

## Research Article

# Occurrence of *Citropsis articulata* in Tropical Forests in Uganda: Implication for Ex Situ Conservation

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*Citropsis articulata* is a medicinal plant that is increasingly threatened by unsustainable methods of harvesting and habitat degradation. Owing to the fact that this plant species is highly utilized for herbal medicine and is currently restricted to a few forest reserves in Uganda, this has significant implications for ex situ conservation. Therefore, the aim of this study was to assess how physiographical factors influence the occurrence and distribution of *C. articulata* in the three forest reserves in Uganda, namely, Budongo, Mabira, and Kibale National Park. The study was carried out in 15 compartmental sites in each of the three forests. In each compartmental site, 4 plots of 60 m × 60 m were systematically established, and within each plot, 4 subplots each of size 20 m × 20 m were randomly setup. A total of 240 subplots were assessed for occurrence of *Citropsis articulata* in each forest. The results indicated a significant ( $p < 0.05$ ) variation in the density of *C. articulata* with the highest recorded in Kibale National Park. *Citropsis articulata* generally occurred at moderate altitudinal landscapes (overall elevation = 1200.0 ± 20.73 m) with soils that are moderately acidic (overall pH = 5.7 ± 0.10), low in salinity (overall salinity = 84.0 ± 3.84 mg/l), and moderate levels of macro- and micronutrients. *Citropsis articulata* was generally associated with plant communities dominated by canopy tree species of genera such as *Chrysophyllum*, *Celtis*, *Markhamia*, *Cynometra*, *Lasiodiscus*, *Trilepisium*, *Funtumia*, and *Diospyros*, thus suggesting that *C. articulata* is a shade-tolerant species. Establishing the ecological requirements of this plant species among other things informs the potential for ex situ production of this plant. This will not only provide alternative sources of plant harvest but also go a long way in relieving the current harvest pressures exerted on the conserved wild populations of this plant species.

## 1. Introduction

*Citropsis articulata* (Willd. ex Spreng) Swingle & Kellerm, family Rutaceae, is commonly known as the African cherry orange. The plant species is native to West, Central, and East African countries including Cameroon, Central African Republic, Congo, Gabon, Ghana, Guinea, Ivory Coast, Liberia, Nigeria, Sierra Leone, Sudan, Tanzania, Togo, and Uganda [1, 2]. *Citropsis articulata* is usually a shrub or small tree, ranging from 2.5 to 5 m in height but sporadically much

taller [1, 3]. This plant species is well known for its aphrodisiac properties, and recent studies have proven its antiplasmodial potential too [4, 5]. Unfortunately, the plant part used for its medicinal purpose is the root and thus the most harvested, and this could endanger its existence. In Uganda, the species is mainly restricted to the understory of moist evergreen forests located mainly in the Albertine rift including Budongo Central Forest Reserve and Kibale National Park but also reported in the Mabira Central Forest Reserve in Central Uganda.

The fact that just a handful of forest reserves in Uganda act as the natural habitats of *C. articulata* could have far-reaching implications. In Uganda, 61.4% of forest reserves are managed by the National Forestry Authority (NFA), whereas 33.6% are managed by Uganda Wildlife Authority (UWA), while 4.7% are jointly managed by NFA and UWA and 0.3% by local governments [6]. Under the management of National Forestry Authority, Central Forest Reserves (CFRs) were set aside to provide forest products, recreation, protect and conserve biodiversity, stabilize soils, and improve climate and protect water catchments, among others [6, 7]; this includes the likes of Budongo and Mabira Central Forest Reserves. Despite the measures put in place by NFA to protect central forest reserves as stipulated in the forestry policy, prohibited activities such as illegal logging, charcoal production, and illicit harvest of nontimber forest products (NFTPs) still persist in most central forest reserves. This in part is attributable to the management weaknesses such as weak law enforcement resulting from limited staffing [6, 8]. The predicament is further compounded by the location of some forests near metropolitan areas in addition to having settlement enclaves within the forest reserve boundaries; case in point is Mabira Central Forest Reserve. On the other hand, Kibale Forest currently managed by UWA was gazetted as a National Park in 1993, at which point management emphasized exclusive conservation with no human use allowed except for research and tourism [9]. We therefore hypothesize that these differences in forest management could impact on the occurrence of *C. articulata* in the three forest reserves.

*Citropsis articulata* is listed among the vulnerable species of Uganda according to the International Union for Conservation of Nature (IUCN) red list for Uganda [10]. Besides, Okeowo [11] noted that *C. articulata* is disappearing in Mabira Central Forest Reserve at an alarming rate. This was attributed to overexploitation and unsustainable methods of harvesting, owing to increased demand and commercial value for its roots [8]. Additionally, factors such as environmental degradation and climate change may further increase the vulnerability of this plant species. This therefore calls for the need to develop and enhance other conservation approaches such as ex situ conservation through offsite production (e.g., cultivation and or domestication). However, the success of any ex situ conservation program, specifically offsite production, requires understanding the ecological conditions and requirements of the plant in question in this case *C. articulata*. For instance, species-specific growth and survival responses to resources particularly physiographical factors play a key role in determining the success of species offsite production. The influence of soil factors on plant growth has been extensively studied (e.g., [12–16]). However, this information does not provide local evidence on how soil conditions impact on the occurrence of *C. articulata* in Ugandan forests. Furthermore, understanding coexisting vegetation assemblages of a species is key because plants are known to interact at both physical and biochemical levels which impact on a plant's regeneration and recruitment in any forest environment [17–19].

Therefore, the aim of this study was to investigate how physiographical (location, topography, and soil) factors influence the occurrence and distribution of *C. articulata* in the three forests of Uganda, namely, Budongo, Mabira, and Kibale National Park. The specific objectives were to (1) establish whether geolocation and forest management have implications on the occurrence and distribution of *C. articulata*, (2) determine whether soil chemical parameters have an effect on the occurrence of *C. articulata* in the three tropical forests of Uganda, and (3) determine the plant species assemblages that co-occur with *C. articulata* in the three forests of Uganda. The findings of this study have extensive implications: first, any indications of habitat specificity and preferences by *C. articulata* would mean that success of any offsite production would entail provision of such conditions to suit its production. Secondly, significant variation in the occurrence of *C. articulata* in the three stipulated forests would indicate that location and management strategies may have an impact on occurrence of *C. articulata*. Therefore, there is need for designing and implementing suitable and continuous monitoring programs to protect and conserve *C. articulata* and possibly curb any anthropogenic activities leading its vulnerability.

## 2. Materials and Methods

**2.1. Study Area.** Uganda lies across the equator in Eastern Africa between the latitudes 4.5°N to 1.5°S and longitudes 29.5°E to 35°E (Figure 1), at an average altitude of 1,100 meters above sea level. This study was conducted in three geolocations, i.e., Mabira Central Forest Reserve, Budongo Central Forest Reserve, and Kibale National Park (Figure 1). The three geolocations were selected based on the following criteria: (1) the presence of *Citropsis articulata*, (2) management status, (3) the degree of human activities in the area, providing a possibility to determine the impact of these activities, and (4) agroecological zone (AEZ) classification. The three geolocations are encircled by varying agroecological zones. The zones are characterized by different farming systems determined by soil types, climate, landforms, and socioeconomic and cultural factors [20].

**2.1.1. Mabira Central Forest Reserve (MCFR).** Gazetted in 1932, Mabira Central Forest Reserve (MCFR) lies partly in Buikwe, Mukono, and Kayunga districts. It occupies an area of 306 km<sup>2</sup> and is situated between latitudes 0°22'N to 0°36'N and longitudes 32°50'E to 33°07'E with an altitudinal range of 1073–1348 m above sea level (Figure 2). The landscape of the forest is generally characterized by gently undulating flat-topped hills to wide shallow valleys occupied by swamps [21, 22]. The flat-topped hills are remnants of the earlier penplain uplifted by tectonic movements which lowered the land south of MCFR and were filled up by river water from the east and west to form present Lake Victoria [23]. The southern part of the forest is situated at or near the watershed of rivers and streams which flow into Lake Victoria and Lake Kyoga to the south and north, respectively. The geology of MCFR is characterized by the

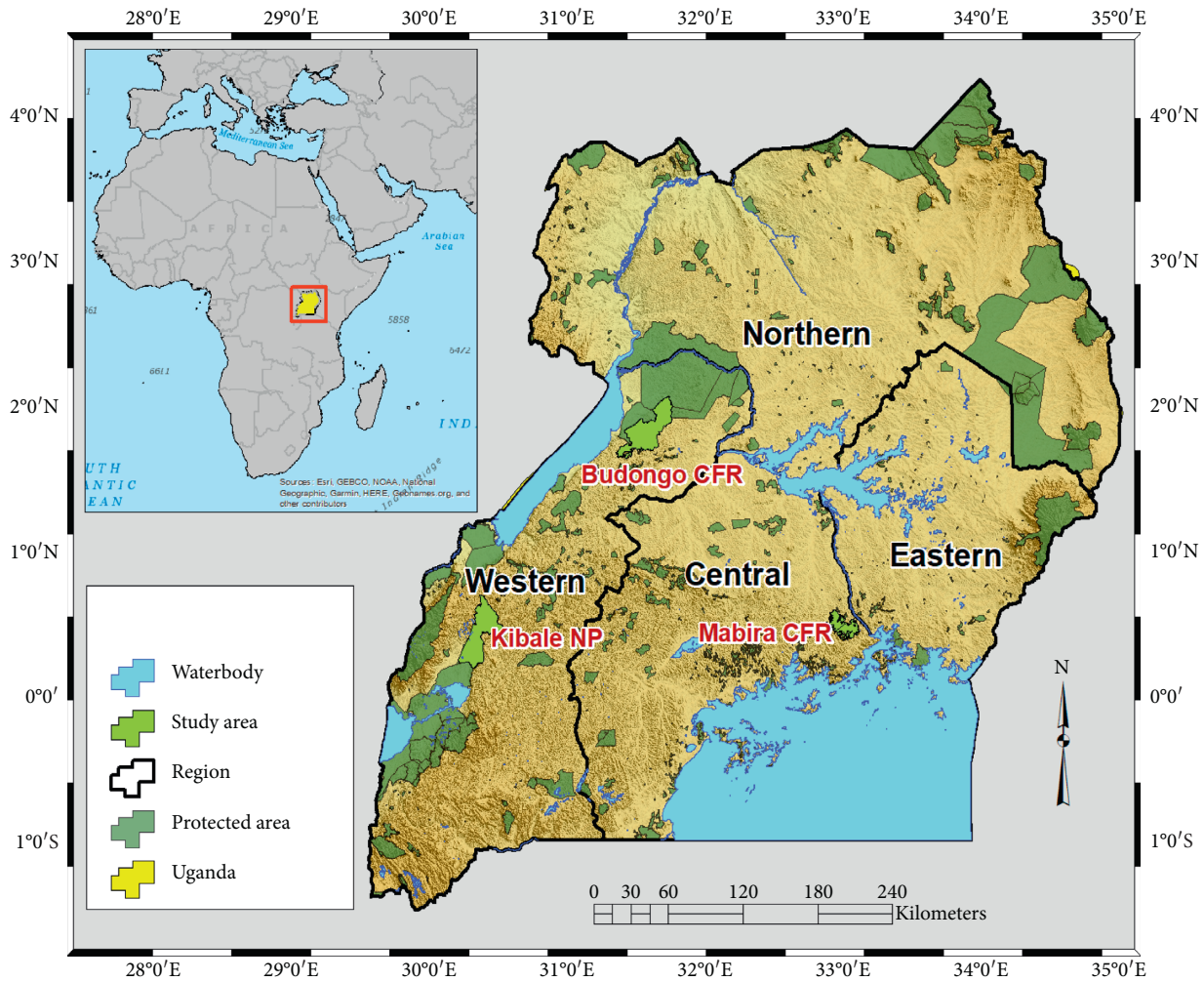


FIGURE 1: Location map of Budongo, Mabira, and Kibale Forest Reserves in Uganda.

