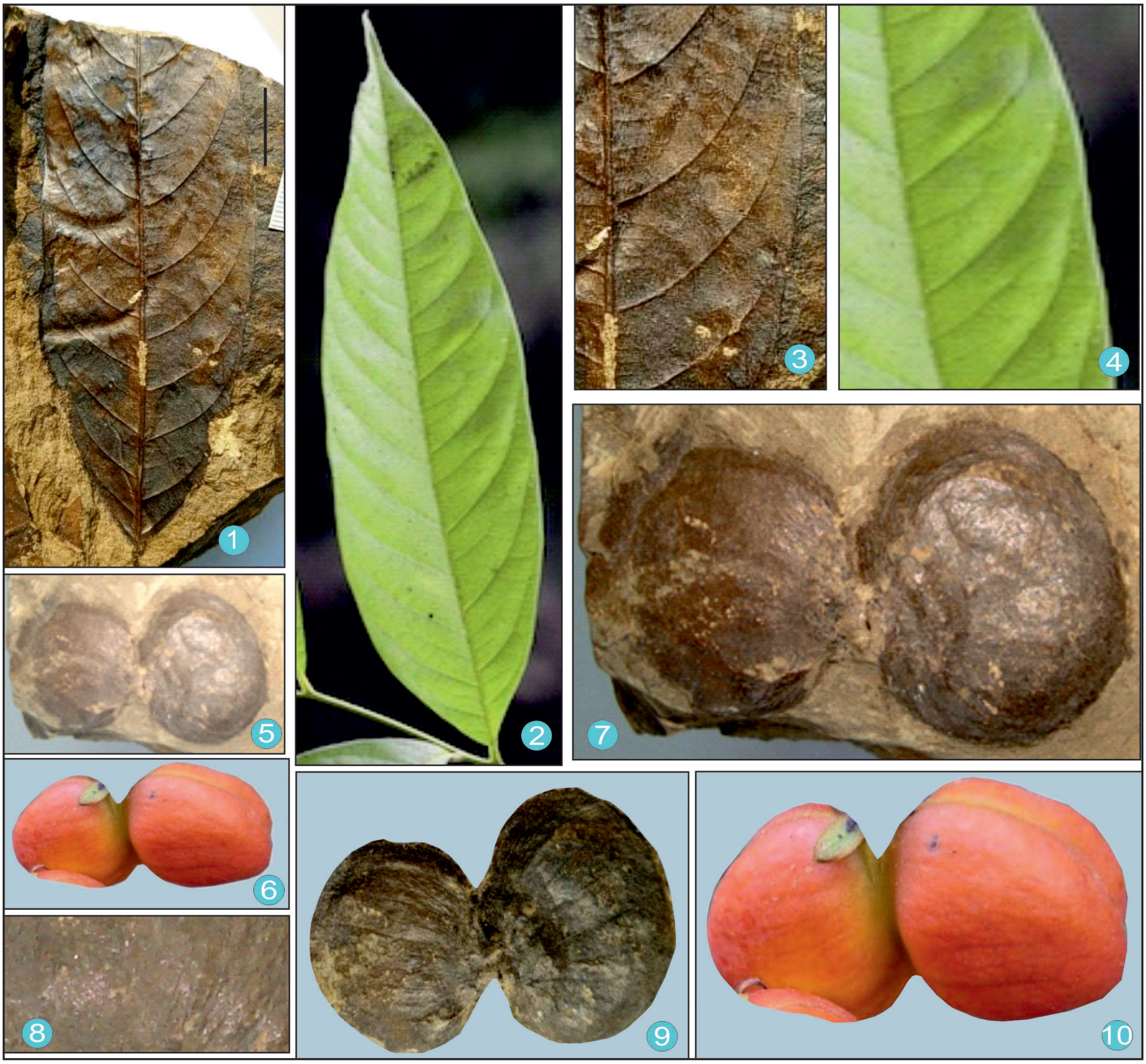
Since the Middle Miocene, fluvial conglomerates, sandstones, and mudstones have formed in the Himalayan foreland basins as a result of the uplift and erosion of the Himalayan orogenic belt (Nakayama and Ulak, 1999). These exposed sedimentary successions, known as the Siwalik Group in India and Pakistan and the Churia Group in Nepal (Nakayama and Ulak, 1999), form the foreland part of the Himalayan fold and thrust belt (Yin, 2006). The widespread Siwalik Group deposits can be divided litho-stratigraphically into three subgroups: (1) an upward coarsening mudstone-sandstone succession (Lower Siwalik Subgroup), (2) the sandstone-dominated Middle Siwalik Subgroup and (3) conglomerates, sandstones, and mudstones of the Upper Siwalik Subgroup (Kumar *et al.,* 2003). In the Darjeeling District, the Upper Siwalik Subgroup is either not exposed or absent (Banerji and Banerji, 1982). Rocks of the tectonically deformed Lower Siwalik subgroup exposed in the Tista River section around Kalijhora in the Darjeeling District have been carried by the South Kalijhora Thrust (SKT) over the Middle Siwalik subgroup (Basak and Mukul, 2000). The Middle Siwalik subgroup is exposed in the footwall of the SKT and continues up to the mountain front over an aerial distance of ~ 4 km. This sedimentary stratified succession is regarded as fluvial deposits (Acharya, 1973; Banerji and Banerji, 1982).

