Systematics, Phytochemistry, Biological Activities and Health Promoting Effects of the Plants from the Subfamily Bombacoideae (Family Malvaceae)

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Abstract: Plants belonging to the subfamily Bombacoideae (family Malvaceae) consist of about 304 species, many of them having high economical and medicinal properties. In the past, this plant group was put under Bombacaceae; however, modern molecular and phytochemical findings supported the group as a subfamily of Malvaceae. A detailed search on the number of publications related to the Bombacoideae subfamily was carried out in databases like PubMed and Science Direct using various keywords. Most of the plants in the group are perennial tall trees usually with swollen tree trunks, brightly colored flowers, and large branches. Various plant parts ranging from leaves to seeds of several species are also used as food and fibers in many countries. Members of Bombacoids are used as ornamentals and economic utilities, various plants are used in traditional medication systems for their anti-inflammatory, astringent, stimulant, antipyretic, microbial, analgesic, and diuretic effects. Several phytochemicals, both polar and non-polar compounds, have been detected in this plant group supporting evidence of their medicinal and nutritional uses. The present review provides comprehensive taxonomic, ethno-pharmacological, economic, food and phytochemical properties of the subfamily Bombacoideae.

Keywords: bombacoideae; pharmacology; phytochemical ingredients; bioactive compounds; medicine

1. Introduction

The plant group Bombacoideae is a subfamily of Malvaceae (kapok, cotton family). The subfamily contains about 304 species, most of them with high economical and medicinal values. Considering their importance, some of the plants are given special cultural status. For instance, the Ceiba pentandra tree is the national tree of Guatemala. Among the Mayan and Aztec civilizations in the Meso-America, the Ceiba species is considered as a sacred “World Tree”. The Indian kapok tree, Bombax ceiba, is worshipped by the Hindu community in North India as a nakshatra tree and home of the female spirits Yakshi [1]. There is West African belief that the first human was born from the trunk of a baobab tree (Adansonia spp.) and these plants are regarded as the “Tree of Life”. Many plants of the Bombacoideae are valued as ornamentals in various parts of the world because of their...
large branches and brightly colored flowers [2]. Moreover, many genera of this subfamily are known for producing fibers, timber, fruits, and vegetables, thereby, regarded as one of the important economic and commercial plant groups.

This group was previously recognized as a distinct family, Bombacaceae, based on the type genus *Bombax* by some traditional taxonomists. From the days of the natural system to the present days of phyletic classification, the status of this plant group is continuously debated. Apart from that, the number of genera under this family varied from one classification system to another. There are various arguments in favor of a distinct family or whether to subsume under a subfamily or tribe. The study of palyno-morphological characteristics supported the justification of separating Bombacaceae from Sterculiaceae, Malvaceae, and Tiliaceae [3]. Most of the traditional methodical educations related to the subfamily Bombacoideae are on the basis of the characteristics of the flower, especially the androecium [4]. Recently, morphological, anatomical, palynological, phytochemical, and molecular phylogenetic analyses have shown that separation of Bombacaceae from its related groups viz. Malvaceae, Tiliaceae, and Sterculiaceae is inconsistent [5]. This plant group includes several plants, which are used for medicinal and economic utilities. A detailed search on the number of publications related to the Bombacoideae subfamily was carried out in databases like PubMed and Science Direct and it was found that, as per the PubMed database, around 20 articles have been published during the years 1999–2020 and among them, 12 articles are full texts (https://pubmed.ncbi.nlm.nih.gov/?term=Bombacoideae; accessed on 12 October 2020). Interestingly, from a total of 20 articles, 16 were published during the last 10 years (2010–2020). Similarly, the Science Direct databases show a total of 53 articles were published during the years 1999–2020, of which, 42 are research articles, 2 are review articles, 4 book chapters, 1 short communication, 2 encyclopedia, and 2 others (https://www.sciencedirect.com/search?qs=Bombacoideae&show=100; accessed on 12 October 2020). Considering the importance, the authors attempted to extensively review the taxonomic, phytochemical, and medicinal utilities of the members of the subfamily Bombacoideae.

2. Taxonomy of the Subfamily Bombacoideae

The advent of new taxonomical tools has revolutionized taxonomical circumscriptions. Morphological and molecular analyses revealed that Bombacaceae is not a monophyletic group. Furthermore, families such as Tiliaceae, Sterculiaceae, and Malvaceae are largely nonmonophyletic. Singh [6] considered that traditional distinctions amongst these four families are random and unpredictable and fusion of four would form a monophyletic group. Bayer et al. [7], grouped these four families together into Malvaceae considering their common characteristics and assumed them to be monophyletic. The Malvaceae sensu lato is characterized by apomorphic inflorescence, presence of bicolor unit, 3-bracted cyme, and trimerous epicalyx. Bombacaceae was distributed into two subfamilies, Bombacoideae and Heliceroideae, within the family Malvaceae. The confinement of Bombacoideae and Malvoideae is still under controversy, as the former appears to be paraphyletic without the latter [8]. Most of the plants are included in the subfamily Bombacoideae. At present, Bombacoideae is one of the clades in the family Malvaceae (Figure 1). The taxonomic location of Bombacoideae as per different systems of classification is shown in Figure 2 [4].
In the Angiosperm Phylogeny Group (APG) classification, erstwhile family Bombacaceae is allocated as subfamily Bombacoideae of the family Malvaceae. Cladogram of the Malvaceae is after Bayer et al. 1999 and online version of APG (http://www.mobot.org/MOBOT/research/APweb; accessed on 10 January 2021).

As a consequence of changes in circumscription and status of Bombacoideae, has led to the inclusion of 22 genera comprised of 120 species under this subfamily mainly distributed in the tropical regions. The Angiosperm Phylogeny Group (APG) IV Classification listed 24 genera in this subfamily. However, the classification of the monospecific Septotheca falls outside the core Bombacoideae in many studies.

Figure 2. Taxonomic location of Bombacoideae as per different systems of classification. Dotted lines specify the changes in the genus limitation and the genera, which is described after the previous action, and are specified by a symbol (*), while the citation marks represent the tribes which are not validly published. Reproduced with permission from Carvalho-Sobrinho et al. [4] (originally Figure 1).
24 genera in this subfamily. However, the classification by Maarten et al. listed 27 genera under Bombacoideae [9]. This classification includes genera like Camptostemon, Lagunaria, and Uladendron in the Bombacoideae subfamily. Molecular phylogenetic analysis established on nuclear (ETS, ITS) and plastid genes (matK, trnL-trnF, trnS-trnG) revealed that there are three key lineages noticeable by the kapok clade, seed, or fruit traits—the winged seed clade, and the spongy endocarp clade [4]. Such studies established the monophyly of the core Bombacoideae subfamily and the entire genera without Pachira. The monospecific Septotheca falls outside the core Bombacoideae in many studies [4,10].

3. Habitat, Distribution, and Characteristics of the Subfamily Bombacoideae

Bombacoideae occupies different habitats in various parts of the world (Figure 3) [11]. Adansonia digitata is confined to semi-arid, stony, hot, dry, and woodland areas, with low rainfall. This plant favors well-drained soils ranging from clays to sandy soils [12]. However, some other plants favor wet and humid habitats. For instance, Bombax ceiba favors humid lowland deciduous forest and is sometimes found near stream banks [13,14]. Species belonging to Spirotheca are epiphytic stranglers. Some species are part of mangrove vegetation in the tropical regions, for example, Pachira aquatica, Camptostemon philippinense, et cetera. The majority of the species in Bombacoideae prefer rain forest biome and seasonally dry biomes [11]. Several representative plant species belonging to the subfamily Bombacoideae grow in different habitats. Adansonia digitata L. grows in the hot, semi-arid region with poorly drained soil [15]. Plants such as Bombax ceiba L., Ceiba pentandra; and Gyranthera caribensis Pittier grow in wet habitats [16]. Pachira aquatica Aubl. and Camptostemon philippinense (S. Vidal) Becc. grow in mangrove habitats [17,18]. Spirotheca rivieri (Decne.) Ulbr. grows in the epiphyte environment [19] and Ceiba pentandra grows in the savannah habitat [15].

Figure 3. Distribution of Bombacoideae in past and present eras. Adapted from Krutzsch, [20], Zizka et al. [11], and Angiosperm Phylogeny website version 14 (www.mobot.org/MOBOT/research/APweb; accessed on 10 January 2021).
The early distribution of this plant group can be ascertained from fossil records. There are various arguments for the distribution of Bombacoideae. Croizat (1952) favored the knowledge of an African entrance with Bombacoideae transferring northwards from Antarctica by Madagascar, across into Africa and through the East Indies to Australia [21]. However, the concept cannot be supported by floral evolution and geological shreds of evidence [22]. According to another view based on palyno-morphological characteristics exhibited by the members of this plant group, the subfamily is assumed to have a triphyletic origin—with southern Central America, East Africa, Madagascar, and Southeast Asia as centers of origin [3]. Fossil records of this subfamily mainly belonged to microfossils (classified as belonging to the pollen genus Bombacacidites) and some macrofossils [23]. This plant group occurred in the North Tethyan flora and reached tropical regions of South America through Central America during the transition phase between the Cretaceous and Tertiary periods. Then they moved to Central Africa in the Paleocene epoch. During the Pliocene and Pleistocene periods, this group extended its distribution to the Caribbean and Central America. When the tropical flora reduced along with the North Tethys during the Upper Paleogene, the Bombacoideae retreated to North India and reached South East Asia during the Miocene epoch. From there, they expanded to New Guinea and North Australia [20,23]. In the present era, the distribution of the extant species mainly falls in the tropical regions, particularly in Africa, America, and Australia. More than 80% of the species’ richness of this subfamily lies in the Neotropical region [8,11].

There are many reports of native species in Asian countries. Various native species are introduced to other parts of the world through human activities and other influences. The center of origin of the species of this plant group differs according to the genus. Species of this plant group can be categorized into two groups—plants endemic to a certain area and plants widely distributed through introduction. Of the endemic species, Adansonia suarezensis H.Perrier and Adansonia gregorii F.Muell. are restricted to Madagascar and NW Australia, respectively [24]. Madagascar has many endemic species of Adansonia such as Adansonia fony Baill., Adansonia madagascariensis Baill., Adansonia za Baill., and Adansonia perrieri Capuron [25–27]. Wild regions of the endemic species are as follows: Adansonia suarezensis, Adansonia fony Baill., Adansonia madagascariensis Baill., Adansonia za Baill., Adansonia perrieri Capuron, and Adansonia granddieri Baill. are the endemic species in the Madagascar region [24]. Similarly, Adansonia gregorii F.Muell., Aguaria excelsa Ducke, Uladendron codesuri Marc.-Berti, Gyranthera darienensis Pittier, Cavanillesia chicamocha Fern. Alonso, Gyranthera caribensis Pittier, and Neobuchia paulinae Urb. are endemic to Australia, Brazil, Venezuela, Panama, Colombia, Venezuela, and Haiti, respectively [4,8,24,28–30].

Native regions of various species in this group fall within the tropical region of Africa, America, and Asia. From their native regions, many species have been introduced to other parts of the world. Adansonia digitata is amongst the most widely distributed ones covering Asia, Australia, Northern America, and some oceanic islands. Distribution of this plant in the Caribbean and parts of America is through human agencies, where people from West Africa were transported between the sixteenth and nineteenth centuries for sugarcane plantations in the New World countries. In the Indian subcontinent, Arab traders or medieval Muslim rulers who maintained African slave armies mainly introduced this species. However, genetic analyses conducted in Indian populations revealed that the introduction occurred through multiple phases [31]. Most of the species have neotropical distribution, with some species having native ranges in Asia. Bombax ceiba has wild distribution in South East Asia and India. The place of origin of some plants is uncertain. The origins of wild areas of Ceiba pentandra (L.) Gaertn. are uncertain but now it is distributed throughout tropical regions including Asia [32].