Buganda-Toro system, which is made up of granitic gneiss and granites overlaid by metamorphosed sediments such as schists, phyllites, quartzites, and amphibolites [21, 23]. MCFR generally has ferrallitic sandy clay loam soils often referred to as Buganda catena and consists of red soil of incipient laterisation on slopes and black clays in the valley bottoms [21, 24]. MCFR experiences an equatorial type of climate characterized by a bimodal rainfall pattern with two wet seasons during March–May and September–November with an average annual rainfall of 1,300 mm [21]. The temperature is typically of the equatorial region with an average annual temperature of about 21–25°C. The proximity of MCFR to Lake Victoria and its occurrence at altitude of more than 1,000 m have a moderating effect on its temperatures. Nevertheless, the MCFR zone generally displays comparatively small seasonal variations in temperature, humidity, and wind throughout the year [21]. According Langdale-Brown et al. [25], the vegetation of MCFR is classified as medium altitude moist semideciduous. However, the forest vegetation has greatly been influenced by human activities such as exploitation, cultivation, and grazing, among others; thus, the vegetation types are

generally characterized by subclimax or human-altered plant communities. The forest reserve is partitioned into three management zones, i.e., strict nature reserve (in which no activities are permitted except scientific research), buffer (in which recreational activities and collection of nontimber forest products are permitted), and production (managed for sustainable supply of timber forest products) [8, 21]. The forest is also masked with village enclaves that are widely distributed within the forest area (Figure 2). The residents of these enclaves largely depend on the forest resources for their livelihood [26], and this may render management of the forest reserve an uphill task. In addition, due to high proximity to metropolitan areas such as Kampala and Jinja, the MCFR area has been subjected to deforestation for agriculture and logging [27]. MCFR is currently managed by National Forestry Authority (NFA) in accordance with the current forestry policy and legal framework [21]. The management plan of the forest prohibits charcoal production and harvesting of resources in large quantities for commercial but allows extraction of food materials, medicine, poles, and fallen logs for firewood in low quantities for subsistence use [21, 28].

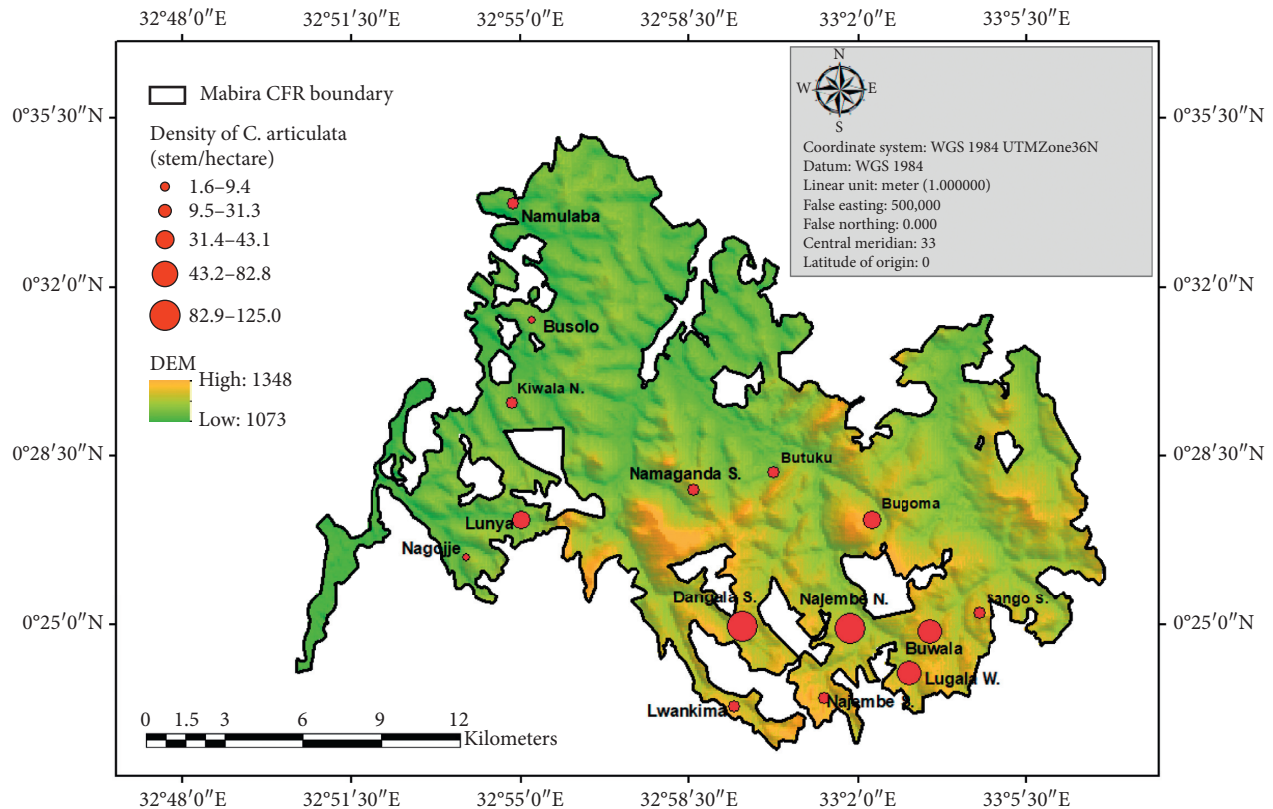


FIGURE 2: Variability in occurrence of *C. articulata* in Mabira Central Forest Reserve.

**2.1.2. Budongo Central Forest Reserve.** Budongo Central Forest Reserve (BCFR), gazetted in 1932, lies partly in Buliisa, Hoima, and Masandi districts. It covers an area of 825 km<sup>2</sup> making it Uganda's largest Central Forest Reserve. The forest is situated between the latitudes 1°37'N and 2°4'N and longitudes 31°20'E and 31°48' E with an altitudinal range of 719 m–1,258 m above sea level (Figure 3). The forest lies towards the north end of lake Albert, on the gentle upper slopes of the watershed, with its western edge only 3–6 km from the top of the escarpment of the western rift valley [29]. The terrain of the forest is characterized by gently undulating hills with generally soft valley bottoms marked with several streams. Majority of the streams join to form two rivers (Sonso and Weisoke) as they approach the western margin of the forest [29]. The forest experiences an equatorial type of climate characterized by a bimodal rainfall pattern with two wet seasons during March–May and September–November with an average annual rainfall of 1,150–1,500 mm. Minimum annual temperature ranges from 17 to 20°C, while the maximum annual temperature is in a range of 28 to 29°C [30]. The geology of the forest comprises rocks of ancient gneisses, schists, and granites of basement complex, covered by the Bunyoro series sediments. The forest is generally underlain with ferrallitic soils, mainly sandy to sandy clay loam of low to moderate fertility [22, 29, 30]. BCFR has been described as a lowland moist semideciduous forest with varying vegetation characteristics, namely, *Cynometra* forest, mixed forest, colonizing forest (woodland), and swamp forest. The forest is mainly dominated by plant species of

*Cynometra*, *Celtis*, and the mahoganies *Khaya* and *Entandrophragma* species [22, 29]. In addition, Budongo Central Forest Reserve is home to some of Uganda's major fauna including approximately 150 species of forest birds and 5 species of diurnal forest primates such as chimpanzees (*Pan troglodytes*). This renders BCFR a forest of high importance for global biodiversity and ranking third in overall importance of Ugandan forests [31–33]. The forest has a history of selective logging which occurred since 1910, intensified between 1935 and 1960 when mechanical logging operated in the forest, and was reduced in the early seventies [34, 35]. Due to overexploitation, enrichment planting of mahogany (*Khaya* and *Entandrophragma*) was carried out to encourage its regeneration. The 1950s and 1960s also witnessed the use of arboricide treatment on trees considered of less or no commercial value [35, 36]. A number of human activities occur around the forest with agriculture as the major economic activity. Commercial sugarcane production and growing of crops such as *Musa* sp. (Banana), *Manihot esculenta* (Cassava), *Phaseolus vulgaris* (Beans), *Zea mays* (Maize), and *Eleusine coracana* (Millet), among others, are evident at forest's edge. BCFR is managed by National Forestry Authority (NFA) in accordance with the current forestry policy and legal framework [21]. The management plan of the forest prohibits charcoal production and harvesting of resources in large quantities for commercial purpose but allows extraction of food materials, medicine, poles, and fallen logs for firewood in low quantities for subsistence use [21, 28]. Despite the tremendous efforts



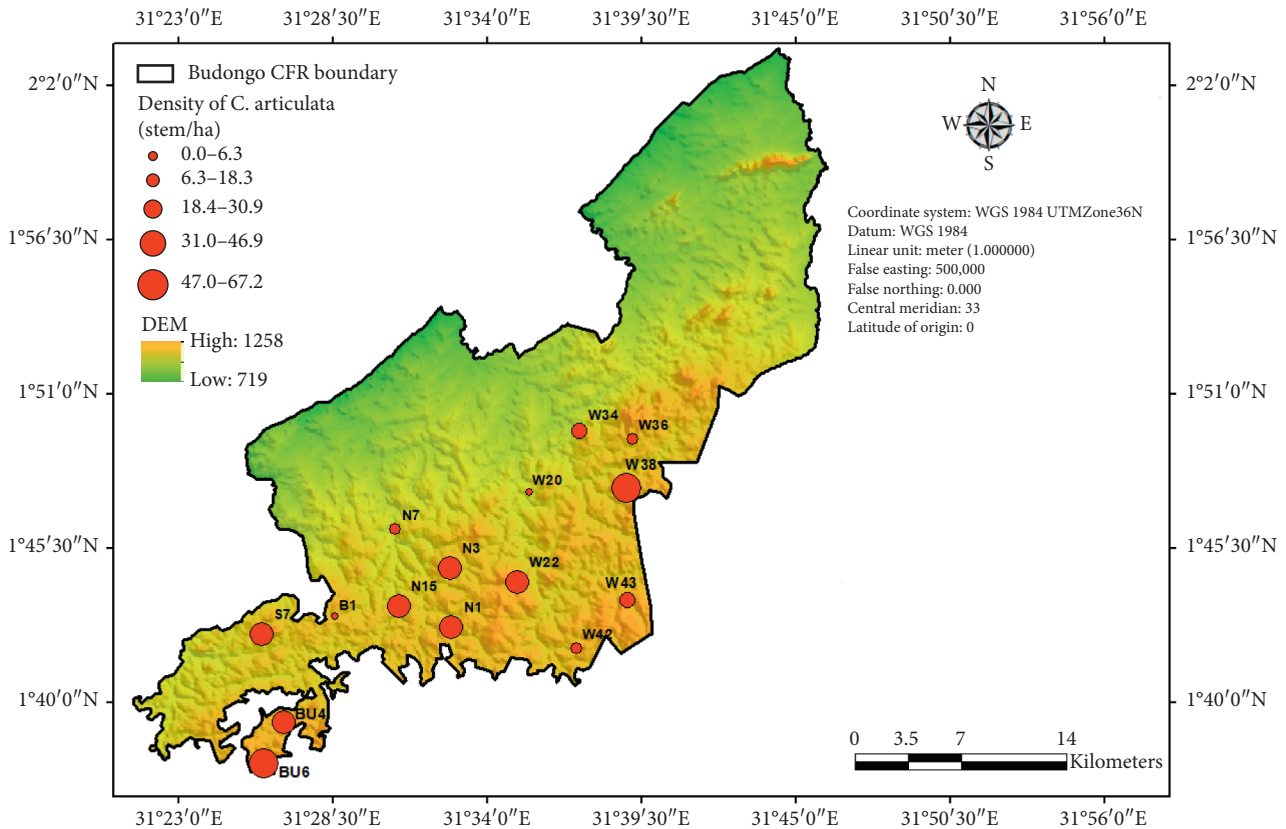


FIGURE 3: Variability in occurrence of *C. articulata* in Budongo Central Forest Reserve. B, Biso; Bu, Busaju; N, Nyakafunjo; S, Siiba; W, Waibira.

made by the Uganda government and NFA to protect the forest and its resources, the forest is still grappling with the problems of illegal logging and charcoal production.