The sedimentary succession of the Middle Siwalik subgroup, about 325 m thick consists of conglomerate beds, medium- to coarse-grained sandstone beds which are often pebbly, medium-grained sandstone beds, fine-grained sandstone beds, heterolithic units, and mudstone beds. Neogene deposits of the Siwalik Foreland Basin of Darjeeling Himalayas are exposed in road cuts and river sections along an east-west traverse between Sevok (Darjeeling District) in the west and Malbazar area (Jalpaiguri District) in the east.

The Upper Tertiary outcrops, forming the outer foothills, are not continuous throughout the area they disappear in the area east of Lethi Nala and re-appear, after a gap of about 10 miles, in the area between the Murti and the Jaldhaka with a greatly reduced width of the outcrop. East of the Jaldhaka, there is another unusually long gap of about 40 miles, beyond which the Upper Tertiary reappears in the Bhutan foothills and the Buxa Duar area of West Bengal. These gaps are occupied by enormous deposits of recent gravel and pebbles.

MATERIALS AND METHOD

The present investigated fossil locality, Sevok (26º54.196´: 88º 28.325´) lies in the foothills of Darjeeling District, West Bengal India, and is approachable by road (Fig. 1). The present fossil, specimens (leaf and fruit) were collected from Middle Siwalik sediments of Sevok-Sikkim road section (Figs. 2, 3). The leaf and fruit impressions are



EXPLANATION OF PLATE I

1. *Harpullia miocenicum* sp. nov.; Fossil leaf in natural size showing shape, size, venation pattern, and nature of base and margin. (BSIP Museum no. 42104A; Holotype); 2. *Harpullia arborea* (Blanco) Radlk.; Modern leaf in natural size showing similarity with the fossil in shape size, venation pattern, and base and margin; 3. *Harpullia miocenicum* sp. nov.; A part of fossil leaf magnified to show the details of venation pattern; 4. *Harpullia arborea* (Blanco) Radlk.; A part of modern leaf magnified to show the similar details of venation pattern as the fossil; 5. *Harpulliocarpon siwalica* gen. et sp. nov.; Fossil fruit in natural size showing its shape and size. (BSIP Museum no. 42104B; Holotype); 6. *Harpullia arborea* (Blanco) Radlk.; Modern fruit in natural size showing similar shape and size as the fossil; 7. *Harpulliocarpon siwalica* gen. et sp. nov.; Fossil fruit magnified to show the details of surface features of fruit and location of seeds in each lobe; 8. *Harpulliocarpon siwalica* gen. et sp. nov.; Fossil fruit highly magnified to show the nature of the seed; 9. *Harpulliocarpon siwalica* gen. et sp. nov.; Fossil fruit slightly magnified to show the nature of striations on the fruit surface; 10. *Harpullia arborea* (Blanco) Radlk.; Modern fruit slightly magnified to show the similar striations on the fruit surface as the fossil.

devoid of cuticles and found to be preserved on light grey shale and studied morphologically with the help of either a hand lens or low-power microscope under reflected light.

A range of herbarium sheets of several extant families and genera was examined at the Central National Herbarium, Sibpur, Howrah, West Bengal to identify the leaf and supporting data of the fruit impressions. For the description of leaf impression, the terminology given by Hickey (1973) and Dilcher (1974) has been followed. In naming the fossils, the usual practice prevalent in the country and abroad have been adopted. The living generic names have been retained.