4. Characteristics

Plants of Bombacoideae are usually perennial tall trees usually with swollen tree trunks. Trees of wet forests are usually evergreen while those of dry forests are deciduous [33]. Tree trunks may contain parenchymatous water storage tissue or mucilage cells.
Pneumatophores are present in the *Camptostemon*, a mangrove genus [8]. Barks are usually thin, often green. Most of the plants of Bombacoideae are characterized by their large size gigantic flowers with brush types [8]. Plants in these groups have a terminal flower and three bracts that exhibit a “bicolor unit”. The first, lowermost bracts remain sterile, however, other bracts subtend cymose partial inflorescences. Flowers are usually subtended by an involucre of bracts. Sepals are usually large and fused and petals are usually fused to the stamen tube [34]. The fruit capsule has a hairy endocarp. Leaves are usually peltately-palmate. Petioles are pulvinate, k connate with or without lobes. Monothecal anthers are present. These characteristics are assumed to have resulted from the splitting of whole stamens. Transitional forms are observed in some plants [8]. Anther walls have 5–7 cells across. Stamens are usually more than two cm long.

Most of the members of this subfamily are trees, especially shrubs, with characteristic two to five carpels, fruit capsules, rarely indehiscent, endocarp usually pubescent, pollen usually without spines, seeds usually glabrous, and exceptionally spinulose [8]. Some plants have a ploidy level other than diploidy. The lowermost chromosome numbers in this group were witnessed in *Bombax insignis* (2n = 18) from India and *Pachira macrocarpa* (2x = 26) from China, while uppermost numbers were documented in *Eriotheca* species (6x = 276) in Brazil [35]. Distinguishing characteristics of the genera in this subfamily is provided in Table 1.

Table 1. General synopsis of the genera under Bombacoideae.

| Genus            | Morphological Character                                      | Number of Species | Distribution                                |
|------------------|-------------------------------------------------------------|-------------------|--------------------------------------------|
| Adansonia L.     | Trunks swollen; leaves simple sometimes lobed; ovary 5–10 locular; fruits indehiscent; 2n = 72, 88, 144, 160. *Adansonia digitata* (2n = 144, 160) | 8 species         | Mainland Africa, Madagascar introduced to many countries |
| Aguiaria Ducke   | Lepidote hairs; leaves simple; staminal tube short with various elongated free filaments; fruits indehiscent; seed ellipsoid | 1 species         | Amazon region of Brazil                    |
| Bernouillia Oliv. | Trees leave digitate, staminal tube long, stamens 15–20, fruits indehiscent; seeds numerous, winged | 3 species         | Mexico to Colombia                         |
| Bombax L.        | Deciduous tree, trunk spiny; leaves digitate; deciduous sepals, fruits indehiscent, seeds winged, determined columella; 2n = 72, 92, 96. | 9 species         | Tropical Africa, Asia, and Australia       |
| Camptostemon Mast. * | Mangrove tree or shrubs; epicalyx fused, enclosing flower; calyx fused; ovary bilocular; fruits indehiscent | 3 species         | Australia, New Guinea, Borneo, Philippines |
| Catostemma Benth. | Trees, leaves simple, calyx campanulate; ovary trilocular, fruits indehiscent; cotyledons folded, unequal | 15 species        | The northern part of South America         |
| Cavanillesia Ruiz. & Pav. | Trunks swollen sometimes, leaves simple or palmately lobed, ovary 3–5 locular; fruits winged; indehiscent; 2n = 72, 86, 88 | 5 species         | Panama to Brazil and Peru                  |
| Ceiba Mill.      | Trunks spiny, sometimes swollen; leaves digitate; staminal tube sometimes thickened, stamens 5–15, fruits indehiscent, seeds winged; 2n = 72, 74, 75, 76, 80, 84, 86, 88, 92 | 21 species        | Tropical America, now introduced into the Old World |
| Chiranthodendron Sesse ex Larreat. | Leaves simple to lobed; flowers leaf-opposed; sepals dark red, petals absent, fruits indehiscent | 1 species         | Mexico, Guatemala                           |
| Genus                  | Morphological Character                                                                 | Number of Species | Distribution                          |
|-----------------------|----------------------------------------------------------------------------------------|-------------------|---------------------------------------|
| Eriotheca Schott & Endl. | Trees unarmed, leaves digitate, staminal tube without phalanges; fruits dehiscent; seeds small, winged; $2n = 92, 210, 270$, $6n = 276$ | 23 species       | Tropical South America                |
| Fremontodendron Coville | Shrubs; leaves simple or lobed, sepals yellow-orange, petals absent, fruits dehiscent | 2 species        | The southern part of North America    |
| Gyranthera Pittier     | Tall deciduous tree, leaves digitate, anthers spirally twisted, fruits dehiscent, seeds winged; $2n = 96$ | 2 species        | Panama, Venezuela                     |
| Huberodendron Ducke    | Tall trees, hairs stellate, leaves simple; calyx campanulate; fruits dehiscent, seeds winged | 3 species        | Costa Rica to Brazil, Bolivia, and Peru. |
| Lagunaria (DC.) Rchb. * | Leaves simple, hairs lepidote, epicalyx fused, filaments diverging at different levels; fruits stinging, dehiscent | 1 species        | Norfolk and Howe Islands, Australia   |
| Matisia Humb & Bonpl.  | Leaves simple, inflorescences cauliflowers, flowers zygomorphic, fruit drupe            | 26 species       | Tropical America                     |
| Neobuchia Urb.         | Trunk spiny, leaves digitate, stamens 5, anthers twisted; stigmatic branches short; seeds exalbuminous | 1 species        | Haiti                                 |
| Ochroma Sw.            | Tree, leaves simple to lobed, venation palmate; stigma spirally grooved; fruits dehiscent; $2n = 78, 88, 90$ | 1 species        | Tropical America                     |
| Pachira Aubl.          | Trunk spiny sometimes; leaves digitate; stamens 90–1000; fruits large, dehiscent, $2n = 72, 82, 88, 92$ (neotropical species), 144, 150 (palaeotropical species) | 47 species       | Tropical Africa, neotropical regions |
| Patinoa Cuatrec.       | Trees with verticillate branches, leaves simple, sessile anthers, ovules many; fruits indehiscent | 4 species        | Colombia to Brazil and Peru;         |
| Pentaplaris L.O. Williams & Standl. * | Leaves simple, stipules fused; epicalyx fused, ovary bilocular, fruits indehiscent; cotyledons foliase | 3 species        | Costa Rica, Ecuador, Bolivia, and Peru, Peru |
| Phragmotheca Cuatrec.  | Trees, lepidote hairs rare, leaves simple, flowers leaf-opposed; fruit a drupe; cotyledons flat or folded | 5 species        | Panama to Peru                       |
| Pseudobombax Dugand    | Trunks swollen sometimes, leaves usually digitate, ovary 5 to 8 locular, fruits dehiscent, seeds winged; $2n = 72, 84, 88$ | 22 species       | Mexico, Tropical South America       |
| Quararibea Aubl.       | Trees; lepidote hairs sometimes, calyx usually ridged; ovary 2 to 4 locular, fruit a drupe; $n = 72$ | 88 species       | Neotropical regions                  |
| Scleronema Benth.      | Tall tree leaves simple, staminal tube short, ovary 2 to 4 locular, fruits dehiscent or indehiscent | 3 species        | Venezuela, Guyana and Brazil         |
| Septotheca Ulbr.       | Tall tree, lepidote hairs, simple leaves, cordate, anthers sessile; fruits dehiscent, seeds winged | 1 species        | Peru, Colombia, and Brazil.          |
| Spirotheca Ulbr.       | Epiphytic stranglers to the tree, trunk spiny sometimes, leaves digitate, stamens 5, anthers spirally twisted, fruits dehiscent; $2n = 88, 92$ | 5 species        | Panama to Peru and Brazil            |
| Uladendron Marc.-Berti * | Leaves simple, slightly lobed, fruits dehiscent, seeds winged; cotyledon distorted | 1 species        | Venezuela                            |

(www.theplantlist.org; accessed on 12 October 2020); * Genera incertae sedis (uncertain placement). Source: (Byng [34]; Fay [36]; Kubitzki and Bayer [8]; Lim [15]; Marinho et al. [35]).
The status of genera under Bombacoideae might be subjected to change in future revisions. The single species *Chiranthodendron pentadactylon* can be crossed with *Fremontodendron* sp. [8] exhibiting compatible genotypes. *Neobuchia paulinae* is an imperfectly known species that may be included in *Ceiba* [8].

### 5. Phytochemical Configuration of Bombacoideae Subfamily

Phytochemical investigations of Bombacoideae plant species resulted in the extraction and isolation of several classes of secondary metabolites. Among the most studied genera, there are *Adansonia*, *Bombax*, and *Chorisia* [2,37,38]. *Bombax ceiba* (syn. *Bombax malabaricum, Bombax malabarica, Salmalia malabarica, Gossampinus malabarica*), *Adansonia digitata*, and *Chorisia speciosa* are the most chemically and biologically investigated species.

A wide spectrum of phytochemicals has been identified and has confirmed that this family is a rich source of phytochemicals. Table 2 lists the main alkaloids, anthocyanins, coumarins, flavonoids, lignans and neolignans, sesquiterpenes and sesquiterpene lactones, sterols, tannins, and triterpenes isolated from the Bombacoideae subfamily. Volatiles and fatty acids were also reported (Table 2).

**Table 2. The main phytochemicals identified in plant species from the Bombacoideae subfamily.**

| Compound               | Plant                                | Part       | Reference |
|------------------------|--------------------------------------|------------|-----------|
| **Alkaloids**          |                                     |            |           |
| Adansonin              | *A. digitata*                        | Seeds and pulp | [39]     |
| Funebral               | *Quararibea funebris*                |            |           |
| Funebradiol            | *Quararibea funebris*                |            |           |
| Funebrine              | *Quararibea funebris*                |            |           |
| **Anthocyanins**       |                                     |            |           |
| Cyanidin-3-glucoside   | *Ceiba acuminata*                   | Flowers    | [43]     |
|                       | *Chorisia speciosa* (Ceiba speciosa (A.St.-Hil., A.Juss. & Cambess.) Ravenna) |            |           |
|                       | *Ochroma lagopus* (Ochroma pyramidale (Cav. ex Lam.) Urb.) |            |           |
| Cyanidin-3,5-diglucoside | *Pachira aquatica*              |            |           |
|                       | *Bombax ceiba*                       |            |           |
|                       | *C. speciosa*                        |            |           |
|                       | *Pseudobombax ellipticum*            |            |           |
|                       | *P. grandiflorum*                    |            |           |
| Cyanidin-3-rutinoside  | *Pachira aquatica*                  | Flowers    | [44]     |
| Cyanidin-7-methyl ether-3-β-d-glucoside | *B. ceiba* |            |           |
| Pelargonidin-5-β-d-glucoside | *B. ceiba* |            |           |
| Pelargonidin-3,5-diglucoside | *B. ceiba* |            |           |
| **Coumarins**          |                                     |            |           |
| Cleomiscosine A        | *Ochroma lagopus*                   | Heartwood  | [46]     |
| Esculetin              |                                      |            |           |
| Fraxetin               |                                      |            |           |
| Scopoletin             |                                      |            |           |
| Scopolin               |                                      |            |           |
| Scopoletin             | *P. aquatica*                        | Stems     | [48]     |
Table 2. Cont.