**2.1.3. Kibale National Park.** Kibale Forest was gazetted in 1932 as a Forest Reserve and later elevated to National Park status in 1993 and is currently under the management of Uganda Wildlife Authority (UWA) [37, 38]. Kibale National Park is situated in western part of Uganda traversing Kabarole, Kamwenge, and Kyenjojo districts. The forest is located 22 km south of Fort Portal City near the foothills of the Rwenzori mountains and positioned between latitudes 0°13'N and 0°41'N and longitudes 30°10'E and 30°35'E (Figure 4). Furthermore, the park is a medium-altitude tropical moist forest covering about 795 km<sup>2</sup> with an altitudinal range of 926 m–1,619 m above sea level (Figure 4). The park is situated in an undulating landscape on the main Uganda plateau, slightly tilted to the south, and is drained by the Mpanga and Dura rivers flowing in a southerly direction and emptying into Lake George [39, 40]. The park experiences an equatorial type of climate characterized by a bimodal rainfall pattern with two wet seasons during March–May and September–November with an average annual rainfall between 1,100 and 1,600 mm. The park experiences moderate temperatures with minimal fluctuations over the year. The average monthly minimum temperature is 15°C, whereas the average monthly maximum temperature is 27°C [37]. The geology of the park consists of rocks formed in the

Precambrian period which were successively folded and metamorphosed. The Buganda-Toro system overlying these rocks forms noticeable ridges of quartzite, schists, and phyllites with bodies of amphibolites, gneisses, and granites [38]. The park is generally underlain by red ferralitic soils, comprising sandy clay loams in the north and clay loams in the south. The soils are deeply weathered, exhibit weakly developed horizons, and are of very low to moderate fertility [38, 41]. The park comprises moist semideciduous and evergreen forest (57%), grassland (15%), woodland (4%), lakes and wetlands (2%), colonizing forest (19%), and plantations of exotic trees (1%) [42]. The park provides critical habitat to eastern chimpanzees (*Pan troglodytes schweinfurthii*), 12 additional primate species, elephants (*Loxodonta africana*), and a diversity of other species [42]. The forest was immensely exploited as a source of commercial timber in 1950s, while still a forest reserve, and thus, a number of compartments are currently at various stages of regeneration [40, 43]. The current management plan of the park incorporates a number of conservation strategies including resource conservation and management, enforcing boundaries, policing against illegal resource extraction, research and ecological monitoring, restoring degraded areas within the park, and tourism [9, 43].

**2.2. Study Sampling Design and Data Collection.** For comparative purposes, the study was carried out in 15 compartments/sites in each of the three study forest reserves, i.e., Budongo, Mabira, and Kibale. The 15 study compartments/

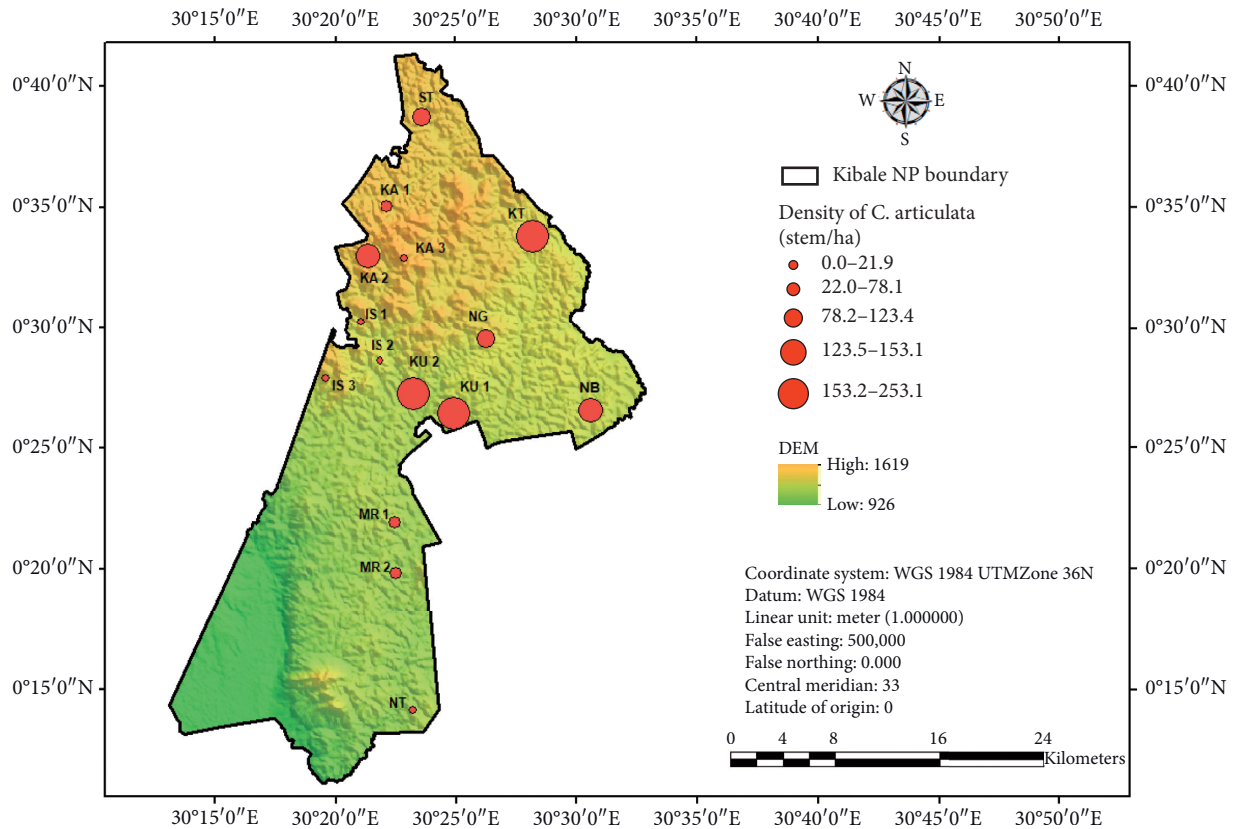


FIGURE 4: Variability in occurrence of *C. articulata* in Kibale National Park. KA, Kanyawara; ST, Sebitoli; IS, Isunga; NG, Ngogo; KU, Kyanancho; MR, Mainaro; NB, Nyamibiriko; NT, Nyabitusi; KT, Kinyantale.

sites were selected from the forest maps with the intent of attaining sufficient extent of spatial coverage of the forest reserve. In each compartmental site, 4 plots of 60 m × 60 m (1.4 ha) were established systematically with the first sample plot selected randomly and the subsequent plots established at an interval of 100 m from either side of the first plot; within each plot, 4 subplots each of size 20 m × 20 m (0.04 ha) were established randomly following McRoberts et al. [44]. Therefore, a total of 240 subplots (20 m × 20 m) were assessed for occurrence of *C. articulata* in each forest.

Within each plot, the number of individuals of *C. articulata* was recorded and georeferenced using a hand-held GPS (Garmin GPSMAP®64) and visualized in ArcMap version 10.5 (Esri, ArcGIS®). To establish the occurrence of *C. articulata* with other plant species, tree and shrub plant species occurring within the subplot of occurrence of *C. articulata* were identified to species level with the assistance of forestry experts and botanists from National Forestry Authority, Budongo Conservation Field Station, and Makerere University Biological Field Station for Mabira, Budongo, and Kibale forests, respectively. The identities of the species were verified using plant species lists from Budongo Conservation Field Station, National Forestry Authority (NFA), and field guide by Hamilton [45], Kalema and Beentje [46], and Katende et al. [47]. The frequency of occurrence of each individual species at site of occurrence of *C. articulata* was expressed as a percentage using the following formula:

$$\text{percentage occurrence of species (Y)} = \frac{\text{number of plots with species (Y)}}{\text{total number of plots with } C. \text{ articulata}} \times 100. \quad (1)$$

Soil samples were collected at the site of occurrence of *C. articulata* following methods by Burt [48]. The soil samples were collected from five (5) subsites within each subplot of occurrence of *C. articulata* at a standard depth of 0–30 cm and mixed thoroughly to form a homogenous composite sample before placing 500 g soil sample in a clean zip lock plastic bag. The samples were labeled appropriately for reference and transported to Mbarara University of Science and Technology, Biology laboratory for chemical analysis. The soil was air-dried and analyzed for 13 soil chemical parameters (pH, conductivity, salinity, phosphorus, potassium, magnesium, calcium, aluminium, chloride, copper, iron, manganese, and sulphur) using the SKW 500 Complete Soil Kit by Palintest®. The soil samples were prepared and analyzed for each chemical parameter using procedure and guidelines specified by the soil kit manufacturer (Palintest®).

**2.3. Data Analysis.** Density of *C. articulata* was computed by converting the count from all sample plots into a hectare basis and presented as mean ± standard error (SE). Variation

in density and height of *C. articulata* in the three forests of Mabira, Budongo, and Kibale were tested using one-way ANOVA (F test), and consequently, Tukey's multiple comparison test used to determine where the means were different at  $p < 0.05$  in GraphPad Prism version 6.0 (GraphPad Software Inc., USA). The relationship between density of *C. articulata* and altitude and soil chemical parameters was determined using Pearson product-moment correlation coefficient. Data of soil chemical properties were analyzed using a statistical Kruskal-Wallis test, and consequently, Dunn's multiple comparison test used to determine where the medians were different at  $p < 0.05$  in GraphPad Prism version 6.0 (GraphPad Software Inc., USA). Relationships between soil chemical parameters were established using Spearman's rank correlation test. Principal component analysis (PCA) was used in the multivariate analysis of soil chemical parameters using Minitab (Minitab Inc., USA).

### 3. Results and Discussion

**3.1. Occurrence of *C. articulata*.** A total of 1686 *C. articulata* individual plants were recorded in the three forests, with Kibale National Park having the highest abundance of 974 individuals followed by Mabira (414 individuals), whereas Budongo had the lowest abundance of *C. articulata* (298 individuals). Density of the *C. articulata* varied significantly ( $p < 0.05$ ) in the three forests (Figure 5(a)). Kibale National Park had the highest density of *C. articulata* with a mean of 100.2 stems  $\text{ha}^{-1}$ , while Budongo Central Forest Reserve presented the lowest average density of 30.9 stems  $\text{ha}^{-1}$ , as indicated in Figure 5(a). The high occurrence of *C. articulata* in Kibale National Park may be attributable to the differences in management practices and strategies for National Parks and Central Forest Reserves. Kibale National Park under the management of Uganda Wildlife Authority (UWA) enjoys the benefits of stricter laws and regulations governing National Parks and perhaps better enforcement compared to Mabira and Budongo Central Forest Reserves that are currently under the management of National Forestry Authority (NFA). Throughout the entire course of this study, illegal activities such as deforestation and charcoal production were not evidenced in Kibale National Park. However, these were more evident in Budongo and Mabira Central Forest Reserves. Occurrence of these illegal activities in the forest reserves can lead to incidental cutting of *C. articulata* by users seeking resources from the forest [8]. In addition, this phenomenon can as well lead to harvest of *C. articulata* by those who know its medicinal value, thus negatively impacting on its abundance. Important to note is that Kibale National Park is generally located at high altitude compared to Budongo and Mabira Central Forest Reserves, a factor which may have also influenced the abundance of *C. articulata*. As shown in Figure 5(d), density of *C. articulata* was found to be positively associated with elevation. The variation in the soil chemical parameters of the three forests may also have further influenced the abundance and distribution of *C. articulata* since soil properties have been reported to be a vital variable in

shaping plant species distribution in tropical forests [49]. It is worth noting that other conditions and factors such as climate, herbivory, and disease may also strongly impact on the abundance and distribution this plant species in the three forests.