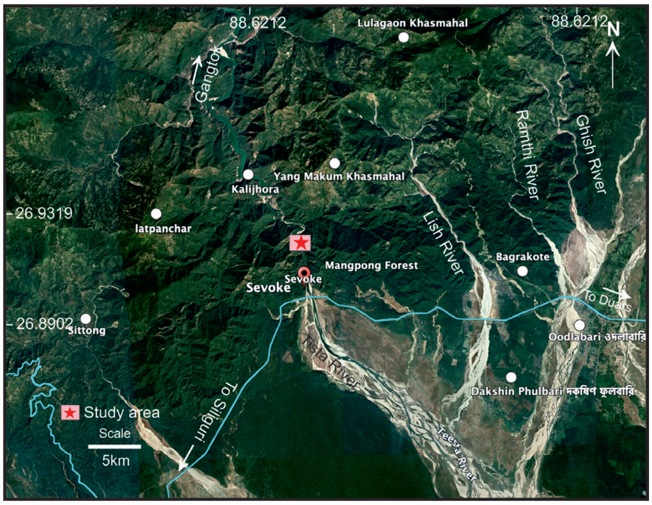


Figure 1. Google map showing the location of the study area.

Figure 2. Fossil spot in the Sevok Road section from where the fossil leaf and fruit were collected.

SYSTEMATICS

Phylum Tracheophyta Sinnott ex Caval- Sm.
Class Magnoliopsida Brongn.
Order Sapindales Dumortier
Family Sapindaceae Juss. De Jussieu
Genus *Harpullia* Roxb.

Harpullia miocenica n. sp. nov.
(Plate. I. Figs. 1, 3)

Material: One specimen.

Diagnosis: Leaf asymmetrical, elliptic to lanceolate; size 10.4 x 4.2 cm; base asymmetrically acute, margins entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein (1˚) single, almost straight, prominent, stout; secondary veins (2˚) about 9 pairs, 0.7 to 1.7 cm apart, alternate to sub-opposite, unbranched, angle of divergence, narrowly to moderately acute (about 55˚-70˚); tertiary veins (3˚) moderate angle of origin usually RR, percurrent, straight to nearly sinuous, oblique to right-angled with mid vein, predominantly alternate and close.

Description: Leaf slightly asymmetrical, elliptic-lanceolate; preserved size 10.4 x 4.2 cm; apical part not preserved; base asymmetrically wide acute; margins entire; texture chartaceous; venation pinnate; eucamptodromous; primary vein (1˚) single, almost straight, prominent, stout; secondary veins (2˚) 9 pairs visible, 0.7 to 1.7 cm apart, alternate to sub-opposite unbranched, angle of divergence, narrowly to moderately, acute (about 55˚-70˚), uniformly curving upwards and joined super adjacent secondary vein at an obtuse angle; tertiary veins (3˚) moderate, angle of origin usually RR, percurrent, straight to nearly sinuous, oblique to right-angled with mid vein, predominantly alternate and close.

Holotype: B.S.I.P. Museum no. 42104A.

Type locality: Sevok Road Section, Sevok. Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age: Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology: After the Miocene age to which the fossil belongs.

Affinities: The most important features of the present fossil leaf like elliptic-lanceolate shape, asymmetrically wide acute base, eucamptodromous venation, unbranched secondary veins with a wide acute angle of divergence, RR, percurrent, straight to nearly sinuous tertiary veins are commonly found in the modern leaves of *Harpullia* Roxb. of the family Sapindaceae. A critical study of Herbarium sheets of different species (12 species) of this genus showed that the leaves of *Harpullia arborea* (Blanco) Radlk. (C.N.H. Herbarium Sheet No. 1874; Plate 1. Figs. 2, 4) resemble closely in shape, size, and nature of secondary veins with the present fossil leaf while, the leaves of *Harpullia cupanioides* Roxb., syn. *H. thanatophora* Blume also showed a little similarity with the present fossil leaf having similar shapes and eucamptodromous venation patterns.

So far, there are only one form species of the genus *Harpullia* Roxb., *Harpullia siwalica* is known from Middle Siwalik sediments of Surai Khola area, Nepal (Prasad and Awasthi, 1996), Arjun Khola area, western Nepal (Prasad *et al.*, 2019) Lower Siwalik sediments of Tanakpur area, Uttarakhand and Neyveli Lignite Mine-1, South Arcot District, Tamil Nadu (Agarwal, 2002). In a comparison of the present fossil leaf with the earlier described species, it has been concluded that the Sevok fossil leaf differs from others mainly in the number of secondary veins. Moreover, the size of *H. siwalica* is smaller (7.3x3.0cm) than the present fossil leaf. Because of this, the present fossil leaf has been described under the specific name, *Harpullia miocenica nov*. sp.