| Compound                          | Plant                  | Part         | Reference |
|-----------------------------------|------------------------|--------------|-----------|
| Apigenin                          | B. ceiba               | Flowers      | [49]      |
| Apigenin O-pentoside              | A. digitata            | Fruits       | [50]      |
| Apigenin-7-O-β-d-rutinoside       | *Chorisia insignis* (Ceiba insignis (Kunth) P.E.Gibbs & Semir) | Leaves | [51]      |
| Catechin                          | A. digitata            | Fruits       | [50]      |
|                                 | *Ceiba pentandra*      | Stem bark    | [52]      |
|                                 | *Ochroma pyramidalae*  | Leaves       | [53]      |
| Cosmetin                          | B. ceiba               | Flowers      | [49]      |
| 5,4’-Dihydroxy-3,6,7,8-tetramethoxyflavone | P. aquatica             | Stems        | [48]      |
|                                  |                        |              |           |
| Epicatechin                       | A. digitata            | Fruits       | [50,54]   |
| Epicatechin 3,5,6,7,8,3’,4’-Heptamethoxyflavone | O. pyramidale        | Leaves       | [53]      |
|                                  | P. aquatica            | Stems        | [48]      |
| Hesperidin (5,3’-dihydroxy-4’-methoxy-flavan-7-O-α-Lrhamnopyranosyl-(1→6)-β-d-lucopyranoside | B. ceiba | Roots | [55]      |
| 5-Hydroxy-7,4’-dimethoxy-3,5,7,8,4’-penta-methoxyflavone | Ceiba pentandra    | Stem bark    | [56]      |
| 5-Hydroxyauranetin                | P. aquatica            | Stems        | [48]      |
| 5-Hydroxy-7,4’-dimethoxy-flavone  | Bombax aniceps        | Roots        | [57]      |
| 5-Hydroxy-3,7,4’-trimethoxy- flavone |                        |              |           |
| 5-Hydroxy-3,6,7,4’-tetra-methoxyflavone | Bombacopsis glabra (Pachira glabra Pasq.) | Stem bark, root bark | [58] |
|                                  | B. ceiba               | Flowers      | [49]      |
| Linarin                           | A. digitata            | Roots        | [59]      |
| 3,7-Dihydroxy-flavan-4-one-5-O-β-d-galactopyranosyl-(1→4)-β-d-glucopyranoside | A. digitata        | Roots       | [57]      |
|                                  | B. aniceps             | Roots        | [57]      |
|                                  | C. insignis            | Leaves       | [51]      |
|                                  | A. digitata            | Fruits       | [50]      |
|                                  | B. ceiba               | Flowers      | [60]      |
|                                  | C. pentandra           |             | [61]      |
| Kaempferol                        | A. digitata            | Fruits       | [50]      |
| Kaempferol 3-O-galactoside        | A. digitata            | Fruits       | [50]      |
| Kaempferol 3,7,4’-trimethyl ether | P. aquatica            | Stems        | [48]      |
| Pentandrin                        | C. pentandra           | Stem bark    | [62]      |
| Pentandrin glucoside              | C. pentandra           | Stem bark    | [62]      |
| Quercetin                         | B. ceiba               | Flowers      | [60]      |
|                                  | A. digitata            | Fruits       | [50]      |
| Compound                        | Plant          | Part         | Reference  |
|--------------------------------|----------------|--------------|------------|
| Quercetin-3-O-glucoside        | *A. digitata*  | Fruits       | [50, 54]   |
| Quercetin-7-O-xylopyranoside   | *A. digitata*  | Stem         | [63]       |
| Retusin                        | *P. aquatica*  | Stems        | [48]       |
| Rhoifolin                      | *Chorisia crispiflora* | Leaves   | [64]       |
|                                | *Chorisia pubiflora* | Leaves   |            |
| Rutin                          | *A. digitata*  | Leaves       | [50]       |
| Saponarin                      | *B. ceiba*     | Flowers      | [49]       |
| Santin-7-methyl ether          | *P. aquatica*  | Stems        | [48]       |
| Shamimin                       | *B. ceiba*     | Leaves       | [66]       |
| Shamimicin                     | *B. ceiba*     | Stem bark    | [67]       |
| Tiliroside                     | *C. speciosa*  | Leaves       | [65]       |
| Tiliroside isomer              | *A. digitata*  | Fruits, leaves | [50]     |
| Tiliroside I                   | *A. digitata*  | Roots        | [54, 68]   |
| Tiliroside II                  | *A. digitata*  | Roots        |            |
| 3,3',4'-Trihydroxy flavan-4-one-7-O-α-L-rhamnopyranoside | *A. digitata* | Roots        |            |
| Vicenin 2                      | *B. ceiba*     | Flowers      | [49]       |
| Vitexin                        | *O. pyramidale* | Leaves | [53]       |
| Xanthomicrol                   | *B. ceiba*     | Flowers      | [49]       |
| **Lignans and neolignans**     |                |              |            |
| Boehmenan                      | *Ochroma lagopus* | Heart wood | [46]       |
| Boehmenan B                    |                |              |            |
| Boehmenan C                    | *O. lagopus*    | Heart wood   | [69]       |
| Boehmenan D                    |                |              |            |
| Bombasin                      |                | Flowers      | [70]       |
| Bombasin-4-O-glucoside         | *B. ceiba*     | Flowers      | [71]       |
| Bombasinol A                   |                |              |            |
| Carolignan A                   | *O. lagopus*    | Heart wood   | [69]       |
| Carolignan B                   |                |              |            |
| Carolignan C                   | *O. lagopus*    | Heart wood   | [69]       |
| Carolignan D                   |                |              |            |
| Carolignan E                   |                |              |            |
| Carolignan F                   |                |              |            |
Table 2. Cont.

| Compound                                                      | Plant      | Part          | Reference |
|---------------------------------------------------------------|------------|---------------|-----------|
| Dihydro-dehydro-diconiferyl alcohol- 4-O-glucopyranoside      | *B. ceiba* | Flowers       | [70]      |
| 5,6-Dihydroxy matairesinol                                    |            |               |           |
| Matairesinol                                                  | *B. ceiba* | Flowers       | [71]      |
| (+)-Pinoresinol                                               |            |               |           |
| Secoisolariciresinol diferulate                               | *O. lagopus* | Heart wood   | [46]      |

**Sesquiterpenes and sesquiterpene lactones**

| Compound                        | Plant                  | Part        | Reference |
|---------------------------------|------------------------|-------------|-----------|
| Aquatidial                      | *Pachira aquatica*     | Root bark   | [72]      |
| Bombamalabin                    |                        |             |           |
| Bombamalone A                   |                        |             |           |
| Bombamalone B                   | *B. malabaricum*       | Roots       | [74]      |
| Bombamalone C                   |                        |             |           |
| Bombamalone D                   |                        |             |           |
| Bombamaloside                   |                        |             |           |
| 7-Hydroxy-cadalene              |                        | Roots       | [75]      |
| Isohemigossypol-1-methyl ether  | *B. anceps*            | Roots       | [57]      |
| Isohemigossypol-2-methyl ether  | *B. ceiba*             | Root bark   | [73,75]  |
| Isohemigossypol-1,2-dimethyl ether |                |            |           |
| Isohemigossypol-2,7-dimethyl ether | *B. ceiba*            | Roots, root bark | [75,76] |
| Lacinilene C                   | *B. ceiba*             | Roots       | [74,75]  |
| Hemigossylic acid lactone-2-hydroxy-7-methyl ether           |            |             |           |
| Hemigossylic acid lactone-2-hydroxy-7-methyl ether           | *C. pentandra*        | Root bark   | [77]      |
| 6-Hydroxy-5-isopropyl-3-methyl-7-methoxy-8,1-naphthalene carbolactone | *B. ceiba* | Roots       | [78]      |
| Isohemigossylic acid lactone-2-methyl ether                  | *B. ceiba*            | Roots       | [74,76]  |
| Isohemigossylic acid lactone-2-methyl ether                  | *C. pentandra*        | Root bark   | [77]      |
| 5-Isopropyl-3-methyl-2,7-dimethoxy-8,1-naphthalene carbolactone | *B. ceiba*            | Roots       | [75]      |
| 5-Isopropyl-3-methyl-2,7-dimethoxy-8,1-naphthalene carbolactone | *C. pentandra*        | Root bark   | [77]      |
| Compound          | Plant          | Part        | Reference |
|-------------------|----------------|-------------|-----------|
| Sterols           |                |             |           |
| Campesterol       | *A. digitata*  | Seeds       | [79]      |
|                   | *B. ceiba*     | Flowers     | [49]      |
|                   | *A. fony*      |             |           |
|                   | *A. za*        | Seeds       | [79]      |
|                   | *A. suarezensis* |            |           |
|                   | *A. grandidieri* |          |           |
|                   | *A. madagascariensis* | | |
| β-Sitosterol      | *B. ceiba*     | Stem bark   | [37]      |
|                   | *B. ceiba*     | Root bark   | [73]      |
|                   | *B. ceiba*     | Flowers     | [80]      |
|                   | *A. digitata*  | Seeds       | [79]      |
|                   | *C. pentandra* | Stem bark   | [62]      |
| Stigmasterol      | *A. digitata*  | Seed        | [79]      |
|                   | *B. ceiba*     | Flowers     | [80]      |
|                   | *A. grandidieri* |          |           |
|                   | *A. madagascariensis* | | |
|                   | *A. fony*      | Seeds       | [79]      |
|                   | *A. za*        |             |           |
|                   | *A. suarezensis* |          |           |
| Tannins           |                |             |           |
| Epicatechin-(4β→8)-epicatechin | *A. digitata* | Fruits     | [54]      |
| Epicatechin-(4β→6)-epicatechin |                |             |           |
| Epicatechin-(2β→O→7, 4β→8)-epicatechin | *A. digitata* | Fruits     | [54]      |
| Epicatechin-(4→8)-epicatechin- (4→β8)-epicatechin | | | |
| Ethyl gallate     | *B. ceiba*     | Seeds       | [81]      |
| Gallic acid       | *B. ceiba*     | Stem bark   | [37]      |
| 1-Galloyl-β-d-glucose |                | Seeds       | [81]      |
| Tannic acid       |                |             |           |
The fruit pulp of *A. digitata* from Mali is characterized by flavonol glycosides and procyanidins as dominant classes of compounds [50]. Tiliroside was identified as a major constituent. *A. digitata* fruits from Nigeria showed hydroxycinnamic acid glycosides, iridoid glycosides, and phenylethanoid glycosides, secondary metabolites not detected in the fruits from Mali [88]. More recently, procyanidins, phenolic acids, and flavonol glycosides were identified in *A. digitata* fruits from Cameroon [89]. In particular, fruit pulp was characterized by the presence of non-flavonoid compounds such as hydroxycinnamic derivatives and flavonoids, mainly flavones, flavanols, proanthocyanidins, and flavonols.

Furthermore, polar compounds identified in leaf extracts consisted of several classes of flavonoids and hydroxycinnamic acids. Leaves from Cameroon [89] exhibited a very similar profile compared to the leaves from Mali [50].

Previously, Tembo et al. [90], quantifying several compounds in fresh *A. digitata* pulp and investigating quantitatively variations of some of these molecules induced by pas-

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### Table 2. Cont.

| Compound                        | Plant               | Part                  | Reference |
|---------------------------------|---------------------|-----------------------|-----------|
| Triterpenes                     |                     |                       |           |
| β-Amyrin                        | *C. speciosa*       | Leaves                | [65]      |
| Lupeol                          | *B. glabra*         | Stem bark, root bark  | [58]      |
|                                 | *B. ceiba*          | Stem bark             | [37]      |
|                                 | *B. malabarica*     | Root bark             | [73]      |
|                                 | *B. anceps*         | Roots                 | [57]      |
| *Cavanillesia hylogeiton*       | Stem bark           | [61]      |
|                                 | *O. pyramidale*     | Leaves                | [53]      |
|                                 | *P. aquatica*       | Root bark             | [72]      |
| Oleanolic acid                  | *B. ceiba*          | Roots                 | [55]      |
|                                 | *O. pyramidale*     | Leaves                | [53]      |
| Ursolic acid                    | *A. digitata*       | Fruits                | [82]      |
| Other compounds                 |                     |                       |           |
| Argentilactone I                | *Chorisia crispiflora* | -                    | [83]      |
| Argentilactone II               | *C. crispiflora*    | -                     | [83]      |
| Bombalin                        | *B. ceiba*          | Flowers               | [70]      |
| Bombaxquinone B                 | *B. anceps*         | Roots                 | [57]      |
|                                 | *B. ceiba*          | Roots                 | [74]      |
|                                 | *C. pentandra*      | Root bark             | [77]      |
|                                 | *B. ceiba*          | Root bark             | [84]      |
| *(R)-6-[(Z)-1-Heptenyl]-5,6-dihydro-2H-pyran-2-one* | *C. crispiflora* | -                     | [83]      |
| Hemigossypolone-6-methyl ether  | *B. ceiba*          | Root bark             | [85]      |
| Isohemigossypolone              | *B. glabra*         | Stem bark, root bark  | [58]      |
|                                 | *B. ceiba*          | Root bark             | [85]      |
|                                 | *C. pentandra*      | Heart wood            | [86]      |
|                                 | *P. aquatica*       | Root bark             | [58,87]  |
| Isohemigossypolone-2-methyl ether | *P. aquatica*     | Root bark             | [87]      |
| Neochlorogenic acid |                         |                       |           |
| *trans*-3-(p-Coumaroyl)-quinic acid | *B. ceiba* | Flowers               | [70]      |
| 3-Methyl-2(3H)-benzofuranone    |                     |                       |           |
treatment and thermal preservation, described a high content of epicatechin, gallic acid, and procyanidin B2 in Malawi *A. digitata* fruits. Nasr et al. [65] isolated two flavonoid glycosides, namely, rhoifolin and tiliroside, in the alcoholic extract of *C. speciosa* leaves from Egypt, together with some sterols and triterpenes. The sesquiterpenes, bombamalin and isohemigossypol-1-methyl ether, and the phenols, 4-hydroxy-3,5-dimethoxybenzoic acid, 3,4,5-trimethoxyphenol-1-(β-xylopyranosyl-(1→2))-β-glucopyranoside, shorealactone, (−)-epicatechin 5-O-β-D-xylopyranoside, and 2-C-(β-D-apiofuranosyl-(1→6))-β-D-glucopyranosyl-1,3,6-trihydroxy-7-methoxyxanthone have been isolated from the ethanol extract of *B. malabarica* root bark [73].