In Kibale National Park, *C. articulata* was majorly abundant in the compartmental sites of Kanyanchu and Kinyantale with densities in the range of 153.2–253.1 stems  $\text{ha}^{-1}$  (Figure 4). In Mabira Central Forest Reserve, *C. articulata* was majorly abundant in the compartmental sites of Najjembe North and Dangala South with density in the range of 89.2–125.0 stems  $\text{ha}^{-1}$  (Figure 2). In Budongo Central Forest Reserve, *C. articulata* was abundant in compartmental sites of Busaju (Bu 6) and Waibira (W 38) with densities in the range of 47.0–67.2 stems  $\text{ha}^{-1}$  (Figure 3). High density of *C. articulata* in these sites could mean that these sites have conducive environmental conditions and thus preferred habitats of *C. articulata*. For instance, common features observed at these sites are that they are all located along gentle slopes and near noticeable streams, conditions which could have favored proliferation of *C. articulata*.

*C. articulata* showed significant variation ( $p < 0.05$ ) in plant height among individuals from the three forests (Figure 5(b)). In Mabira Central Forest Reserve, plant height ranged from 0.1 m to 8.7 m and a mean height of  $3.1 \pm 0.12$  m, making this the highest mean height recorded in the study. In Kibale National Park, plant height ranged from 0.2 m to 8.5 m and a mean height of  $2.8 \pm 0.08$  m, making this the second highest height recorded in this study. On the other hand, the plant height of *C. articulata* in Budongo Central Forest Reserve was in a range of 0.1 m to 5.2 m and a mean of  $1.5 \pm 0.06$  m, thus making this the lowest mean height of *C. articulata* recorded in this study. The stems of *C. articulata* in Budongo Central Forest Reserve were generally short compared to its counterparts in the other two forests which may be attributable to the varying soil conditions in the different forests. Budongo soils generally had a higher salinity compared to other forests. Salinity is reported to be a serious environmental factor limiting the productivity of plants because some plants are sensitive to salinity caused by high concentrations of salts in the soil [50]. There is also a likelihood that the communities surrounding Budongo Central Forest Reserve are more knowledgeable about the medicinal value of this plant and thus leading to more harvesting pressure. This could limit the plants ability to reach considerable heights when compared with counterparts in the other forests (KNP and MCFR). It is expected that the more wide spread the knowledge is about a medicinal plant, the more the harvesting pressure exerted on the plant. It is also worth noting that the use of arboricide treatment on trees considered of less or no commercial value was witnessed in Budongo Central Forest since the 1950s till 1970s [35], an action which may have affected the earlier establishment and growth of *C. articulata* resulting in the low heights recorded in this study.

In this study, elevation of occurrence of *C. articulata* varied significantly ( $p < 0.05$ ) in the three forest reserves.

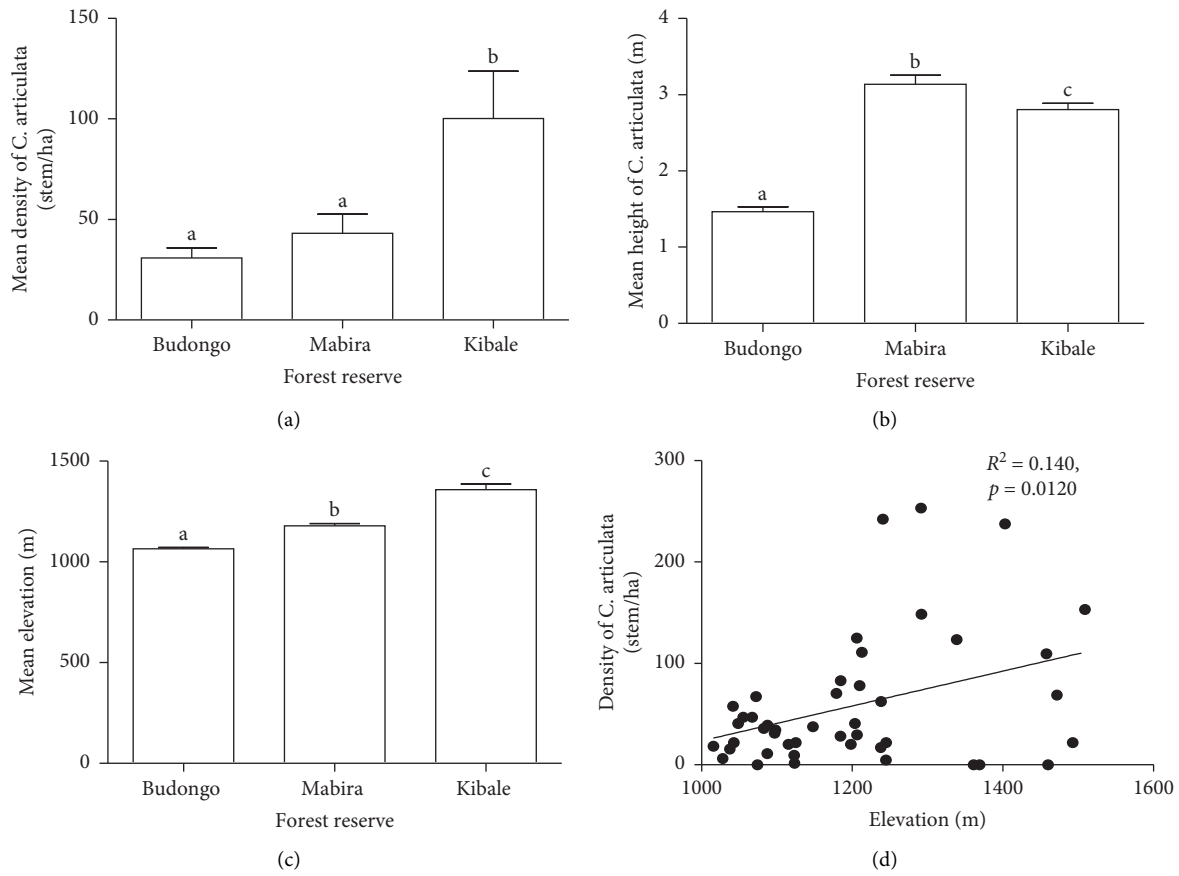


FIGURE 5: (a) Variation in density of *C. articulata* in three forests of Uganda. (b) Variation in height of *C. articulata*. (c) Altitudinal variation in site of occurrence of *C. articulata* in three forests of Uganda (habitat of *C. articulata*). Error bars represent standard error, and column bars with different lowercase letters indicate significant difference at  $p < 0.05$  based on Tukey's multiple comparison test. (d) Relationship between density of *C. articulata* and altitude.

Kibale National Park had the highest elevation of occurrence of *C. articulata* with a mean of  $1358.0 \pm 26.59$  m. On the other hand, Budongo Central Forest Reserve presented the lowest altitude of occurrence of *C. articulata* with a mean elevation of  $1064.0 \pm 7.59$  m (Figure 5(c)). The results also showed a significant positive relationship ( $p < 0.05$ ) between density of *C. articulata* and elevation (Figure 5(d)). *Citropsis articulata* generally had high occurrence at moderate elevation levels. Elevation partially influences microenvironment of tropical forest ecosystems by controlling the spatial redistribution of light, temperature, water availability, and soil nutrients, thereby affecting understory plant species [51]. Furthermore, Ohdo and Takahashi [52] report that increase in elevations leads to an increase in climatic stress that consequently reduces the canopy height resulting in an increase in the number understory flora. This may therefore explain the high occurrence of *C. articulata* at moderate elevation levels.

**3.2. Soil Chemical Parameters.** Results of the present study indicate a considerable degree of soil variability in the three forests based on soil chemical parameters as indicated by the principal component analysis (Figure 6). This may be

attributable to the variability in the parent material, geo-location, and environmental factors. The aforementioned factors often impact and bring about variation in the soil chemical parameters as described below.

Soil pH is arguably one of the most informative measurements that can be made to determine soil characteristics. Just by looking at pH, one can tell much more about a soil than merely indication of whether it is acidic or alkaline [53]. For instance, soil pH is known to govern many plant soil chemical relations, predominantly the availability of micronutrients and toxic ions, owing to its influence on solubility [15]. The results of this study indicated that *C. articulata* generally occurs in moderately acidic soils. The highest pH (median = 5.95) was recorded in Budongo Central Forest Reserve, while Kibale National Park presented the lowest pH (median = 5.63); however, the soil pH did not vary significantly ( $p > 0.05$ ) in the three forests (Figure 7(a)). Tropical forests are known to have acidic soils, owing to the enormous amounts of precipitation that often leads to increased soil acidification through weathering and leaching [54, 55]. However, in some cases, production of carbonic acids from intensive root and microbial respiration has been described to be a major contributing factor to soil acidification [56]. These two phenomena could explain the



low pH observed in the three forest areas. Nevertheless, at low pH, the availability of essential micronutrients such as iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) is increased [15, 57].

Soil electrical conductivity (EC) provides a simple electrochemical indication of the level of soluble salts present in soil. It is an important indicator of soil health and affects plant yields, suitability, and nutrient availability, in addition to influencing activity of soil microorganisms which influence key soil processes [58]. The optimal electrical conductivity of any plant is species specific and depends on environmental conditions [59, 60]. In this study, electrical conductivity of the soil at site of occurrence of *C. articulata* varied significantly ( $p < 0.05$ ) in the three forests with EC ranging from 57.8 to 450.8  $\mu\text{S}/\text{cm}$  (Figure 7(b)). The highest EC (median = 208.5  $\mu\text{S}/\text{cm}$ ) was recorded in Budongo Central Forest Reserve, while Kibale National Park presented the lowest EC (median = 112.3  $\mu\text{S}/\text{cm}$ ). The variation in the soil electrical conductivity in the three forests may be due to the varying microclimatic conditions and soil mineral content [58]. This is also supported by the positive relationship between salinity and electrical conductivity indicated in Table 1. The notably high electrical conductivity in Budongo Central Forest Reserve may have impacted on the productivity of *C. articulata* as demonstrated by the low abundances and plant heights recorded in this study. This is also evident in the negative relationship ( $-0.446$ ,  $p = 0.02$ ) between EC and occurrence of *C. articulata* shown in Figure 8(a). High electrical conductivities are known to induce nutrient stress and enhance plant antioxidant enzyme activities, thus suppressing plant growth and quality [60].

Soil salinity impacts on several aspects of plant development such as germination, vegetative growth, and reproductive development [50]. In this study, soil salinity at site of occurrence of *C. articulata* varied significantly ( $p < 0.05$ ) in the three forests with salinity levels ranging from 32.8 to 230.3 mg/l (Figure 7(c)). The highest salinity levels (median = 103.0 mg/l) were recorded in Budongo Central Forest Reserve, whereas Kibale National Park presented the lowest soil salinity (median = 58.5 mg/l). This variation may also be attributable to variation in soil mineral content and microclimatic conditions in the three forests. It is important to note that high concentrations of salts such as sodium chloride and sodium sulfate in soil may interfere with the absorption of water by plants. This is because the osmotic pressure in the soil solution is nearly as high as or higher than that in the plant cells. Additionally, high salinity levels also interfere with the exchange capacity of nutrient ions, thereby resulting into osmotic stress, nutrient deficiency, and oxidative stress in plants [50, 58]. The negative relationship between salinity and occurrence of *C. articulata* ( $r = -0.465$ ,  $p = 0.015$ ), as indicated in Figure 8(b), is more evidence to this.