Harpullia Roxb. comprises about 27 species, distributed in Madagascar, northern Australia, and tropical Asia. *Harpullia arborea* (Blanco) Radlk. is a sub-canopy tree distributed in wet evergreen forests of Indo-Malaysia and Australia. In India, it is common in the South and Central Sahyadris (Hooker, 1872; Henry, 1893; Brandis, 1971; Mabberley, 1997).

Phylum Tracheophyta Sinnott ex Caval- Sm.
Class Magnoliopsida Brongn.
Order Sapindales Dumortier
Family Sapindaceae Juss. De Jussieu
Genus *Harpulliocarpon* gen. nov.

Harpulliocarpon siwalica gen et sp. nov.
(Plate I, Figs. 5, 7, 8, 9)

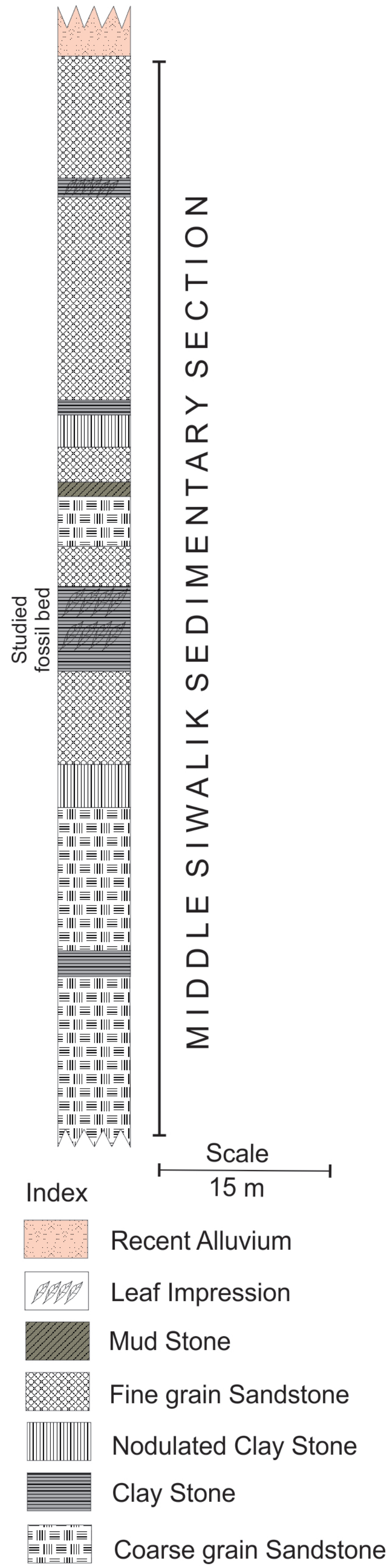


Figure 3. A part of the litho-column of the Sevok Road section shows the location of the studied fossiliferous bed.

Material: One well-preserved fruit compression.

Diagnosis: Fruit capsule type, bilobbed, lobe rounded to oval in shape, size 2.5x2.2cm and 2.0x2.2cm, in each lobe there are two cells and each cell possesses a seed. On the fruit surface, striations are seen. Striations arise from the center of attachment and run towards the rounded marginal side.

Description: Fruit capsular, inflated, bilobbed, lobe rounded to oval in shape, joined with each other, one lobe is slightly smaller than the other, size 2.5 x 2.2 cm and 2.0 x 2.2 cm, in each lobe, there are two cells and each cell possesses a seed. Seeds are seen and are unequal in size. On the fruit surface, some prominent striations are seen. Striations arise from the center of attachment and run towards the rounded marginal side.

Holotype: B.S.I.P Museum no. 42104B.

Type locality: Sevok Road Section, Oodlabari area, Darjeeling District, West Bengal, India.

Horizon & Age: Geabdat Sandstone Formation (Middle Siwalik); Upper Miocene (Sarmatian to Pontian).

Etymology: After the name of the 'Siwalik formation' to which fossils belong.

Affinities: Characteristic features of the present fossil fruit like capsular type bilobed fruit having round to oval shaped lobes. The presence of one seed in each cell of the lobe and the nature of striations on the seed surface are found common in the modern fruits of *Harpullia arborea* (Blanco) Radlk. of the family Sapindaceae (C.N.H. Herbarium Sheet No. 1874; Figs. 6, 10).