Five new compounds, namely, bombamaloside and bombamalones A–D (Figure 4), were obtained by Zhang et al. [74] from the H$_2$O/acetone (3:7) extract of *B. malabaricum* roots, along with other known constituents such as bombaxquinone B, lacinilene C, isohemigossypol-1-methyl ester, and 2-O-methylisohemigossylic acid lactone.

![Figure 4. The chemical structures of new isolated compounds from Bombacoideae species.](image)

Aquatidial (Figure 4) was previously isolated from a chloroform extracts of *P. aquatica* roots together with the known compounds lupeol, triacontyl *p*-coumarate, and isohemigossypolone [72]. Aquatidial is a new bis-norsesquiterpene with an uncommon skeleton, putatively derived from isohemigossypolone. Two new naphthofuranones, 11-hydroxy-2-O-methylhibiscolactone A and O-methylhibiscone D (Figure 4), have been extracted from the *P. aquatica* stems [48].

Several volatiles have also been described from some Bombacoideae species. Sulfur compounds (15.3%), benzenoids (7.8%), monoterpane hydrocarbons (0.6%), and oxygenated monoterpenes (0.2%) were identified in the flowers of *A. digitata* [91]. The oil obtained from the flowers of *C. pentandra* showed monoterpene hydrocarbons (34%), sesquiterpene hydrocarbons (26.9%), oxygenated monoterpenes (8.4%), benzenoids (7.8%), and miscellaneous compounds (2%) [91].

The most common fatty acids in the Bombacoideae subfamily are oleic, linoleic, linolenic, stearic, and palmitic acids. The cyclopropenoid fatty acids, malvalic acid and sterculic acid, have been identified in *A. digitata* [92–94], *A. fony* [94], and *Bombax oleagineum*, *C. acuminata*, and *C. pentandra* [61]. Recently, the seeds’ *n*-hexane extract of *C. speciosa* from
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Italy showed linoleic acid (28.22%) and palmitic acid (19.56%) as the most abundant fatty acids [95]. Percentages of 16.15 and 11.11% were found for malvalic acid and sterulic acid, respectively.

Linoleic acid (38.8%), palmitic acid (24.3%), and oleic acid (21.9%) were identified as the dominant fatty acids of *C. pentandra* seed oil from Malaysia [96]. Malvalic and sterulic acids were also identified. A lower percentage of linoleic acid was found in the seed oil of *C. pentandra* from India [97]. Saturated fatty acids and monounsaturated fatty acids were obtained from the seeds of *P. aquatica* by using the Soxhlet apparatus and n-hexane as solvent. Palmitic acid and oleic acid were the most abundant with percentages of 49.0 and 18.2%, respectively [98]. Linoleic acid (11.2%) is the only polyunsaturated fatty acid identified.

6. Details of the Extraction and Isolation Procedure of Major Compounds from Bombacoideae for Industrial Applications

Different bioactive constituents, mainly terpenes, flavonoids, alkaloids, steroids, and fatty acids, have been isolated from the Bombacoideae subfamily. The extraction technique is the first pivotal step to obtaining active phytochemicals from plants. The choice of extraction procedure would depend mainly on the advantages and disadvantages of the process, including yield, biological activity, environmental friendliness, and safety. The fruit pulp of *A. digitata* revealed the presence of iridoids and phenols by using 70% ethanol as solvent [88]. Proanthocyanidins were obtained as major constituents from the pericarp of *A. digitata* fruits [54] by using a hydroalcoholic solution (methanol/H2O 80:20 v/v). Maceration with 95% ethanol of *B. malabarica* root bark led to the isolation of several sesquiterpenes, triterpenes, phenols, and sterols [73]. Conversely, cadinene sesquiterpenes were extracted from the roots of *B. malabaricum* by using H2O/acetone (3:7 v/v) [74]. *B. malabaricum* flowers extracted by 70% (v/v) aq. ethanol is characterized by different lignans.

Until now, the most applied extraction technique to isolate phytochemicals from the Bombacoideae subfamily is maceration. Researchers are exploring other extraction procedures using less energy and less solvent while producing higher yields and that are more environmentally friendly. Some advanced methods (i.e., pressurized and accelerated fluid extraction, supercritical extraction) have demonstrated to be useful in mediating related extraction difficulties along with increased extraction yields. Two of the most commonly employed extraction techniques of flavonoids are microwave- (MAE) and ultrasound-assisted extraction (UAE). High extraction efficiency and less destruction of the active constituents are the many advantages of UAE [99–101]. Nevertheless, MAE is preferred over UAE because MAE has been shown to increase the mass transfusion through the solid matrix, faster mixing of the extraction solvent thus preserving the highest possible driving forces, and ensuring the highest quality and quantity of the extracted constituents. Indeed, several works have proven that MAE allows for great extraction yields, a reduction of the volumes of solvents used, and a reduction of the extraction times [99,100]. MAE has been applied to extract flavonoids, tanshinones, coumarins, and terpenes [101]. These characteristics along with the simplicity of operation would position MAE as a valuable and suitable technology for industries with the growing demand for increased productivity and efficiency. However, until now little progress has been described for the MAE application to Bombacoideae species. Surely, taking into account all the MAE features, in the future, it will be possible to optimize the process by exploiting the opportunity to apply this innovative extraction method to the study of species belonging to the Bombacoideae family.

7. Application in Food/Use as Food

From ancient periods until today, many plants of the Bombacoideae have been used as food in various corners of the world. Parts used may range from leaves, seeds, tuberous roots to stem, flowers, et cetera. There are various variations in the use of food according to genera and cultures associated. Native African populations commonly use fruits of *Adansonia digitata* as famine food to make sauces, decoctions, and refreshing beverages [102].
The leaves, seeds, and pulp of the fruit of this plant are all edible. Lim (2012) reported the use of young leaves, seeds, fruit pulp, and tuberous roots of *Adansonia gregorii* F. Muell as food. Along with *Adansonia* spp, *Ceiba pentandra* is another one of the plant foods common to West Africa. Leaves of this plant are cooked in the form of slurry sauce [103]. The utilization as food for this plant group is not restricted to Africa but observed in other parts of tropical countries. In Central and South America, flowers and tender leaves of *Pachira aquatica*, a wetland tree, are cooked and used as vegetables [15]. Young roots of *Bombax ceiba* are eaten raw or roasted in Cambodia. The cuipo tree (*Cavanillesia platanifolia*), growing in Central America, is used by the natives for getting water. To collect water, a piece of the root is cut and the bark is removed on one end after keeping the root horizontal. When the clean end of the root is lowered, the water drains out through the cut end [104].

The use and preparation of food from the members of Bombacoideae dates back to time immemorial. For instance, in South America, from the ancient pre-Colombian period [105], flowers of *Quararibea funebris* were used as an additive to chocolate drinks. Ancient Mayans used the sap from *Pseudobombax ellipticum* to make an intoxicating drink by fermentation. This drink was likely used in religious ceremonies such as sacrifice and self-mutilation [33]. The use of various members of Bombacoides as fruits, vegetables, and other forms are highlighted in Table 3.

### Table 3. Plant and parts used as a food.

| Name of the Species                      | Parts Used                     | Mode of Usage                  | Country                              | Reference  |
|-----------------------------------------|--------------------------------|--------------------------------|--------------------------------------|------------|
| *Adansonia digitata* L.                 | Leaves and seeds               | Soup, sauce, fermentation, gruel | Southern Africa, Italy               | [15,106]   |
| *Adansonia gregorii* F. Muell.          | roots, fruit pulp, seeds, tuberous, young leaves | Food                           | Aborigines in Australia               | [15]       |
| *Bombax ceiba* L.                       | Dry cores of the flower        | soup                           | Shan State (Myanmar) and Northern Thailand | [107] |
|                                          | Flower buds                    | Vegetable                       | South India                          | [108]      |
|                                          | Seeds                          | Roasted and eaten               |                                      | [32]       |
| *Bombax costatum* Pellegr. & Vuillet    | Unripe fruits and flowers      | Soup                           | Burkina Faso                         | [109]      |
| *Catostemma fragrans* Benth.            | Aril                           | Fresh                          | Guianas                              | [110]      |
| *Cavanillesia platanifolia* (Humb. & Bonpl.) Kunth | Seed, Root                   | Sweet, water source             | Peru                                 | [104,111] |
| *Ceiba pentandra* (L.) Gaertn.          | Young leaves, petals, capsules | Vegetable                      | Tropical countries of Asia and America, Thailand | [15,32] |
| *Ceiba aesculifolia* (Kunth) Britten & Baker f. | Young leaves, ripe fruits       | Vegetable, Stew                 | Mexico                               | [32]       |
| *Pachira glabra* Pasq.                  | Young Leaves                   | Vegetable                       | Equatorial Africa                    | [32]       |
| *Pachira insignis* (Sw.) Savigny         | Seeds, young leaves, flowers   | Vegetable                       | South America                        | [15]       |
| *Patinoa almirajo* Cuatrec.             | Fruit                          | Edible fruit                    | Brazil, Colombia                     | [32]       |
| *Pseudobombax ellipticum* (Kunth) Dugand | Fruit                          | Beverage                        | South America                        | [33]       |
| *Quararibea cordata* (Bonpl.) Vischer   | Fruit                          | Juice, drinks                   | South America                        | [15]       |
| *Quararibea funebris* (La Llave) Vischer | Flowers                        | Chocolate Drinks, desserts      | South America                        | [33]       |
| *Quararibea obliquifolia* (Standl.) Standl. | Flowers                      | Spice                           | South America                        | [112]      |
| *Quararibea obliquifolia* (Standl.) Standl. | Fruit                        | Fresh                           | Ecuador                              | [113]      |
8. Traditional and Economic Uses

Various members of Bombacoideae are used as fiber and other utilities and some are also used as ornamental plants. *Adansonia digitata* is a multipurpose plant with various economic and social values [106]. In African countries, *Adansonia digitata* is very popular and reported to have more than three hundred traditional uses [102]. *Ceiba* Mill. is now popular throughout the tropical regions for ornamental landscaping [114]. Many species of the genus *Ceiba* were sacred to the Mayan civilization as depicted in ancient ceramics because of their cultural importance [33].