Phosphorous (P) is one of the key macronutrients and a critical determinant of plant growth and productivity, and its availability can influence growth of plants in forest ecosystems [61–63]. In the present study (Figure 7(d)), soil phosphorus content varied significantly among the three forests

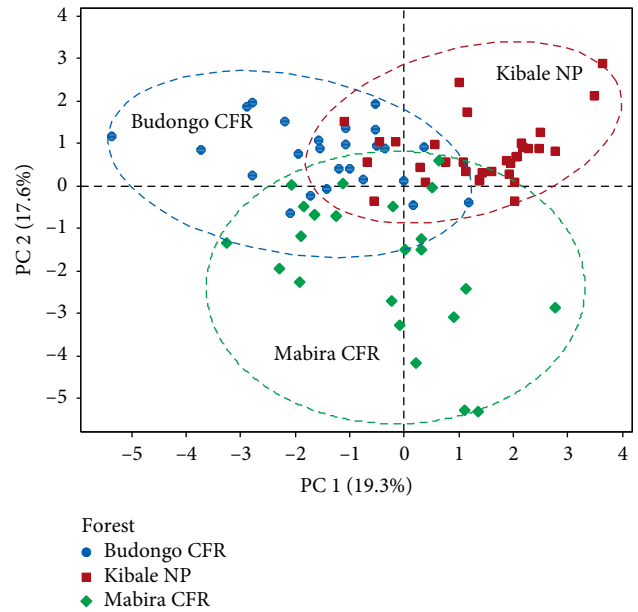


FIGURE 6: Principal component analysis of soil chemical parameters for Budongo Central Forest Reserve, Mabira Central Forest Reserve, and Kibale National Park in Uganda.

( $p < 0.05$ ). This was highest in soils from Kibale National park with a median value of 51.4 mg/l and lowest in soils from Budongo Central Forest Reserve (median = 7.5 mg/l). In addition to geochemical processes, site conditions such as rainfall, temperature, moisture, soil aeration, and salinity often affect the rate of P mineralization from organic matter decomposition and thus phosphorus content in the soil [58, 64]. In this case, the low phosphorus levels in soils of Budongo Central Forest Reserve could be attributable to the high salinity and consequently EC levels, which are known to lower phosphorus content of soil [50]. This is also evidenced by the negative correlation between phosphorus and EC and salinity (Table 1). On the one hand, the results indicated a positive relationship between soil phosphorus content and occurrence of *C. articulata* (Figure 8(c)). This may be attributed to the fact that sufficient phosphorus levels encourage vigorous root and shoot growth, promote early maturity, and increase water use efficiency and plant yield. On the other hand, P deficiency is known to stunt vegetative growth and plant yield [58]. On this note, the low phosphorus levels in the soils of Budongo Central Forest Reserve may account for the short *C. articulata* plant stems (Figure 5(b)).

In the present study, potassium (K) content in soils at site of occurrence of *C. articulata* varied significantly ( $p < 0.05$ ) in the three forests with potassium levels ranging from 60.0 to 850.0 mg/l (Figure 7(e)). The highest potassium levels (median = 220.8 mg/l) were recorded in Kibale National Park, whereas Mabira Central Forest Reserve presented the lowest potassium levels (median = 105.0 mg/l). The variation in the amounts of K in the soils from the three forest reserves may be attributed to the fact that soil potassium is affected by differences in soil parent material/rock and the weathering process [65]. The results also indicated a positive relationship between soil potassium and occurrence

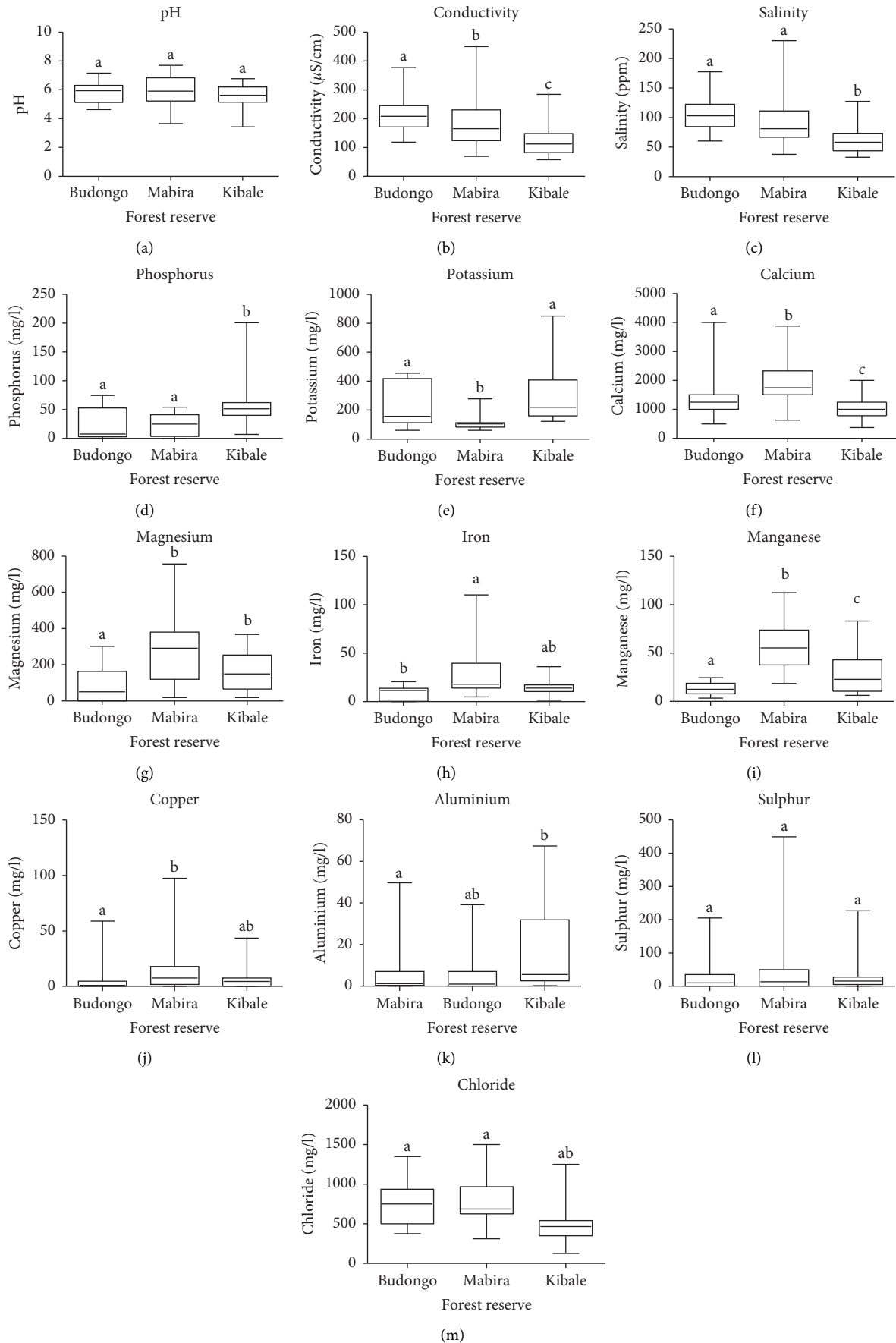


FIGURE 7: (a–m) Variation in the soil chemical parameters at site of occurrence of *C. articulata* in three forest reserves in Uganda. Box and whiskers with different lowercase letters indicate significant difference at  $p < 0.05$  based on Dunn's multiple comparison test.

TABLE 1: Associations between soil chemical parameters.

| Parameter                                | pH      | Conductivity ( $\mu\text{S}/\text{cm}$ ) | Salinity (mg/l) | P (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Al (mg/l) | S (mg/l) |
|--|---------|--|-----------------|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|
| Conductivity ( $\mu\text{S}/\text{cm}$ ) | 0.186   |  |                 |          |          |           |           |           |           |           |           |          |
| Salinity (mg/l)                          | 0.175   | 0.923**                                  |                 |          |          |           |           |           |           |           |           |          |
| Phosphorus [P] (mg/l)                    | -0.252* | -0.190                                   | -0.205          |          |          |           |           |           |           |           |           |          |
| Potassium [K] (mg/l)                     | 0.009   | -0.108                                   | -0.142          | 0.275*   |          |           |           |           |           |           |           |          |
| Calcium [Ca] (mg/l)                      | 0.188   | 0.174                                    | 0.222*          | -0.251*  | -0.466** |           |           |           |           |           |           |          |
| Magnesium [Mg] (mg/l)                    | 0.058   | -0.022                                   | -0.046          | -0.091   | -0.098   | 0.126     |           |           |           |           |           |          |
| Iron [Fe] (mg/l)                         | 0.009   | -0.270*                                  | -0.230*         | -0.259*  | -0.178   | 0.173     | 0.261*    |           |           |           |           |          |
| Manganese [Mn] (mg/l)                    | 0.052   | -0.109                                   | -0.155          | -0.203   | -0.216   | 0.177     | 0.372**   | 0.260*    |           |           |           |          |
| Copper [Cu] (mg/l)                       | 0.050   | -0.073                                   | -0.079          | -0.043   | -0.197   | 0.137     | 0.152     | 0.212     | 0.273*    |           |           |          |
| Aluminium [Al] (mg/l)                    | -0.236* | -0.202                                   | -0.199          | 0.236*   | 0.153    | -0.228*   | 0.217     | 0.288**   | 0.033     | 0.089     |           |          |
| Sulphur [S] (mg/l)                       | -0.089  | -0.153                                   | -0.161          | -0.057   | -0.105   | -0.039    | 0.034     | 0.004     | -0.103    | 0.112     | 0.032     |          |
| Chloride [Cl] (mg/l)                     | -0.116  | 0.167                                    | 0.257*          | -0.182   | -0.209   | 0.377**   | 0.228*    | 0.189     | 0.157     | 0.124     | 0.128     | -0.005   |

\*Correlation is significant at  $p < 0.05$ ; \*\*correlation is significant at  $p < 0.01$ .

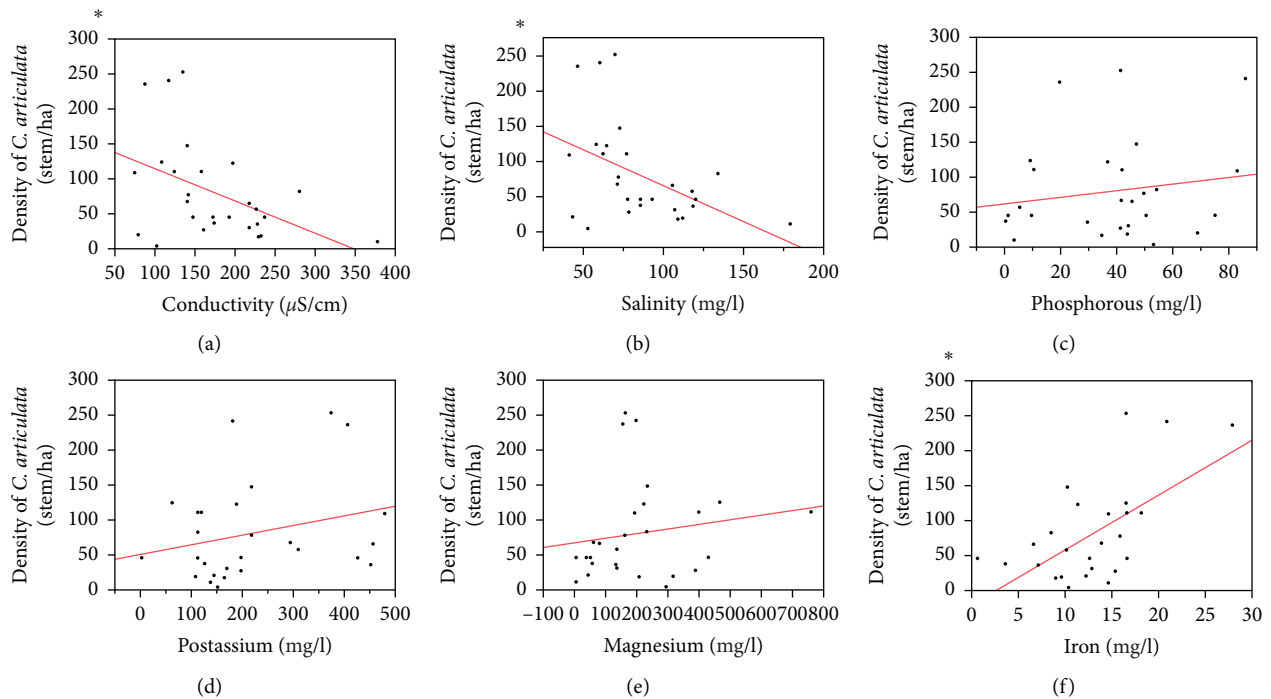


FIGURE 8: Continued.