So far, there is no record of the fossil fruit of *Harpullia* Roxb. from Tertiary sediments of India, The present fossil fruit is reported for the first time from the Middle Siwalik sediments of Darjeeling District, West Bengal, India, and has been described as *Harpulliocarpon siwalica* gen. et sp. nov.

DISCUSSION AND CONCLUSIONS

A study on plant fossils recovered from the Siwalik sediments of the Darjeeling area revealed the presence of a new fossil leaf and fruit resembling the extant taxa, *Harpullia arborea* (Blanco) Radlk. of the family Sapindaceae. The genus, *Harpullia* Roxb. comprises about 27 species of small to medium-sized rainforest trees. They have a wide distribution ranging from India eastwards through Malaysia, Papuasia, and Australasia to the Pacific Islands. They grow naturally, usually in or on the margins of rainforests or associated vegetation. The major center of diversity of about twenty species, occurs throughout New Guinea including its surrounding islands region. Australia is another center of smaller diversity of about eight species, growing naturally from northeastern New South Wales through eastern Queensland to Cape York Peninsula and coastal Territory. The fossil assemblage known from the study area is represented by four other sapindaceous taxa viz. *Paranephelium seriensis, P. miocenica, Cupania oodlabarensis,* and *Filicium koilabasensis* showing their resemblance with the extant taxa, *Paranephelium xestophyllum* Miq., *P. macrophyllum* King, *Cupania pleuropteris* Hiern and *Filicium decipience* (Wight & Arn.) Hook. f. respectively (Prasad *et al*., 2015).

The present-day distribution of all the above comparable taxa suggests the existence of broad-leaved tropical evergreen forests under warm humid climate in the area during the Upper Miocene epoch instead of mixed deciduous forests there at present.

Fossil leaves and woods of sapindaceous taxa are also known from other Siwalik localities in the Himalayan foothills as well as the Tertiary sediments of India and abroad. Fossil leaves resembling the genera, *Arytera, Euphoria, Lepisanthus, Nephelium, Sapindus,* and *Otophora* are reported from Miocene sediments of the Himalayan foothills of India and Nepal (Prasad *et al*., 2019). However, the fossil woods showing affinity with the genus, *Euphoria* are known from early Tertiary of Deccan Intertrappean, Central India (Mehrotra, 1987), Miocene of Cuddalore Series, South India (Awasthi *et al*., 1982), Pliocene of Kankawati Series of Kutch, Western India and Miocene of Kalagarh, Uttarakhand (Prasad,1993). Fossil woods of the genus, *Schleichera* are known from the Miocene of Kankawati Series, Gujrat, Western India (Awasthi *et al.,* 1982) and from the early Eocene of Cambay Shale Formation of Vastan Lignite Mines, Gujrat, Western India (Singh *et al*., 2015) and Vagadkhol Formation, Western India (Singh *et al.,* 2011). Some sapindaceous fossil woods are also documented from the Tertiary sequence of Sumatra, Egypt, and Columbia under the form genus, *Sapindoxylon* (Singh *et al*., 2015). Moreover, the fossil leaves and roots belonging to the family Sapindaceae are known from the Tertiary sequence of Panama, the USA, and Brazil (Jud *et al.,* 2021). The above fossil records indicate that the family Sapindaceae has a wide distribution throughout India and abroad.

The oldest records of Sapindaceae are from the late Cretaceous and Paleocene of North America. However, Harrington (2008) in a recent evaluation of the evolutionary history of Sapindaceae opined that the family Sapindaceae originated during the Pliocene–Miocene, rather than in the Paleocene. In India, the oldest records of Sapindaceae are represented mostly by fossil woods from the late Cretaceous of Deccan Intertrappean beds (Dayal, 1965, Mehrotra, 1987) and woods and leaves from the Miocene of India and Nepal (Prasad, 1993, Prasad, 2008). The comparable species, *Harpullia arborea* is a dense evergreen tree that grows up to more than 100 meters long and is distributed from India and Sri Lanka throughout Southeast Asia and Malaysia to Australia and the Western Pacific. Thus, the present-day distribution indicates that they do not grow in and around the fossil locality in the Himalayan foothills which suggests that they have either migrated toward the southeast or extinct from the foothills area because of change in climate after the Miocene due to the uplift of the Himalaya.

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