Many Bombacoideae species are economically important. Some species are collected for their wood that is soft and can easily be carved into canoes and other useful products. One popular wood is balsa wood obtained from the *Ochroma pyramidale* [16] and other species were widely used for making dugout canoes in ancient South America. Ancient Peruvians are believed to have used legendary Kon-Tiki rafts made from balsa wood to navigate across the Pacific Ocean and settle in the Polynesian islands [115]. The silky cotton-like fluff (kapok) present in the seed pods of *Ceiba pentandra* is used for stuffing pillows, bedding, and soft toys in various parts [116]. Silk hair present in seeds of *Bombax ceiba* are used in India from time immemorial for stuffing cushions, mattresses, pillows, and making clothes [117]. Various traditional and economic uses of the members of this subfamily are summarized in Table 4.

| Name of the Species               | Parts Used      | Purpose                        | Country            | Reference  |
|----------------------------------|-----------------|--------------------------------|--------------------|------------|
| *Adansonia digitata* L.          | Fruit shell     | Fuel                           | Tanzania           | [118]      |
|                                  | Leaves          | Fodder                         | The Sahelian region, Africa | [118]      |
|                                  | Fiber from bark | Ropes, textile, basketry, fishing lines | Africa             | [118]      |
|                                  | Tree trunk      | Reservoir of water             | Sudan              | [15]       |
|                                  | Roots           | Red dye                        | East Africa        | [118]      |
| *Aguiaria excelsa* Ducke          | Wood            | Boat, construction             | Brazil             | [28]       |
| *Bombax ceiba* L.                | Fiber           | Mattress, pillows, cloth       | Asia               | [117]      |
| *Bombax insignis* Wall.          | Wood            | Timber, boat construction, matches, plywood | India, Sri Lanka, Nepal | [119,120] |
| *Bombax costatum* Pellegr. & Vuillet | Wood          | Drum, xylophone, match stick, home appliances, door frame, fuelwood | Africa             | [109]      |
|                                  | Tannin          | Dye                            | Africa             | [109]      |
| *Bombax rhodognaphalon* K. Schum. | Leaves, roots  | Witchcraft                     | Africa             | [122]      |
| *Catasetoma commune* Sandwith     | Wood            | Timber                         | Central and Latin America | [123]      |
| *Cavanillesia umbellata* Ruiz & Pav. | Bark          | Drum hoops                     | Peru               | [111]      |
|                                  | Wood            | Door fillings, light boxes, toothpicks, paper pulps | Peru               | [111]      |
| *Ceiba aesculifolia* (Kunth) Briten & Baker f. | Fiber          | Fiber                          | Mexico, Guatemala  | [32]       |
Table 4. Cont.

| Name of the Species                  | Parts Used      | Purpose                                      | Country                    | Reference |
|-------------------------------------|-----------------|----------------------------------------------|----------------------------|-----------|
| *Ceiba pentandra* (L.) Gaertn.      | Fiber, wood     | Paper, fiber, insulation material, pillows, toys | Tropical countries         | [32,116]  |
| *Ceiba samauma* (Mart. & Zucc.) K.Schum. | Seed            | Thermal insulation                           | Ecuador                    | [124]     |
| *Ceiba trischistandra* (A.Gray) Bakh. | Fruit wall      | Fiber                                        | Java, Peru, and Brazil     | [32]      |
| *Huberodendron patinoi* Cuatrec.   | Wood            | Timber                                       | Colombia                   | [125]     |
| *Ochroma pyramidale* (Cav. ex Lam.) Urb. | Wood            | Bowls, rafts, canoes, toys, carvings (Balsa) | Venezuela                  | [16]      |
| *Pachira aquatica* Aubl.            | Whole tree      | Ornamental, fortune tree                      | East Asia, South East Asia | [15]      |
| *Pachira insignis* (Sw.) Savigny     | Wood            | Paper                                        | South America              | [32]      |
| *Pentaplaris davidsmithii* Dorr & C. Bayer | Wood            | Firewood                                     | Bolivia                    | [126]     |
| *Quararibea funebris* (La Llave) Vischer | Flowers        | Perfume                                      | South America              | [33]      |
| *Quararibea malacocalyx* A.Robyns & S.Nilsson | Seed fiber    | Thermal and acoustic insulation               | Ecuador                    | [124]     |
| *Scleronema micranthum* (Ducke) Ducke | Wood            | Construction, joinery, flooring, furniture   | Brazil                     | [127]     |
| *Spirotheca rivieri* (Decne.) Ulbr. | Wood            | Box, Linings                                 | Brazil                     | [128]     |

9. Ethnopharmacology

In various tropical countries, plants of Bombacoideae are used in traditional medicine mainly for pharmacological properties like anti-inflammatory, astringent, antimicrobial, stimulant, antipyretic, analgesic, and diuretic [2]. For instance, various parts of *Bombax ceiba* such as the stem bark, flowers, fruits, seeds, leaves, and root of young plants, are traditionally used as remedy in South India [108]. Its main therapeutic applications include diabetes, urinogenital disorders, gastrointestinal and skin diseases, gynecological, and general debility [129]. Another important plant from this subfamily in the Indian ayurvedic system is *Ceiba pentandra* known as Sweta Salmali for its acrid, bitter, thermogenic, diuretic, and purgative properties. The known pharmacological activities of *Ceiba pentandra* include hepatoprotective, antidiabetic, antipyretic, laxative, and anti-inflammatory [130]. *Adansonia digitata* is one of the most studied species for its therapeutic properties against antipyretic, diarrhea, dysentery, and as a substitute for cinchona in traditional medicinal preparations [105]. Different species under Bombacoideae having reported ethnopharmacological uses are summarized in Table 5.
Table 5. Plants belonging to Bombacoideae with ethnopharmacological uses.

| Species                  | Country | Parts Used | Disease                                                                 | Mode of Usage                     | Reference |
|-------------------------|---------|------------|-------------------------------------------------------------------------|-----------------------------------|-----------|
| Adansonia digitata L.   | India   | Pulp       | Diarrhea and dysentery                                                  | External application              | [118]     |
|                         | India   | Leaves     | Swellings                                                              | Crushed and applied               | [118]     |
|                         | South and East Africa | Leaves | Malaria and fever                                                      | Mixed with water                  | [131]     |
|                         | Cameroon, Central Africa | Fruits, seeds | Dysentery, fever                                                       | Decoction                         | [131]     |
|                         | South Africa | Leaves | Diarrhea, fever, kidney and liver diseases, inflammation, asthma      | Infusion                          | [132]     |
|                         | Nigeria  | Bark       | Sickle-cell anemia                                                     | Aqueous extract                   | [15,133]  |
|                         | Burkina Faso | Leaves | Toothache, gingivitis                                                  |                                   | [134]     |
| Bernoullia flammea Oliv.| Guatemala | Seeds     | Intoxication                                                          | Smoke                             | [135]     |
|                         | India    | Root       | A nocturnal emission, cold, and cough, dysentery, diarrheaa, snake bite, gonorrhea, leucorrhrea | Drink the powdered solution; applied the paste | [1,136]  |
|                         | India, Nepal | Bark | Wounds, diarrheaa, digestive disorder, heartburn, kidney stone         | Paste, Juice                      | [1,136,137]     |
|                         | India, Pakistan | Stem, root | Acne, skin blemishes, pimples                                         | Powder                            | [136,137]  |
|                         | India, Pakistan | Root | Diabetes                                                               |                                   | [129,137]  |
|                         | China    | Bark, root | Muscular injury                                                        |                                   | [137]     |
|                         | Bangladesh | Seeds, roots | Leprosy                                                                |                                   | [137]     |
|                         | India    | Fruits     | Urolithiasis                                                           | Oral administration              | [129]     |
|                         | India    | Gum        | Asthma, piles, diarrheaa and dysentery, dental caries, scabies         |                                   | [1]       |
|                         | India    | Flower     | Hematuria, anemia, leucorrhrea, hydrocoele, gonorrhea, menstrual disorders, boils and sores |                                   | [1]       |
| Bombax ceiba L.         | India    | Bark       | Dysentery                                                              | Tea                               | [122]     |
| Bombax insignis Wall.   | India    | Bark       | Venereal disease, constipation, infections                             |                                   | [122]     |
| Bombax buonopozense P. Beauv. | Africa | Leaves | Venereal disease, constipation, infections                             |                                   | [122]     |
| Senegal, Sierra Leone, Burkina Faso | Bark | Diuretic properties, dysentery, epilepsy |                                   |                                   | [109,122]     |
| Senegal                | Leaves   | Oedema, snake bite, convulsions, measles                              | Extract, decoction, paste         |                                   | [109,121]  |
Table 5. Cont.

| Species | Country | Parts Used | Disease | Mode of Usage | Reference |
|---------|---------|------------|---------|---------------|-----------|
| Bombax rhodognaphalon K. Schum. | Tanzania, Mozambique | Bark | Diarrhea | | [122] |
| Catostemma fragrans Benth. | Guianas | Bark | Fever | Decoction | [138] |
| Catostemma commune Sandwith | Guianas | Seed | Snoring | | [138] |
| Cavanillesia plataniifolia (Humb. & Bonpl.) Kunth | South America, Peru | Bark, oil | Underweight | Infusion | [111,122] |
| Ceiba pentandra (L.) Gaertn. | South America | Immature fruits, roots, leaves barks | Cough, hair shampoo; component of ayahuasca, psychoactive drugs | | [15,32] |
| | Java | Leaves | Intestinal catarrh and urethritis, gonorrhea | Infusion | [15] |
| | Congo | Bark | Management of sickle cell anemia | Aqueous extracts | [139] |
| Ceiba ventricosa (Nees & Mart.) Ravenna | Brazil | Bark | Vomitive and aphrodiastic | Decoction | [15] |
| Chiranthodendron pentadactylon Larreat. | Mexico | Flowers | Gastrointestinal disorder, diarrhea, dysentery, blood pressure | Infusion | [122] |
| Eriotheca globosa (Aubl.) A.Robyns | South America | Ripe fruits | Cuts, wounds | Application | [122] |
| Fremontodendron californicum (Torr.) Coul. | North America | Bark | Throat irritation | Infusion | [122] |
| Huberodendron patinoi Cuatrec. | Colombia | Bark | Leishmaniasis | | [140] |
| Huberodendron swietenioides (Gleason) Ducke | Ecuador | Leaves | Diabetes | Aqueous infusion | [124] |
| Matisia glandifera Planch. & Triana | Colombia | Bark, leaves | Malaria | | [141] |
| Ochroma pyramidale (Cav. ex Lam.) Urb. | Brazil | Root bark | Emetic | | [142] |
| Pachira aquatica Aubl. | Nicaragua | Bark | Stomach complaint, headache | | [15] |
| Pachira glabra Pasq. | India | Leaf | Blood pressure, Anemia | | [122] |
| Pseudobombax ellipticum (Kunth) Dugand | Guatemala | Bark | Cough and catarrh | Decoction | [143] |
| Pseudobombax grandiflorum (Cav.) A.Robyns | Brazil | Bark | Wound healing | Decoction | [144] |
| Quararibea cordata (Bonnpl.) Vischer | South America | | Astringent, tonic, antiseptic, for skin infections | | [122] |
| Quararibea funebris (La Llave) Vischer | South America | Flowers | Hallucinogenic, psychopathic fears | | [40] |
| Scleronema micranthum (Ducke) Ducke | Brazil | Leaf | Toothache | | [145] |
10. Pharmacological Potential of Bombacoideae

The different species, viz. *Adansonia digitata*, *Bombax ceiba*, *B. malabaricum*, and *Ceiba pentandra* of the Bombacoideae family [136,146], were reported for their various pharmacological potentials, which are summarized in the following section (Table 6; Figure 5).

Table 6. Pharmacological studies on some of the plant species of Bombacoideae subfamily.

| Plant Species and Part | Part(s) and Solvent | Assay | Results | References |
|-----------------------|---------------------|-------|---------|------------|
| *Adansonia digitata* L. | Methanolic leaf extracts; ethanolic leaf | *In vitro* DPPH, ABTS, FRAP, β-carotene bleaching test, superoxide scavenging assay; CAT and SOD, and GSH assay | The DPPH scavenging activity recorded highest in seed extract (27.69%) and lowest in fruit wall (20.69%) extract. The antioxidant status of the STZ induced diabetic rats are normalized by reducing the elevated levels of reduced glutathione (GSH) superoxide dismutase (SOD), and catalase (CAT) | [50,147–150] |
| *Bombax malabaricum* DC. | Methanolic fruit extracts; | DPPH, ABTS, FRAP assay, β-carotene bleaching test, superoxide scavenging assay | Scavenge the DPPH free radicals with the percentage of inhibition of 13.4, 29.23, and 39.21%, respectively | [50,149] |
| *Bombax ceiba* L. | n-hexane and methanol extracts of flower | DPPH radical scavenging, lipid peroxidation, myeloperoxidase activity | Scavenged DPPH radicals over a concentration range of 0.55–0.0343 mg/mL and 0.5–0.0312 mg/mL, respectively | [49,151] |
| *Bombax ceiba* L. | Methanolic root; aqueous soluble partitioned of the methanolic root; methanol, dichloromethane, and petroleum ether extracts of roots | The extract exhibited dose-dependent DPPH and reducing power assay. Phenolic constituents donate OH leading to resonance stabilization | Methanolic root extract could scavenge DPPH radicals, lipid peroxidation, and ascorbyl radicals with an EC$_{50}$ value of 87 µg/mL | [152–155] |
| *Bombax ceiba* L. | Aqueous and ethanolic bark Methanolic stem bark | DPPH, ABTS, nitric oxide and superoxide radical scavenging activity, lipid peroxidation, metal chelating, and total antioxidant capacity | Inhibited lipid peroxidation in rat liver microsome induced by ascorbyl and peroxynitrite radicals with an IC$_{50}$ value of 141 µg/mL and 115 µg/mL, respectively | [156,157] |
| *Bombax ceiba* L. | Methanolic extract of the whole plant | DPPH scavenging assay | IC$_{50}$ values of aqueous extracts of *B. ceiba* varied between 85.71 and 102.45 µg/mL and for ethanolic extract, it varied between 85.48 and 103.4 µg/mL | [158] |
| *Bombax ceiba* L. | Diethyl ether and light petroleum ether extracts of flowers; Aqueous flower extracts; Methanolic flower extracts | DPPH, metal chelating and beta carotene bleaching test, hydroxyl radical, hydrogen peroxide radical, FRAP assay, reducing power assay | Petroleum ether of *B. ceiba* flowers exhibited DPPH and Fe-chelating activities with IC$_{50}$ values of 37.6 and 33.5 µg/mL and diethyl ether extracts exhibited beta-carotene bleaching test with an IC$_{50}$ value of 58.3 µg/mL | [80,159–162] |
| *Bombax ceiba* L. | the aqueous methanol extract of the calyx | Methyglyoxal induced oxidative stress in HEK-293 cells | Reduced the level of reactive oxygen species (ROS), NADPH oxidase (NOX), and thereby lowered the mitochondrial dysfunction in methylglyoxal induced protein glycation | [163] |
### Table 6. Cont.