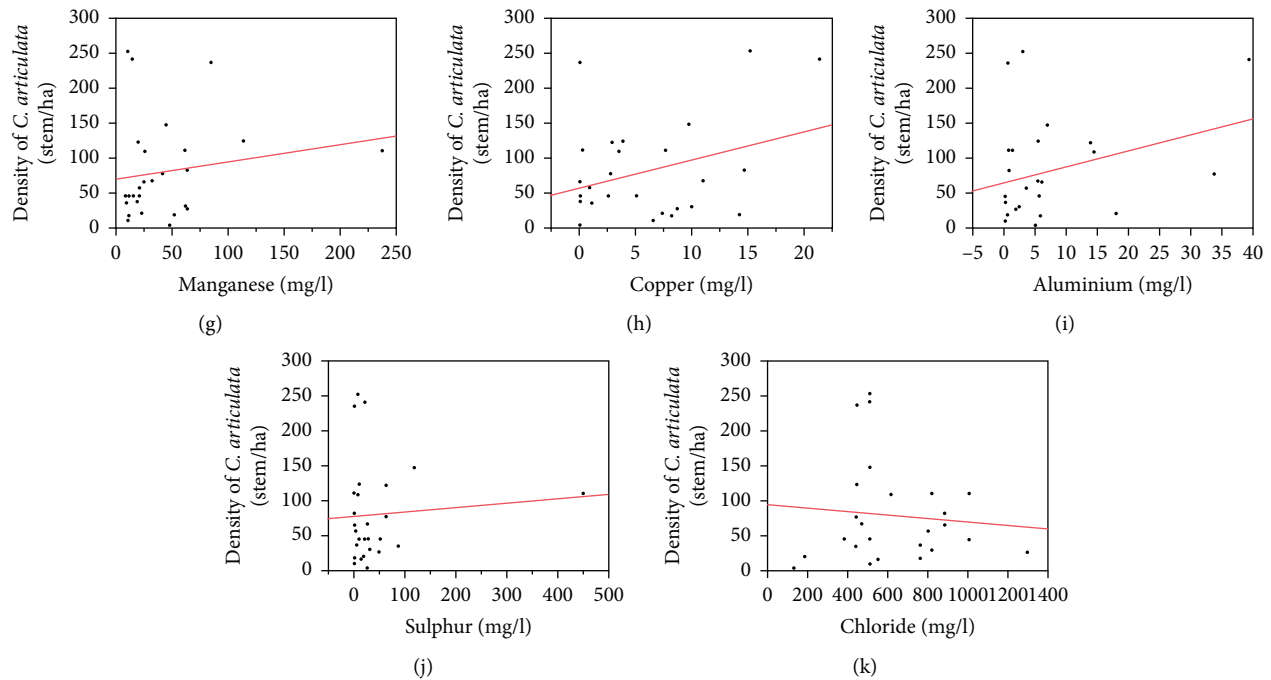


FIGURE 8: (a–k) Relationships between soil chemical parameters and density of *C. articulata*. Scatter plots with \* showed significant associations between density of *C. articulata* and the soil chemical parameter at ( $p < 0.05$ ) based on the Pearson product-moment correlation coefficient.

of *C. articulata* (Figure 8(d)). Potassium is among the vital plant nutrients required for plant growth, reproduction, and physiology. It is not only a constituent of the plant structure but also plays a vital role in regulating several biochemical processes related to enzyme activation, carbohydrate metabolism, and protein synthesis, among others [66, 67].

Calcium plays a vital role in translocation of carbohydrates and proteins and prevents toxic accumulation of aluminium, manganese, and oxalic acid in plants [68]. Soil calcium content at the sites of occurrence of *C. articulata* varied significantly ( $p < 0.05$ ) in the three forests with calcium levels ranging from 375.0 to 4000.0 mg/l (Figure 7(f)). The highest calcium levels (median = 1750.0 mg/l) were recorded in Mabira Central Forest Reserve, whereas Kibale National Park presented the lowest calcium levels (median = 1000.0 mg/l). Soil calcium content is affected by several factors, including those related to the origin and nature of soil parent materials due to weathering and soil formation processes, topography, and water movement within the soil [69, 70]. In any case, these may vary from one forest to another and thus lead to varying soil calcium concentrations in the three forests. Although high level of calcium is not directly harmful, it may decrease the availability of phosphorus and potassium, as evidenced in the negative relationships indicated in Table 1.

In this study, soil magnesium (Mg) content at sites of occurrence of *C. articulata* also varied significantly ( $p < 0.05$ ) among the three forests (Figure 7(g)). Mabira forest soils presented the highest magnesium content with a median value of 291.3 mg/l, while Budongo had the lowest magnesium content (median = 50.0 mg/l). This variability may be credited to the fact that soil magnesium content is affected by several

factors such as origin and nature of soil parent materials, topography, and water movement within the soil [70]. Results also indicated a positive relationship between soil magnesium content and occurrence *C. articulata* (Figure 8(e)). Important to note is that magnesium is the central core of the chlorophyll molecule in plant tissue and also plays a vital role in activation of specific enzyme systems [71]. Therefore, when deficient, it results in the shortage of chlorophyll leading to poor and stunted plant growth. The low magnesium concentration in soils of Budongo central forest reserve may also explain the occurrence of relatively short *C. articulata* stems (Figure 5(b)).

Soil iron content at sites of occurrence of *C. articulata* also varied significantly ( $p < 0.05$ ) among the three forests (Figure 7(h)). Mabira forest soils presented the highest iron content with a median value of 18.0 mg/l, while Budongo forest had the lowest soil iron content (median = 11.5 mg/l). The iron content in soil is influenced by soil mineralogy, texture, and organic matter content [72]. This may account for the variability in the iron content of soils from the three forests. Results further indicated that the occurrence *C. articulata* generally increased with increasing levels of soil iron content (Figure 8(f)). Iron is one of the trace elements required in very small quantities for plant nutrition. It is a key element in energy transformations needed for syntheses and other biochemical processes that occur in the plant cells [73, 74].

Manganese (Mn) is one of the key micronutrients in soil required in trace amounts for several plant biochemical processes. It is a constituent of some respiratory enzymes, some enzymes responsible for protein synthesis, and also plays a vital role in nitrogen metabolism [68, 75, 76]. Soil manganese content at sites of occurrence of *C. articulata* also



varied significantly ( $p < 0.05$ ) among the forests (Figure 7(i)). Mabira forest soils presented the highest manganese content with a median value of 55.3 mg/l, while Budongo had the lowest manganese content (median = 12.5 mg/l). This variability may be attributable to the fact that the behavior of Mn in superficial deposits is very diverse and is influenced by different environmental factors that affect its availability in the soil [74]. Although not statistically significant ( $p > 0.05$ ), a positive relationship between soil manganese content and density of *C. articulata* was evident in this study (Figure 8(g)). Important to note is that plants need manganese in moderately variable amounts, and excessive amounts especially under low soil pH can be toxic when accumulated in plant tissues, thus leading to chlorosis and necrosis of the leaves [77]. On the contrary, when in low amounts, manganese deficiency which often leads to a drop in photosynthetic activity in plants [75] occurs.

Copper is another micronutrient needed by plants in very small quantities. It plays a vital role in several enzyme systems involved in the process of photosynthesis and lignin synthesis [74]. This in part is supported by the positive relationship between soil copper content and density of *C. articulata* shown in Figure 8(h). Results also indicated that Mabira forest soils had the highest copper content with a median value of 7.5 mg/l, while Budongo had the lowest copper content with median = 1.0 mg/l (Figure 7(j)). The results generally indicate that soils at site of occurrence of *C. articulata* generally had low copper content. Due to its versatility, copper has great ability to chemically interact with mineral and organic components of soil, thus rendering soluble copper concentrations extremely low [74, 78]. In any case, copper is needed in trace amounts by plants; therefore, excess amounts of copper would have detrimental effects by chiefly impacting on plant growth and morphology [75, 79].

Aluminium (Al) is among the most abundant elements in the Earth crust and a major factor that inhibits plant growth and reduces crop yield in acid soil [80]. Soil aluminium content at sites of occurrence of *C. articulata* showed minimal variation in the three forests (Figure 7(k)). Kibale National Park soils presented the highest aluminium content with a median value of 5.6 mg/l, while Budongo had the lowest aluminium content (median = 1.0 mg/l). The results generally indicate that soils at sites of occurrence generally had low aluminium content. Some beneficial effects of aluminium on plant growth when in low concentrations have been found to induce growth stimulation by improving nutrient uptake especially in plants which have adapted to acid soils [81]. This is also evident in the positive relationship between aluminium and density of *C. articulata* shown in Figure 8(i). Nevertheless, aluminium when in high amounts may act as a primary factor in reducing crop yields in acid soils mostly by causing severe disruptive changes in the root system such as inhibition of root elongation [82–84].

Soils at sites of occurrence of *C. articulata* generally had low sulphur content, and this did not vary significantly ( $p > 0.05$ ) among the forests (Figure 7(l)). Nevertheless, Kibale National Park soils presented the highest sulphur content with a median value of 15.9 mg/l, while Budongo

had the lowest sulphur (median = 10.0 mg/l). The low sulphur content may be attributable to the fact that its various forms are converted to sulphates which are highly mobile and thus readily leached in soils [68]. In any case, tropical forest soils often experience intensive leaching over a long period of time, owing to a climate where precipitation always exceeds evapotranspiration [55]. Although not statistically significant ( $p > 0.05$ ), results of this study indicated a positive relationship between soil sulphur content and density of *C. articulata* (Figure 8(j)). Sulphur as an essential constituent of protein is very vital in formation of chlorophyll in plants and sulphide linkages in cell walls and sulphhydryl enzymes [85, 86], and thus, its availability in the soil impacts on productivity of the plant.

Results of the present study showed that soil chloride content at sites of occurrence of *C. articulata* ranged from 125 mg/l to 1500 mg/l (Figure 7(m)). Budongo Central Forest Reserve had the highest chloride content with median = 750.0 mg/l, while Kibale forest had the lowest chloride content with a median = 468.3 mg/l. Given the fact that chloride deposition is mainly affected by weathering process and environmental conditions, all of which may vary with location could account for variability in soil chloride content in the three forests. Nevertheless, high chloride concentrations in Budongo Central Forest Reserve may have far-reaching influence on the soil salinity. This is because increase in concentration of chloride ions in the soil solution increases soil salinity. This is shown by the positive association between chloride and salinity (Table 1). Chlorides are taken up by most plants from the soil solution primarily to balance the cations in the cell sap and regulate the osmotic pressure in the plant cells. However, high concentrations of chlorides have detrimental and toxic effects and may reduce plant yield [87–89]. This may explain the negative relationship between soil chloride content and occurrence of *C. articulata* evident in this study (Figure 8(k)).

### 3.3. Plant Species Co-Occurring with *C. articulata*.

Plant-plant species interactions play a vital role in sustaining plant communities in tropical forest ecosystems [19]. This interaction ranges from use of nutrients that are often in short supply relative to plant demand, sharing water supplies, and production of chemicals by one species that either impact directly or serve as signals to neighbors [19]. In the present study, a total of 135 plant species were sighted at the site of occurrence of *C. articulata* in the three selected forest areas in Uganda (Table 2). In Kibale National Park, the species majorly co-occurring with *C. articulata* were *Uvariopsis congensis*, *Tabernaemontana holstii*, *Markhamia lutea*, *Funtumia Africana*, *Diospyros abyssinica*, *Chrysophyllum albidum*, *Celtis durandii*, and *Aphania senegalensis*. In Mabira Central Forest Reserve, *Acalypha neptunica*, *Aphania senegalensis*, *Blighia unijugata*, *Celtis* spp., *Funtumia elastica*, and *Trilepisium madagascariense* were the major plant species occurring in tandem with *C. articulata*. In Budongo Central Forest Reserve, co-occurring species majorly included *Cynometra alexandri*, *Celtis* spp., *Alchornea laxiflora*, and *Lasiodiscus mildbraedii*. The occurrence of *C. articulata* around these

TABLE 2: Plant species assemblages cooccurring with *C. articulata*.

| S. no. | Species                                       | Family         | Occurrence (%) |            |             |
|--------|---|----------------|----------------|------------|-------------|
|        |   |                | Kibale NP      | Mabira CFR | Budongo CFR |
| 1      | <i>Acalypha bipartita</i> <sup>Φ</sup>        | Euphorbiaceae  | —              | 19.2       | —           |
| 2      | <i>Acalypha Neptunica</i> <sup>Φ</sup>        | Euphorbiaceae  | —              | 53.9       | —           |
| 3      | <i>Alangium chinense</i>                      | Cornaceae      | 6.5            | 3.9        | —           |
| 4      | <i>Albizia coriaria</i> <sup>Φ</sup>          | Leguminosae    | —              | 7.7        | —           |
| 5      | <i>Albizia gummifera</i>                      | Leguminosae    | 3.2            | 11.5       | —           |
| 6      | <i>Albizia grandibracteata</i>                | Leguminosae    | 3.2            | 7.7        | —           |
| 7      | <i>Albizia Zygia</i> <sup>Φ</sup>             | Leguminosae    | —              | 34.6       | —           |
| 8      | <i>Alchornea Laxiflora</i> <sup>Ψ</sup>       | Euphorbiaceae  | —              | —          | 57.1        |
| 9      | <i>Alstonia boonei</i>                        | Apocynaceae    | —              | 11.5       | 7.1         |
| 10     | <i>Aningeria altissima</i>                    | Sapotaceae     | 9.7            | —          | 7.1         |
| 11     | <i>Antiaris toxicaria</i>                     | Moraceae       | 6.5            | 34.6       | 3.6         |
| 12     | <i>Antidesma laciniatum</i> <sup>Ψ</sup>      | Euphorbiaceae  | —              | —          | 10.7        |
| 13     | <i>Aphania senegalensis</i>                   | Sapindaceae    | 51.6           | 42.3       | —           |
| 14     | <i>Balanites wilsoniana</i>                   | Balanitaceae   | 6.5            | —          | —           |
| 15     | <i>Belonophora hypoglauca</i> <sup>Ψ</sup>    | Rubiaceae      | —              | —          | 14.3        |
| 16     | <i>Bersama abyssinica</i> <sup>‡</sup>        | Meliantaceae   | 6.5            | —          | —           |
| 17     | <i>Blighia unijugata</i>                      | Sapindaceae    | 22.6           | 53.9       | —           |
| 18     | <i>Blighia welwitschii</i> <sup>Φ</sup>       | Sapindaceae    | —              | 11.5       | —           |
| 19     | <i>Broussonetia papyrifera</i> <sup>Φ</sup>   | Moraceae       | —              | 50.0       | —           |
| 20     | <i>Caloncoba schweinfurthii</i> <sup>Ψ</sup>  | Flacourtiaceae | —              | —          | 10.7        |
| 21     | <i>Cassia spp.</i> <sup>Φ</sup>               | Leguminosae    | —              | 3.9        | —           |
| 22     | <i>Cassipourea gummifera</i> <sup>‡</sup>     | Rhizophoraceae | 16.1           | —          | —           |
| 23     | <i>Celtis africana</i>                        | Ulmaceae       | 19.4           | 7.7        | —           |
| 24     | <i>Celtis durandii</i>                        | Ulmaceae       | 41.9           | 42.3       | —           |
| 25     | <i>Celtis mildbraedii</i>                     | Ulmaceae       | —              | 46.1       | 35.7        |
| 26     | <i>Celtis wightii</i>                         | Ulmaceae       | —              | 15.4       | 35.7        |
| 27     | <i>Celtis zenkeri</i>                         | Ulmaceae       | —              | 11.5       | 17.9        |
| 28     | <i>Chaetachme aristata</i>                    | Ulmaceae       | 29.0           | 19.2       | 3.6         |
| 29     | <i>Chrysophyllum albidum</i>                  | Sapotaceae     | 48.4           | 26.9       | 32.1        |
| 30     | <i>Chrysophyllum gorungosanum</i>             | Sapotaceae     | 6.5            | 11.5       | —           |
| 31     | <i>Chrysophyllum gynoecium</i> <sup>‡</sup>   | Sapotaceae     | 6.5            | —          | —           |
| 32     | <i>Chrysophyllum muerense</i> <sup>Ψ</sup>    | Sapotaceae     | —              | —          | 7.1         |
| 33     | <i>Chrysophyllum perpulchrum</i> <sup>Ψ</sup> | Sapotaceae     | —              | —          | 14.3        |
| 34     | <i>Cleistopholis patens</i> <sup>Ψ</sup>      | Annonaceae     | —              | —          | 3.6         |
| 35     | <i>Coffea spp.</i>                            | Rubiaceae      | 16.1           | 23.1       | 10.7        |
| 36     | <i>Cola gigantea</i>                          | Malvaceae      | —              | 23.1       | 21.4        |
| 37     | <i>Cordia africana</i> <sup>‡</sup>           | Boraginaceae   | 6.5            | —          | —           |
| 38     | <i>Cordia millenii</i> <sup>Ψ</sup>           | Boraginaceae   | —              | —          | 3.6         |
| 39     | <i>Coroton macrostachyus</i> <sup>Φ</sup>     | Euphorbiaceae  | —              | 3.9        | —           |
| 40     | <i>Croton megalocarpus</i> <sup>‡</sup>       | Euphorbiaceae  | 12.9           | —          | —           |
| 41     | <i>Croton sylvaticus</i> <sup>Ψ</sup>         | Euphorbiaceae  | —              | —          | 7.1         |
| 42     | <i>Cynometra alexandri</i>                    | Leguminosae    | 9.7            | —          | 67.9        |
| 43     | <i>Desplatsia dewevrei</i> <sup>Ψ</sup>       | Malvaceae      | —              | —          | 3.6         |
| 44     | <i>Diospyros abyssinica</i>                   | Ebenaceae      | 54.8           | 3.9        | —           |
| 45     | <i>Dombeya mukole</i> <sup>‡</sup>            | Malvaceae      | 3.2            | —          | —           |
| 46     | <i>Dovyalis microcalyx</i> <sup>‡</sup>       | Flacourtiaceae | 6.5            | —          | —           |
| 47     | <i>Drypetes ugandensis</i> <sup>Ψ</sup>       | Euphorbiaceae  | —              | —          | 17.9        |
| 48     | <i>Ehretia cymosa</i> <sup>‡</sup>            | Boraginaceae   | 6.5            | —          | —           |
| 49     | <i>Entandrophragma utile</i> <sup>Ψ</sup>     | Meliaceae      | —              | —          | 3.6         |
| 50     | <i>Fagara angolensis</i> <sup>‡</sup>         | Rutaceae       | 9.7            | —          | —           |
| 51     | <i>Fagaropsis angolensis</i> <sup>‡</sup>     | Rutaceae       | 12.9           | —          | —           |
| 52     | <i>Ficus asperifolia</i> <sup>Φ</sup>         | Moraceae       | —              | 11.5       | —           |
| 53     | <i>Ficus brachypoda</i> <sup>‡</sup>          | Moraceae       | 3.2            | —          | —           |
| 54     | <i>Ficus capensis</i> <sup>Φ</sup>            | Moraceae       | —              | 3.9        | —           |
| 55     | <i>Ficus dawei</i> <sup>‡</sup>               | Moraceae       | 6.5            | —          | —           |
| 56     | <i>Ficus exasperata</i>                       | Moraceae       | 6.5            | 30.8       | 7.1         |
| 57     | <i>Ficus mucoso</i>                           | Moraceae       | 6.5            | 7.7        | —           |
| 58     | <i>Ficus natalensis</i> <sup>Φ</sup>          | Moraceae       | —              | 3.9        | —           |
| 59     | <i>Ficus ovata</i> <sup>Φ</sup>               | Moraceae       | —              | 3.9        | —           |

TABLE 2: Continued.