| Plant Species and Part | Part(s) and Solvent                                                                 | Assay                                      | Results                                                                                                                                   | References |
|------------------------|-----------------------------------------------------------------------------------|--------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|------------|
| **Antioxidant activity** |                                                                                   |                                            |                                                                                                                                          |            |
| **Ceiba pentandra (L.)** Gaertn | seed extracts                                                                     | DPPH, FRAP, reducing assay, and hydroxyl radical scavenging assay | Decoction, maceration, and methanol scavenged DPPH radical with IC<sub>50</sub> values of 87.84, 54.77, and 6.15 µg/mL, respectively.     | [164]      |
|                        | Methanol extracts of stem bark; ethyl acetate fraction of stem bark                 | hydroxyl radical, against lipid peroxidation; DPPH radical scavenging | Scavenge DPPH, nitric oxide, and hydroxyl radicals with IC<sub>50</sub> values of 27.4, 24.45, and 51.65 µg/mL.                           | [165,166]  |
|                        | ethanol leaf extract; aqueous and methanol extracts of stem bark                    | DPPH, nitric oxide, and hydroxyl radical scavenging | The aqueous and methanol stem bark extracts inhibited superoxide (IC<sub>50</sub> values of 51.81 and 34.26 µg/mL), hydrogen peroxide (44.84 and 1.76 µg/mL) and protein oxidation induced by H<sub>2</sub>O<sub>2</sub> (120.60 and 140.40 µg/mL). | [167,168]  |
| **Antimicrobial activity** |                                                                                   |                                            |                                                                                                                                          |            |
| **Adansonia digitata L.** | Methanolic, ethanolic leaf, and stem bark extracts                                  | agar well diffusion method                 | The order of sensitivity from highest to least was Staphylococcus aureus > Escherichia coli > Pseudomonas aeruginosa > Bacillus subtilis > Salmonella typhi. | [169]      |
|                        | Methanolic stem bark                                                               | Agar well diffusion method                |                                                                                                                                          | [157]      |
| **Bombax ceiba L.**    | Methanolic flower extracts                                                         | Agar disc diffusion assay and MIC study.  | Exhibited antibacterial activity against Klebsiella pneumonia, E. coli, P. aeruginosa, S. aureus, B. subtilis, S. aureus, B. cereus, P. aeruginosa, Salmonella typhi, E. coli, Vibrio mimicus, Shigella boydii, and Shigella dysenteriae with 7–13 mm zone of inhibition | [38,161]  |
|                        | methanol, dichloromethane, and petroleum ether extracts of roots                   | Agar disc diffusion assay                 | The methanol, dichloromethane, and PE extracts exhibited mild to moderate antibacterial activity against different bacterial strains including Sarcina lutea, Bacillus megaterium, B. subtilis, S. aureus, B. cereus, P. aeruginosa, Salmonella typhi, E. coli, Vibrio mimicus, Shigella boydii, and Shigella dysenteriae with 7–13 mm zone of inhibition | [155]      |
| **Bombax malabaricum DC.** | n-hexane and methanol extracts of flower                                           | Agar disc diffusion method                | n-hexane and methanol extracts (at 100 µg/mL) of demonstrated antimicrobial activities                                                | [49]       |
| **Ceiba pentandra (L.)** Gaertn | Ethyl acetate fraction of leaf and bark; ethanol leaf extract                      | Agar dilution method                      | ethyl acetate fraction of leaf and bark of C. pentandra showed antimicrobial activity against E. coli, Salmonella typhi, B. subtilis, Klebsiella pneumonia, and S. aureus | [167,170] |
|                        | aqueous, methanol, ethanol, and acetone extract of seed                            | Disc diffusion method                     | dose-dependently inhibits antibacterial activity against E. coli and S. aureus                                                          | [171]      |
| Plant Species and Part | Part(s) and Solvent | Assay                          | Results                                                                 | References |
|-----------------------|--------------------|-------------------------------|------------------------------------------------------------------------|------------|
| **Adansonia digitata** L. | seed and pulp extracts | MTT assay                     | At 10, 100, and 500 µg/mL dose, the inhibition ranges between 22.57 and 29.96% for MCF-7 cell line; 25.85 and 37.81% for Hep-G2 cell line and 20.75 and 27.34% for COLO-205 cell line. Dichloromethane and methanolic extract demonstrated cytotoxic activity against human breast development cell lines BT474 with IC\textsubscript{50} value of 15.3 ± 0.4 µg/mL. | [172] |
| **Bombax ceiba** L. | diethyl ether and light petroleum ether extracts of flowers | sulfurhodamine B (SRB) assay, brine shrimp lethality bioassay | Antiproliferative activity against human renal adenocarcinoma cell (ACHN) with respective IC\textsubscript{50} values of 53.2 and 45.5 µg/mL. The petroleum ether, dichloromethane, and methanolic extracts of B. ceiba roots exhibited cytotoxic effect with IC\textsubscript{50} values of 22.58, 37.72, and 70.72 µg/mL, respectively. | [80] |
| **Ceiba pentandra** (L.) Gaertn | petroleum and acetone stem bark extracts | Dalton’s lymphoma ascites (DLA or solid tumor) model | At 15 and 30 mg/kg doses could reduce tumor weight by >50% and tumor volume on the 30th day in Dalton’s lymphoma ascites. The petroleum ether, benzene, chloroform, acetone, and ethanolic extract of this plant demonstrated cytotoxicity in a concentration dependent manner after 3 h of incubation with EAC cells with EC\textsubscript{50} values of 53.30, 70.58, 250.48, 67.30, and 56.11 µg/mL, respectively. | [50,148,150,173] |
| **Bombax ceiba** L. | dichloromethane, ethanol, and aqueous extracts of thalamus and flower; n-hexane fraction of sepals | Alpha-amylase and alpha-glucosidase inhibition assay | The IC\textsubscript{50} values for alpha amylase inhibition for water extract of thalamus, ethanolic extract of thalamus, ethanolic extract of flower, dichloromethane extract of thalamus, water extract of flower, and dichloromethane extract of flower were 32.95, 33.45, 33.85, 33.85, 34.95, 35.13, and 35.65 µg/mL, respectively. | [174,175] |
| **Bombax ceiba** L. | ethanolic root extracts | Alloxan induced diabetic rat | At 400 mg/kg decreased the blood glucose level in diabetic mice | [176] |
| **Ethanolic leaf extracts** | STZ- induced diabetic mice | Ethanolic leaf extracts | At 70, 140, and 280 mg/kg doses it decreased fasting blood glucose, glycosylated hemoglobin in diabetic rats | [177] |
| **Bark extracts** | STZ- induced diabetic rats | At 600 mg/kg dose the extract could significantly decrease elevated levels of blood glucose in diabetic rats. | [178] |
| Plant Species and Part | Part(s) and Solvent | Assay | Results | References |
|------------------------|---------------------|-------|---------|------------|
| **Anticancer activity** |                     |       |         |            |
| *Ceiba pentandra* (L.)*Gaertn* | Aqueous stem bark extracts; aqueous (AE) and methanol (ME) extracts of bark | Dexamethasone-induced insulin resistant rats; STZ- induced diabetic rats; Alpha-amylase and alpha-glucosidase assay | At 75 or 150 mg/kg doses could decrease the level of glycemia in insulin resistant rats. Aqueous stem bark extracts of inhibited alpha-amylase and glucosidase with IC<sub>50</sub> values of 6.15 and 76.61 µg/mL, respectively, whereas the methanol extract inhibited alpha-amylase and glucosidase with IC<sub>50</sub> values of 54.52 and 86.49 µg/mL, respectively. | [165,168,179,180] |
| **Anti-inflammatory activity** |                     |       |         |            |
| *Adansonia digitata* L. | methanol leaf extracts, aqueous leaf extract | iNOS and NF-κB expression in LPS-stimulated RAW264.7 cell | Inhibit NO production with an IC<sub>50</sub> value of 28.6 µg/mL. | [181] |
|                      | fruit pulp extract | inhibition of proinflammatory cytokine IL-8 expression | Leaf extract (70 µg/mL) exhibited better anti-inflammatory activity when compared to pulp extract (247 µg/mL). | [182] |
| *Bombax ceiba* L. | Petroleum ether, ethanol, and aqueous extracts | HRBC membrane stabilization method. | At 1000 µg/mL concentration exhibited anti-inflammatory potential by stabilizing the HRBC membrane | [183] |
| *Ceiba pentandra* (L.)*Gaertn* | ethyl acetate extract of aerial part | MTX-induced nephrotoxic rats | At 400 mg/kg dose could inhibit methotrexate (MTX)-initiated apoptotic and inflammatory cascades. | [184] |
| **Hepatoprotective activity** |                     |       |         |            |
| *Adansonia digitata* L. | aqueous extract of fruit; methanolic extract of the fruit | CCL<sub>4</sub> induced hepatotoxic rats; paracetamol-induced hepatotoxicity in rats | Reduction in serum AST, ALT, ALP, bilirubin levels were observed in carbon tetrachloride (CCL<sub>4</sub>) induced hepatotoxic rats. Level of ALT, AST, ALP, total bilirubin, and total protein measurements were normalized in paracetamol-induced hepatotoxic rats. | [185–189] |
| *Bombax ceiba* L. | Aqueous flower extracts; Methanolic flower extracts | Histological studies; enzyme assay alkaline phosphates, alanine transaminases, aspartate transaminases, and total bilirubin assay | Decreased elevated levels of glutamic-oxaloacetic transaminase (SGOT), glutamic pyruvic transaminase (SGPT), alkaline phosphatize (ALP), bilirubin, and triglycerides, total protein. | [159,190] |
|                      | ethanolic root extracts | Enzyme assay in alloxan induced diabetic mice | At 400 mg/kg decreased the hepatotoxicity in diabetic mice by reducing the elevated levels of SGOT and SGPT | [176] |
| *Ceiba pentandra* (L.)*Gaertn* | the methanol extract of stem bark | Enzyme assay paracetamol-induced liver damage in rats | Reduces levels of SGOT, SGPT, ALP, and total bilirubin content. | [191] |
10.1. Antioxidant Properties

*Adansonia digitata* L.

The methanolic fruit pulp and leaf extracts of *A. digitata* exhibited in vitro antioxidant activities as studied by 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH), 2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonate) (ABTS), ferric reducing antioxidant power (FRAP), β-carotene bleaching test, superoxide-scavenging assays [50,150]. The methanol extracts of leaf, seed, bark, fruit wall, and floral extracts of *A. digitata* were reported for their DPPH scavenging potential [147]. The DPPH scavenging activity was highest in seed extract (27.69%) and lowest in fruit wall (20.69%) extract. The methanolic leaf extract of *A. digitata* could maintain the antioxidant status of the streptozotocin (STZ) induced diabetic rats by normalizing the elevated levels of reduced glutathione (GSH) superoxide dismutase (SOD), and catalase (CAT) [148]. The ethanolic leaf, bark, and fruit extracts of *A. digitata* could scavenge the DPPH free radicals with percentages of inhibition of 13.4, 29.23, and 39.21%, respectively [149].

*Bombax ceiba* L.