| S. no. | Species   | Family          | Occurrence (%) |            |             |
|--------|---|-----------------|----------------|------------|-------------|
|        |   |                 | Kibale NP      | Mabira CFR | Budongo CFR |
| 60     | <i>Ficus saussureana</i> <sup>ψ</sup>           | Moraceae        | —              | —          | 3.6         |
| 61     | <i>Funtumia africana</i> <sup>‡</sup>           | Apocynaceae     | 54.8           | —          | —           |
| 62     | <i>Funtumia elastica</i>                        | Apocynaceae     | 3.2            | 50.0       | 21.4        |
| 63     | <i>Glyphaea brevis</i> <sup>ψ</sup>             | Malvaceae       | —              | —          | 3.6         |
| 64     | <i>Greenwayodendron suaveolens</i> <sup>ψ</sup> | Annonaceae      | —              | —          | 10.7        |
| 65     | <i>Guarea cedrata</i> <sup>ψ</sup>              | Meliaceae       | —              | —          | 7.1         |
| 66     | <i>Harungana madagascariensis</i>               | Guttiferae      | 3.2            | 3.9        | 3.6         |
| 67     | <i>Holoptelea grandis</i>                       | Ulmaceae        | —              | 7.7        | 7.1         |
| 68     | <i>Khaya anthotheca</i> <sup>ψ</sup>            | Meliaceae       | —              | —          | 7.1         |
| 69     | <i>Khaya senegalensis</i> <sup>ϕ</sup>          | Meliaceae       | —              | 7.7        | —           |
| 70     | <i>Kigelia africana</i>                         | Bignoniaceae    | 9.7            | 7.7        | —           |
| 71     | <i>Klainedoxa gabonensis</i> <sup>ψ</sup>       | Irvingiaceae    | —              | —          | 3.6         |
| 72     | <i>Lasiodiscus mildbraedii</i> <sup>ψ</sup>     | Rhamnaceae      | —              | —          | 53.6        |
| 73     | <i>Leptonychia mildbraedii</i> <sup>‡</sup>     | Malvaceae       | 12.9           | —          | —           |
| 74     | <i>Linociera johnsonii</i>                      | Oleaceae        | 3.2            | —          | —           |
| 75     | <i>Lychmodiscus cerospermus</i> <sup>ψ</sup>    | Sapindaceae     | —              | —          | 10.7        |
| 76     | <i>Macaranga kilimandscharica</i> <sup>‡</sup>  | Euphorbiaceae   | 3.2            | —          | —           |
| 77     | <i>Macaranga spinosa</i> <sup>ϕ</sup>           | Euphorbiaceae   | —              | 15.4       | —           |
| 78     | <i>Maerua duchesnei</i>                         | Capparaceae     | —              | 3.9        | 7.1         |
| 79     | <i>Maesa lanceolata</i> <sup>‡</sup>            | Myrsinaceae     | 3.2            | —          | —           |
| 80     | <i>Maesopsis eminii</i>                         | Rhamnaeae       | 3.2            | —          | 3.6         |
| 81     | <i>Mammea africana</i> <sup>ψ</sup>             | Guttiferae      | —              | —          | 7.1         |
| 82     | <i>Manilkara butugi</i>                         | Sapotaceae      | —              | 11.5       | 3.6         |
| 83     | <i>Manilkara dawei</i> <sup>ψ</sup>             | Sapotaceae      | —              | —          | 3.6         |
| 84     | <i>Margaritaria discoidea</i>                   | Phyllanthaceae  | 3.2            | 38.5       | 7.1         |
| 85     | <i>Markhamia lutea</i>                          | Sapotaceae      | 41.9           | 15.4       | —           |
| 86     | <i>Melanodiscus spp.</i> <sup>ψ</sup>           | Sapindaceae     | —              | —          | 3.6         |
| 87     | <i>Millettia dura</i> <sup>‡</sup>              | Leguminosae     | 9.7            | —          | —           |
| 88     | <i>Mildbraediendron excelsum</i> <sup>ψ</sup>   | Leguminosae     | —              | —          | 3.6         |
| 89     | <i>Mimusops bagshawei</i>                       | Sapotaceae      | 22.6           | 30.8       | —           |
| 90     | <i>Monodora excelsa</i> <sup>‡</sup>            | Annonaceae      | 16.1           | —          | —           |
| 91     | <i>Monodora myristica</i> <sup>ϕ</sup>          | Annonaceae      | —              | 3.9        | —           |
| 92     | <i>Myrianthus holstii</i>                       | Moraceae        | 6.5            | 7.7        | 10.7        |
| 93     | <i>Neoboutonia macrocalyx</i> <sup>‡</sup>      | Euphorbiaceae   | 3.2            | —          | —           |
| 94     | <i>Newtonia buchananii</i>                      | Leguminosae     | 16.1           | 7.7        | —           |
| 95     | <i>Pancovia turbinata</i> <sup>‡</sup>          | Sapindaceae     | 25.8           | —          | —           |
| 96     | <i>Parinari excelsa</i> <sup>‡</sup>            | Rosaceae        | 16.1           | —          | —           |
| 97     | <i>Phoenix spp.</i> <sup>‡</sup>                | Arecaceae       | 6.5            | —          | —           |
| 98     | <i>Piptadeniastrum africanum</i> <sup>ϕ</sup>   | Leguminosae     | —              | 11.5       | —           |
| 99     | <i>Polyscias fulva</i>                          | Araliaceae      | 3.2            | 11.5       | —           |
| 100    | <i>Premna angolensis</i> <sup>‡</sup>           | Verbenaceae     | 9.7            | —          | —           |
| 101    | <i>Prunus africana</i>                          | Rosaceae        | 6.5            | 3.9        | —           |
| 102    | <i>Pterygota mildbraedii</i> <sup>‡</sup>       | Malvaceae       | 3.2            | —          | —           |
| 103    | <i>Ricinodendron heudelotii</i> <sup>ψ</sup>    | Euphorbiaceae   | —              | —          | 10.7        |
| 104    | <i>Rinorea ardisiaeflora</i> <sup>ψ</sup>       | Violaceae       | —              | —          | 21.4        |
| 105    | <i>Rinorea brachypetala</i> <sup>ψ</sup>        | Violaceae       | —              | —          | 17.9        |
| 106    | <i>Rinorea dentata</i> <sup>ψ</sup>             | Violaceae       | —              | —          | 3.6         |
| 107    | <i>Rinorea ilicifolia</i>                       | Violaceae       | —              | 11.5       | 3.6         |
| 108    | <i>Ritchiea albersii</i> <sup>ψ</sup>           | Capparaceae     | —              | —          | 3.6         |
| 109    | <i>Rothmannia whitfieldii</i> <sup>‡</sup>      | Rubiaceae       | 16.1           | —          | —           |
| 110    | <i>Sapium ellipticum</i> <sup>‡</sup>           | Euphorbiaceae   | 9.7            | —          | —           |
| 111    | <i>Scolopia rhamniphylla</i> <sup>‡</sup>       | Flacourtiaceae  | 12.9           | —          | —           |
| 112    | <i>Solanum mauritianum</i> <sup>‡</sup>         | Solanaceae      | 3.2            | —          | —           |
| 113    | <i>Spathodea campanulata</i>                    | Bignoniaceae    | 3.2            | 3.9        | 14.3        |
| 114    | <i>Sterculia dawei</i> <sup>ϕ</sup>             | Malvaceae       | —              | 11.5       | —           |
| 115    | <i>Strombosia scheffleri</i> <sup>‡</sup>       | Olacaceae       | 12.9           | —          | —           |
| 116    | <i>Strombosia spp.</i>                          | Olacaceae       | —              | 3.9        | —           |
| 117    | <i>Tabernaemontana holstii</i>                  | Apocynaceae     | 45.2           | 50.0       | 17.9        |
| 118    | <i>Tapura fischeri</i> <sup>ψ</sup>             | Dichapetalaceae | —              | —          | 3.6         |

TABLE 2: Continued.

| S. no. | Species                                    | Family        | Occurrence (%) |            |             |
|--------|--|---------------|----------------|------------|-------------|
|        |  |               | Kibale NP      | Mabira CFR | Budongo CFR |
| 119    | <i>Teclea grandifolia</i> <sup>Φ</sup>     | Rutaceae      | —              | 11.5       | —           |
| 120    | <i>Teclea nobilis</i>                      | Rutaceae      | 71.0           | 26.9       | 3.6         |
| 121    | <i>Tetrapleura tetraptera</i> <sup>Ψ</sup> | Leguminosae   | —              | —          | 17.9        |
| 122    | <i>Thecocariss lucida</i> <sup>Ψ</sup>     | Euphorbiaceae | —              | —          | 14.3        |
| 123    | <i>Trema orientalis</i>                    | Ulmaceae      | —              | 3.9        | 3.6         |
| 124    | <i>Trichilia dregeana</i>                  | Meliaceae     | 9.7            | 26.9       | —           |
| 125    | <i>Trichilia mantineana</i> <sup>Φ</sup>   | Meliaceae     | —              | 11.5       | —           |
| 126    | <i>Trichilia prieureana</i> <sup>Ψ</sup>   | Meliaceae     | —              | —          | 14.3        |
| 127    | <i>Trichilia rubescens</i>                 | Meliaceae     | —              | 42.3       | 17.9        |
| 128    | <i>Trichilia welwitschii</i> <sup>Φ</sup>  | Meliaceae     | —              | 3.9        | —           |
| 129    | <i>Trilepisium madagascariense</i>         | Moraceae      | 19.4           | 61.5       | 7.1         |
| 130    | <i>Uvaria welwitschii</i> <sup>‡</sup>     | Annonaceae    | 3.2            | —          | —           |
| 131    | <i>Uvariopsis congensis</i>                | Annonaceae    | 64.5           | 3.9        | 3.6         |
| 132    | <i>Vitex amboniensis</i> <sup>Ψ</sup>      | Verbenaceae   | —              | —          | 3.6         |
| 133    | <i>Voacanga thouarsii</i> <sup>Φ</sup>     | Apocynaceae   | —              | 19.2       | —           |
| 134    | <i>Warburgia ugandensis</i> <sup>‡</sup>   | Canellaceae   | 16.1           | —          | —           |
| 135    | <i>Xymalos monospora</i> <sup>‡</sup>      | Monimiaceae   | 6.5            | —          | —           |

<sup>Φ</sup>Species was unique to sites of occurrence of *C. articulata* in Mabira Central Forest Reserve; <sup>Ψ</sup>species was unique to sites of occurrence of *C. articulata* in Budongo Central Forest Reserve; <sup>‡</sup>species was unique to sites of occurrence of *C. articulata* in Kibale National Park; — species not sighted at the site of occurrence of *C. articulata* in that particular forest.

plant communities could be a sign that these communities provide a conducive environment for the growth and regeneration of *C. articulata*. Plant species of genera such as *Chrysophyllum*, *Funtumia*, *Celtis*, and *Cynometra* often form large crowns that make up the canopy layer in the forest. Studies have shown that canopy plant species often has exerting influence on microsite conditions, thus acting as a biodiversity filter upon the plants that attempt to regenerate in the understory [90, 91]. The fact that *C. articulata* was majorly observed occurring under canopy-shaded areas is an indication that this plant species is shade tolerant. Shade-tolerant plant species are highly sensitive to the understory light heterogeneity in a tropical forest which is often influenced by the canopy cover [92]. Furthermore, plants are capable of detecting and responding to neighboring plants, thus producing consequences for plant performance and playing an important role in plant's phytochemistry [93]. This implies that neighboring plants may also have an effect on the production of secondary metabolites by *C. articulata* which consequently has an effect on the efficacy of the plant when used for medicinal purposes. Some co-occurring species such as *Chrysophyllum*, *Cynometra*, and *Celtis* are sought after for timber forest products (TFPs) and charcoal production. Therefore, occurrence of *C. articulata* around these plant communities increases its vulnerability to destruction or harvest. Insights into plant communities associated with *C. articulata* occurrence provided by this study are very important for any ex situ conservation efforts.

**3.4. Implication for Ex Situ Conservation of *C. articulata*.** Knowledge about physiographic factors governing plant growth is important for conservation and management strategies of any plant species both in situ and ex situ especially for species like *C. articulata* that shows restricted occurrences

and is under threat from unsustainable harvesting methods, habitat degradation, and possibly climate change. In a case where forest management fails to provide the necessary protection and consequently conservation, ex situ conservation such as growing the plant outside the wild becomes a safety backup for in situ conservation and an alternative source of plant harvest and use [15]. Our findings offer insights into the soil conditions and topographical requirements of *C. articulata*, in addition to the associated plant species assemblages. These parameters are central to identifying suitable sites for any ex situ conservation program be it translocation, living gene banks, herbal gardens, or offsite production of *C. articulata*.

#### 4. Conclusion

The current study has shown that although *C. articulata* is generally low occurring, it is significantly abundant in Kibale National Park, a forest currently managed by Uganda Wildlife Authority (UWA). This points to a fact that *C. articulata* can thrive in areas where human access, and consequently anthropogenic activities are highly restricted and therefore consequently vulnerable in Budongo and Mabira Central Forest Reserves that are not highly restricted. Therefore, this calls for continuous monitoring of species at risk such as *C. articulata* and enhanced and effective enforcement of existing laws governing management of Central Forest Reserves for their successful management and conservation. Findings also revealed that *C. articulata* generally occurs at moderate altitudinal landscapes with soils that are moderately acidic, low in salinity, and having considerable levels of macro- and micronutrients. *C. articulata* is generally associated with plant communities dominated by canopy tree species of genera such as *Chrysophyllum*, *Celtis*, *Markhamia*, *Cynometra*, *Lasiodiscus*, *Trilepisium*, *Funtumia*, and *Diospyros*, thus suggesting that



*C. articulata* is a shade-tolerant species. Understanding these ecological requirements of this plant species among other things unlocks the potential for ex situ production of this plant. This will not only provide alternative sources of plant harvest but also go a long way in relieving the current harvest pressures exerted on the wild populations of this plant species and also act as backup for in situ conservation.

## Data Availability

Datasets used in this study will be made available by the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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