The methanolic root extract of *Bombax ceiba* could scavenge DPPH radicals, lipid peroxidation, and ascorbyl radicals with an EC50 value of 87 µg/mL. The extract also inhibited lipid peroxidation in rat-liver microsome induced by ascorbyl and peroxynitrite radicals with IC50 values of 141 µg/mL and 115 µg/mL, respectively [192]. In another study, the methanol root extract of *B. ceiba* scavenged DPPH radical with an EC50 value of 15.07 µg. The extract also could reduce the Fe3+ to Fe2+ in a dose-dependent manner with the maximum activity at 500 µg. The study also demonstrated that the administration of 3 g root powder could raise the antioxidant status in the human volunteer. The antioxidant activity properties of the root extract are attributed to their high phenolic and tannin contents [152]. The aqueous soluble partition (AQSF) of the methanolic root extracts of *B. ceiba* scavenged DPPH radical with an IC50 value of 3.33 µg/mL [153]. Further, the methanol and petroleum ether root extract of *B. ceiba* was reported to scavenge DPPH radical with IC50 values of 144.77 and 214.83 µg/mL [155]. The methanolic stem bark extract of *B. ceiba* exhibited antiradical activity with EC50 values of 18.78, 23.62, and 139.4 µg/mL for nitric oxide, DPPH, and reducing power activity assay, respectively [193]. Similarly, Hossain et al. [154] reported the antioxidant activity of methanolic root extract of *B. ceiba* by DPPH scavenging assay (IC50 value of 58.6 µg/mL). Gandhare et al. [156] reported that aqueous and ethanolic extracts of the *B. ceiba* bark exhibited DPPH, ABTS, nitric oxide, and superoxide radical scavenging activity along with total antioxidant activity. Besides the
extract also inhibited lipid peroxidation and reduced ferric ions. The IC\textsubscript{50} values of aqueous extracts of \textit{B. ceiba} varied between 85.71 and 102.45 \(\mu\)g/mL, and for ethanolic extract, it varied between 85.48 and 103.4 \(\mu\)g/mL. Komati et al. [163] reported that aqueous methanol extract of \textit{B. ceiba} calyx reduced the level of reactive oxygen species (ROS), NADPH oxidase (NOX), and thereby lowered the mitochondrial dysfunction in methylglyoxal induced protein glycation. Further, in HEK-293 cells, Mn and Cu/Zn-superoxide dismutase and glutathione reductase antioxidant enzymes levels were improved. The whole plant methanolic extract of \textit{B. ceiba} scavenged DPPH radical with an IC\textsubscript{50} value of 68 \(\mu\)g/mL [158].

The petroleum ether (PE) of \textit{B. ceiba} flowers exhibited DPPH and Fe-chelating activities with IC\textsubscript{50} values of 37.6 and 33.5 \(\mu\)g/mL and diethyl ether extracts (DE) exhibited beta-carotene bleaching test with an IC\textsubscript{50} value of 58.3 \(\mu\)g/mL. The antioxidant properties of \textit{B. ceiba} flower extracts are attributed to the presence of beta-sitosterol and some fatty acids [80]. Similarly, another study reported that aqueous flower extracts of \textit{B. ceiba} could scavenge DPPH radicals with an IC\textsubscript{50} value of 50.21 \(\mu\)g/mL [159]. The aqueous flower extracts of \textit{B. ceiba} exhibited antioxidant activities against DPPH, hydroxyl, hydrogen peroxide, and ferric ion reducing antioxidant power (FRAP) activity with IC\textsubscript{50} values of 1.70 mg/mL, 4.20 mg/mL, 3.51 mg/mL, and 2.15 mg/mL, respectively [160]. The hexane, benzene, chloroform, ethyl acetate, acetone, methanol, and ethanol extracts prepared from methanolic flower extract of \textit{B. ceiba} exhibited DPPH scavenging activity [161]. The hexane, chloroform, and methanolic extracts prepared from dried powder extracts of \textit{B. ceiba} flower exhibited antioxidant activity in terms of FRAP, DPPH, and reducing power assay [162].

\textit{Bombax malabaricum} DC.

The n-hexane and methanol flower extracts of \textit{B. malabaricum} scavenged DPPH radicals over a concentration range of 0.55–0.0343 mg/mL and 0.5–0.0312 mg/mL, respectively. The maximum DPPH scavenging was observed in the range of 0.55–0.5 mg/mL for both extracts [49]. The antioxidant potential of flower extract was attributed to the presence of bioactive constituent, viz. apigenin, cosmetin, xanthomicrol, saponarin, vicenin 2, isovitexin, and linarin. Similarly, in another study, the aqueous, acetone, and ethanol flower extracts of \textit{B. malabaricum} flowers showed DPPH radical-scavenging properties along with Oxygen radical absorbance capacity (ORAC), reducing power, and liposome peroxidation inhibition activities [151].

\textit{Ceiba pentandra} L.

The different stem bark extracts of \textit{C. pentandra} such as decoction, maceration, and methanol scavenged DPPH radical with IC\textsubscript{50} values of 87.84, 54.77, and 6.15 \(\mu\)g/mL, respectively. The extracts also restrained the \(\text{H}_2\text{O}_2\)-induced hemolysis and lipid peroxidation [165]. The Soxhlet seed oil extracts at 100 mg/mL concentration of \textit{C. pentandra} exhibited DPPH, and OH radical scavenging along with FRAP, reducing power activities by 47.65%, 39.69%, and 309 FRAP units, and 20.52 \(\mu\)g of ascorbic acid equivalent, respectively [193]. The in vitro antioxidant evaluation of \textit{C. pentandra} ethanol leaf extract demonstrated that the extract could scavenge DPPH, nitric oxide, and hydroxyl radicals with IC\textsubscript{50} values of 27.4, 24.45, and 51.65 \(\mu\)g/mL, respectively. The Gas chromatography-mass spectrometry (GC-MS) study revealed the presence of 9 compounds, amongst which, hexadecanoic acid was found to be the most prominent compound [167]. In another study, Fitria et al. [166] demonstrated that a compound vavain or 5, 3′-dihydroxy-7, 4′, 5′-trimethoxyisoflavone isolated from the ethyl acetate fraction of stem bark of \textit{C. pentandra} could scavenge DPPH radical with IC\textsubscript{50} value of 81.66 \(\mu\)g/mL. However, the ethyl acetate extract of the aerial part of \textit{C. pentandra} scavenged the DPPH radicals with an IC\textsubscript{50} value of 0.0716 mg/mL [184]. The aqueous and methanol stem bark extracts of \textit{C. pentandra} inhibited superoxide (\(\text{O}_2^-\)) (IC\textsubscript{50} values of 51.81 and 34.26 \(\mu\)g/mL), hydrogen peroxide (44.84 and 1.78 \(\mu\)g/mL), and protein oxidation induced by \(\text{H}_2\text{O}_2\) (120.60 and 140.40 \(\mu\)g/mL) [168].
10.2. Anti-Inflammatory Activity

*Adansonia digitata* L.

The methanol leaf extracts of *A. digitata* reduced iNOS and NF-κB expression in LPS-stimulated RAW264.7, thereby showing its anti-inflammatory potential [181]. The extract could inhibit NO production with an IC$_{50}$ value of 28.6 µg/mL. Similarly, the Dimethyl sulfoxide (DMSO) fruit pulp and aqueous leaf extract of *A. digitata* inhibited expressions of proinflammatory cytokine IL-8 [182]. The leaf extract (70 µg/mL) exhibited better anti-inflammatory activity compared to pulp extract (247 µg/mL).

*Bombax ceiba* L.

The petroleum ether, ethanol, and aqueous bark extracts of *B. ceiba* at 1000 µg/mL concentration exhibited anti-inflammatory potential by stabilizing the Human red blood cell (HRBC) membrane. Amongst the different solvent extracts, better anti-inflammatory activity is shown by ethanol extract followed by aqueous and petroleum ether extract [183].

*Ceiba pentandra* (L.) Gaertn

The ethyl acetate extracts of aerial parts of *C. pentandra* upon oral administration at 400 mg/kg dose could inhibit methotrexate (MTX)-initiated apoptotic and inflammatory cascades. The extract could improve the architecture of histopathological changes observed in the renal tissue of MTX-induced nephrotoxic rats [184].

10.3. Antimicrobial Activity

*Adansonia digitata* L.

The methanolic and ethanolic leaf and stem bark extracts of *A. digitata* inhibited the growth of *S. aureus* and *E. coli* at different concentrations, viz, 100, 200, 500, and 1000 mg/mL with a minimum bactericidal concentration (MIC) at 100 mg/mL [169].

*Bombax ceiba* L.

The methanolic stem bark extract of *B. ceiba* could inhibit the growth of both Gram-negative (*Escherichia coli, Pseudomonas aeruginosa, and Salmonella typhi*) and Gram-positive bacteria (*Bacillus subtilis, Staphylococcus aureus*) dose-dependently. The order of sensitivity from highest to lowest was *S. aureus* > *E. coli* > *P. aeruginosa* > *B. subtilis* > *S. typhi* [157]. The methanolic flower extract of *B. ceiba* exhibited antibacterial activity against *Klebsiella pneumonia*, *E. coli*, *P. aeruginosa* (Gram-negative), and *S. aureus*, *B. subtilis* (Gram-positive) bacteria with the MIC value ranging between 3.125 and 12.500 µg/mL [161]. The methanol, dichloromethane, and PE extracts of *B. ceiba* roots exhibited mild to moderate antibacterial activity against different bacterial strains including *Saccharomyces lutea*, *Bacillus megaterium*, *B. subtilis*, *S. aureus*, *B. cereus*, *P. aeruginosa*, *Salmonella typhi*, *E. coli*, *Vibrio mimicus*, *Shigella boydii*, and *S. dysenteriae* with a 7–13 mm zone of inhibition [155].

*Bombax malabaricum* DC.

The n-hexane and methanol extracts (at 100 µg/mL) of *B. malabaricum* demonstrated antimicrobial activities against Gram-positive (*E. coli, Neisseria gonorrhoeae, P. aeruginosa*), Gram-negative (*S. aureus, B. subtilis, Streptococcus faecalis*), and fungi (*Aspergillus niger, A. flavus Candida albicans*). Of the two extracts, the methanol extract showed better activity against all the studied bacterial strains and *C. albicans*. Further, only the methanol extract exhibited moderate activities against *A. niger* and *A. flavus* [49].

*Ceiba pentandra* (L.) Gaertn

The ethyl acetate fraction of leaf and bark of *C. pentandra* showed antimicrobial activity against *E. coli, Salmonella typhi, B. subtilis, Klebsiella pneumonia*, and *S. aureus* [170]. Similarly, aqueous, methanol, ethanol, and acetone seed extracts of *C. pentandra* exhibited antimicrobial activity against *E. coli, S. aureus, K. pneumonia, Enterobacter aerogenes*, *P. aeruginosa, Salmonella typhimurium, S. typhi, Staphylococcus epidermidis*, and *Proteus vulgaris* [171]. Another study revealed that ethanol leaf extract of *C. pentandra* dose-dependently inhibits antibacterial activity against *E. coli* and *S. aureus* [167].
10.4. Anticancer and Cytotoxicity Activity

Adansonia digitata L.

The seed and pulp extracts of *A. digitata* (at 10, 100, and 500 µg/mL) exhibited anticancer activity against MCF-7 (breast cancer cell), Hep-G2 (liver cancer cell), and COLO-205 (colon cancer cell) in a dose dependent manner [172]. The results of the MTT study revealed that the inhibition ranges between 22.57 and 29.96% for MCF-7 cell line; 25.85 and 37.81% for Hep-G2 cell line, and 20.75 and 27.34% for COLO-205 cell line. The dichloromethane and methanolic leaf extracts of *A. digitata* demonstrated cytotoxic activity against human breast development cell lines BT474 evaluated by MTT assay. The methanol leaves of the plant exhibited moderate cytotoxic activity (56%) against the BT474 cell line with IC \(_{50}\) values of 15.3 ± 0.4 µg/mL [185].

Bombax ceiba L.

The diethyl ether and light petroleum ether extracts of *B. ceiba* flowers exhibited antiproliferative activity against human renal adenocarcinoma cell (ACHN) with respective IC \(_{50}\) values of 53.2 and 45.5 µg/mL. The antiproliferative properties were attributed to the presence of beta-sitosterol and some fatty acids in *B. ceiba* flowers [80]. The brine shrimp lethality bioassay revealed that the petroleum ether, dichloromethane, and methanol extracts of *B. ceiba* roots exhibited cytotoxic effect with LC \(_{50}\) values of 22.58, 37.72, and 70.72 µg/mL, respectively [155].

Ceiba pentandra (L.) Gaertn

The petroleum and acetone stem bark extracts of *C. pentandra* at 15 and 30 mg/kg doses could reduce tumor weight by >50% and tumor volume on the 30th day in Dalton’s lymphoma ascites (DLA) model [173]. Similarly, both these extracts of *C. pentandra* exhibited cytotoxic effects against Ehrlich ascites carcinoma (EAC) cells as evaluated by trypan blue assay [173]. At 15 mg/kg doses, both the extracts showed improvement in mean survival time and decline in tumor induced increase in body weight. Further, the petroleum ether, benzene, chloroform, acetone, and ethanolic extract of this plant demonstrated cytotoxicity in a concentration dependent manner after 3 h of incubation with EAC cells with EC \(_{50}\) values of 53.30, 70.58, 250.48, 67.30, and 56.11 µg/mL, respectively.

10.5. Hepatoprotective Activity

Adansonia digitata L.

The aqueous fruit pulp extract of *A. digitata* showed hepatoprotective potential in carbon-tetrachloride (CCL\(_4\))-induced hepatotoxic rat models as significant reductions in serum aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatize (ALP), and bilirubin levels were observed in extract-treated hepatotoxic rats [186,187]. The liver protection potential could be attributed to the presence of triterpenoids, β-sitosterol, β-amyrin palmitate, and α-amyrin or without, and ursolic acid in the fruit pulp [188]. The methanolic fruit pulp extract of *A. digitata* exhibited hepatoprotective potential in paracetamol-induced hepatotoxic rat models. The disturbances in the liver function such as ALT, AST, ALP, total bilirubin, and total protein measurements of the hepatotoxic rats were normalized due to the administration of paracetamol [189].

Bombax ceiba L.

The hepatoprotective property of aqueous [159] and methanolic [190] flower extracts of *B. ceiba* was studied in CCl\(_4\)-induced hepatotoxic rats. Treatment with extracts decreased elevated levels of glutamate oxaloacetate transaminase (SGOT), glutamic pyruvic transaminase (SGPT), alkaline phosphatize (ALP), bilirubin, triglycerides, and total protein. Treatment with the extract further attenuated the damage caused to the liver as seen by histological studies. The young roots of *B. ceiba* exhibited hepatoprotective activities in alloxan induced diabetic mice. Administration of ethanolic root extracts at 400 mg/kg decreased the hepatotoxicity in diabetic mice by reducing the elevated levels of SGOT and SGPT [176].
Ceiba pentandra (L.) Gaertn

The ethyl acetate fraction of methanolic stem bark extract of *C. pentandra* exhibited a hepatoprotective effect against paracetamol-induced hepatotoxic rats by reducing the serum enzyme levels of SGOT, SGPT, ALP, and total bilirubin content [191].

10.6. Antidiabetic Activity

*Adansonia digitata* L.

The methanolic fruit pulp and leaf extracts of *A. digitata* exhibited in vitro antidiabetic activities by inhibiting the digestive enzyme α-glucosidase dose-dependently [50]. The IC\(_{50}\) values of the fruit extracts ranged between 1.71 ± 0.23 and 2.39 ± 0.22 µg/mL while the leaf extract had an IC\(_{50}\) value of 1.71 ± 0.23 µg/mL. Similarly, the methanolic leaf extract of this plant inhibited α-amylase, α-glucosidase, and aldolase reductase [150]. The antidiabetic potency of the extracts may be attributed to the presence of catechin, epicatechin, rutin, quercitrin, quercetin, kaempferol, luteolin (flavonoids), gallic, chlorogenic, caffeic, and ellagic acids (phenolic acids). The methanolic leaf extract of *A. digitata* reduced the elevated blood glucose, glycosylated hemoglobin levels in streptozotocin (STZ)-induced diabetic rats [148].

*Bombax ceiba* L.

The dichloromethane, ethanol, and aqueous thalamus and flower extracts of *B. ceiba* were reported for their antidiabetic properties in terms of their capacity to inhibit alpha-amylase and alpha-glucosidase enzymes under in vitro condition. The corresponding IC\(_{50}\) values for alpha-amylase inhibition activities for thalamus were 36.22 µg/mL (dichloromethane extract), 35.32 µg/mL (ethanolic extract), and 31.31 µg/mL (aqueous extract) and for flowers, 38.13 µg/mL (dichloromethane extract), 35.23 µg/mL (ethanolic extract), and 33.00 µg/mL (aqueous extract) [174]. The n-hexane fraction of sepals [175] and ethanolic leaf extracts [177] of *B. ceiba* exhibited antidiabetic activities in STZ-induced diabetic rats. The n-hexane fraction at 0.1 gm/kg bw, b.d. dose reduced the fasting blood sugar level and restored the levels of serum insulin, Hb, and glycated hemoglobin in diabetic rats. Histological studies of also showed marked improvement in diminution in the area of the islets of Langerhans of pancreases in diabetic rats treated with the plant extracts [175]. Similarly, the leaf extract of *B. ceiba* (at 70, 140, and 280 mg/kg doses) decreased the fasting blood glucose, glycosylated hemoglobin, and increased the oral glucose tolerance in the STZ-induced diabetic mice. Administration of ethanolic root extracts at 400 mg/kg decreased blood glucose levels in diabetic mice as compared to untreated diabetic mice at different time points (0–24 h). [176]. However, at 600 mg/kg dose the extract could significantly decrease elevated levels of blood glucose in diabetic rats [178].

*Ceiba pentandra* (L.) Gaertn

The aqueous stem bark extracts of *C. pentandra* exhibited antihyperglycemic, insulin-sensitizing potential, and cardioprotective effects in dexamethasone-induced insulin-resistant rats. Extracts of both 75 or 150 mg/kg doses could decrease the level of glycemia [179]. The decoction extracts of stem bark of *C. pentandra* decreased glucose level by increasing glucose uptake in the liver and skeletal muscle cells by 56.57% and 94.19%, respectively. The extract also reduced the glucose release in liver cells by 33.94% in a hypoglycemic milieu [165]. The ethanolic bark extract of *C. pentandra* at 200 mg/kg dose exhibited antihyperglycemic activity in STZ-induced diabetic rats by decreasing the levels of blood glucose, total cholesterol, and triglycerides, preventing degeneration of liver and pancreas, and increasing serum insulin and liver glycogen content [180]. The aqueous stem bark extracts of *C. pentandra* inhibited alpha-amylase and glucosidase with IC\(_{50}\) values of 6.15 and 7.61 µg/mL, respectively, whereas the methanol extract inhibited alpha-amylase and glucosidase with IC\(_{50}\) values of 54.52 and 86.49 µg/mL, respectively [168].
10.7. Miscellaneous Activities

The petroleum ether and methanol extract from *B. ceiba* stem bark displayed increased osteogenic activity as demonstrated by Chauhan et al. [37] in UMR-106 cells and surgical ovariectomy models in female Wistar albino rats. It has been reported that the administration of the extracts for 28 days ameliorated the consequences of ovariectomy-induced bone porosity, restoring the normal architecture of bone in experimented rats. The in vitro osteogenic activity of the extracts could be attributed to the presence of lupeol, gallic acid, and β-sitosterol in *B. ceiba*.

Komati et al. [163] reported the antiglycation properties of aqueous methanolic calyx extract of *B. ceiba* in methylglyoxal-induced protein glycation and oxidative stress in HEK-293 cells. The extract could inhibit advanced glycation end products (AGEs) formation and restrained Receptor for advanced glycation end products (RAGE) up-regulation in HEK-293 cells.

The aqueous and crude ethanol fruit extracts of *B. ceiba* exhibited diuretic effects in rats. Both aqueous and ethanol extracts could increase the urine output in the rats. The aqueous extract increased the urinary Na+ and K+ levels demonstrating the diuretic effect of the extracts [194]. The ethanolic leaf, bark, and fruit extracts of *A. digitata* exhibited antipyretic activity in albino rats at 400 and 800 mg/kg doses [149].

11. Mechanism of Action of Extracts and Bioactive Compounds of the Plants’ Species with Pharmacological Properties

The different plant species of Bombacoideae are well known for their medicinal properties and can act as a useful bio-resource for medicines, nutraceuticals, pharmaceuticals, and chemical analogs for synthetic drugs. Bombacoideae plant species contain several bioactive phytocompounds such as alkaloids, anthocyanins, coumarins, flavonoids, lignans and neolignans, sesquieterpenes, sesquiterpene lactones, sterols, tannins, triterpenes, et cetera, which may be responsible for their antimicrobial properties. The antimicrobial action of phytocompounds might be due to their capacity to disintegrate cytoplasmic membrane, destabilize proton motive force, electron flow, active transport, and coagulation of the cell content in microbes [195]. Silva and Fernandes [196] also reviewed the antimicrobial properties of plants and concluded that different chemical classes of phytochemicals including alkaloids, flavonoids, terpenoids, phenols, tannins, et cetera may be responsible for their antimicrobial potential.

Several phytochemicals of the different classes of compounds such as alkaloids, flavonoids, saponins, terpenoids, vitamins, glycosides, phenols, et cetera play significant roles in inhibiting or arresting cancer cell progression by different mechanisms such as (a) by inhibiting cancer cell-activating signaling pathways such as Cdc2, CDK2, and CDK4 kinases, topoisomerase enzyme, cyclooxygenase, and COX-2, Bcl-2, cytokines, PI3K, Akt, MAPK/ERK, MMP, and TNK; (b) activating mechanisms of DNA repairing, viz. p21, p27, p51, and p53 genes, and Bax, Bid, and Bak proteins; or (c) by stimulating the formation of protective enzymes, viz. Caspase-3, 7, 8, 9, 10, and 12 [197].

Plants enriched with phenolic acids, flavonoids, coumarins, lignans, terpenoids, et cetera can exert antioxidant action by scavenging radicals and chelating metal ions by acting as reducing agents, hydrogen donors, singlet oxygen quenchers, metal chelators, or reductants of ferryl hemoglobin [198]. Therefore, the antioxidant potential of different species of Bombacoideae may be due to the presence of several classes of phytoconstituents including vicenin 2, linarin, saponarin, cosmetin, isovitexin, xanthomicrol, vavain, apigenin, beta-sitosterol, et cetera [151,184].

The different bioactive phytocomponents could exhibit anti-inflammatory activities by down regulating of signaling pathways like NF-κB pathway. This is done by different mechanisms such as (a) inhibiting common mediators of inflammation like NO, iNOS, and pro-inflammatory cytokines like TNF-α, IL-1β, IL-6, and IL-12p40; (b) inhibition of chemokines such as RANTES and MCP-1; (c) downregulating mediators of inflammation such as cyclooxygenase-2 (COX-2), prostaglandins, and leukotrienes; (d) reducing the
production of ROS and lipid peroxidation; and (e) upregulating enzymatic (superoxide dismutase, catalase, etc.) and non-enzymatic (glutathione, etc.) defense systems [199]. The different species of Bombacoideae such as A. digitata and C. pentandra could inhibit inhibition against proinflammatory cytokine IL-8 expression or by reducing iNOS and NF-κB expression [181,182], and the activity is attributed to the presence of different phytoconstituents, viz. quercitrin, cinchonains 1a and 1b, cis-clovamide, trans-clovamide, and glochidioboside [184]. The phytoconstituents of different plants could show antidiabetic activities by inhibiting carbohydrate metabolizing enzymes like amylase and glucosidase enzymes, or by stimulating insulin release or by increasing glucose uptake by cells or by decreasing insulin resistance [200]. Several studies have rightly pointed out that different Bombacoideae plants could exhibit antidiabetic activities by inhibiting α-amylase and α-glucosidase enzymes [148].

12. Conclusions

Plants are considered important natural resources as food supplements and in traditional and modern medicine in different regions of the world. Bioactive phytochemicals are valued candidates for the discovery of new drugs. Detailed reporting of plants with food value, and therapeutic and economic importance, of subfamily Bombacoideae, was undertaken in this review. Isolated phytochemicals of diversified classes of secondary metabolites are reported to possess numerous therapeutic properties against different ailments. The bioactive phytochemicals from plants of this subfamily will play important roles in the development of new drug leads with less toxicity and side effects.

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