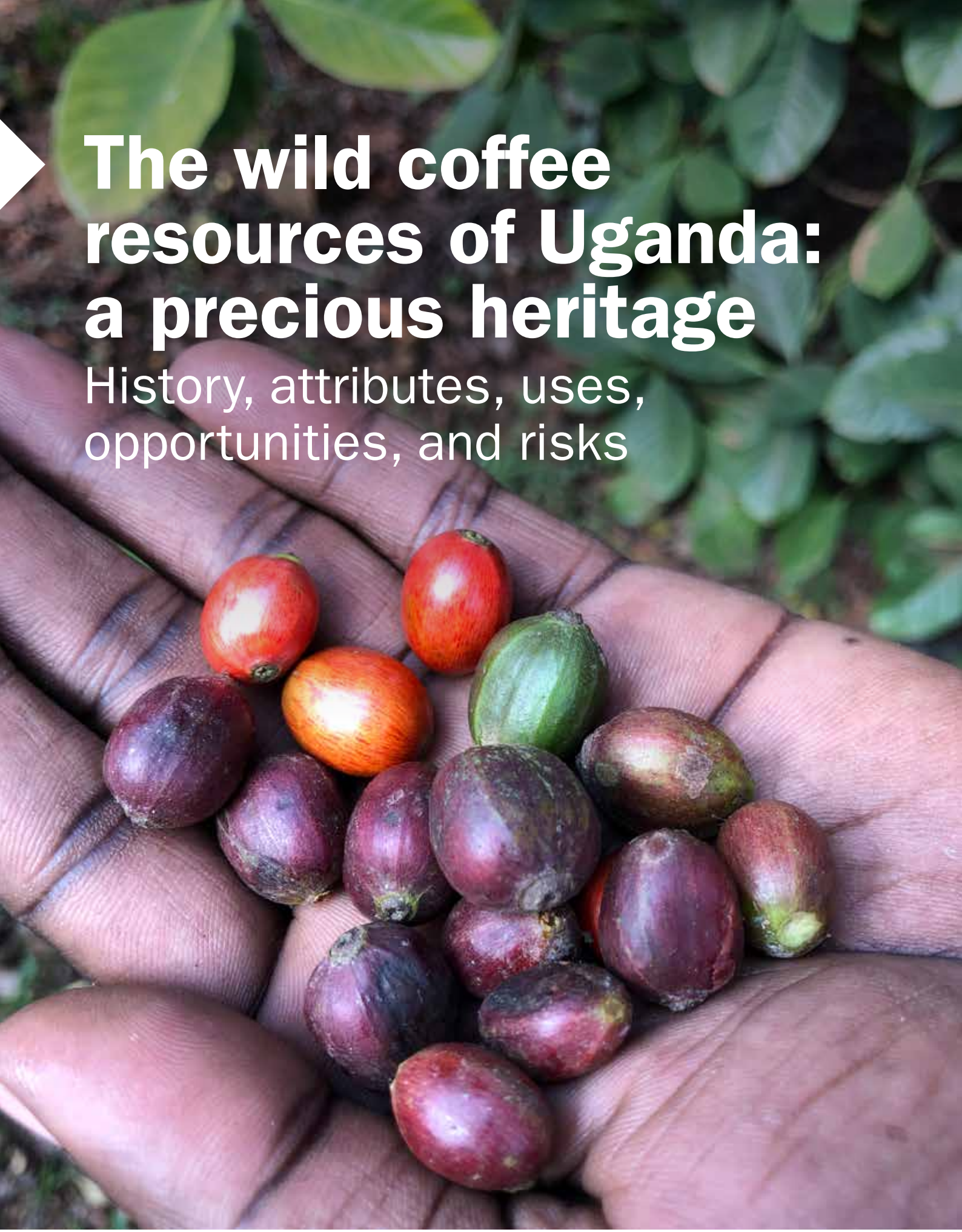

The wild coffee resources of Uganda: a precious heritage

History, attributes, uses, opportunities, and risks

Royal Botanic Gardens Kew

DARWIN INITIATIVE

NARO

Volcafe Group / Uganda KYAGALANYI

The wild coffee resources of Uganda: a precious heritage

History, attributes, uses, opportunities, and risks

The Coffee Natural Capital of Uganda

Coffee natural capital for environmental and livelihood sustainability in Uganda was a three-year project (October 2020 to September 2023) funded by the Darwin Initiative and undertaken by a team in Uganda (The National Agricultural Research Organization (NARO), Makerere University, and Kyagalanyi Coffee Ltd. (Volcafe) and the UK (Royal Botanic Gardens, Kew). The main objectives of the project were to: undertake a detailed survey of Uganda's wild coffee species (coffee natural capital), including conservation status and extinction risk; conduct farm and field trials, agronomic assessments, and value chain appraisals for excelsa coffee; undertake preliminary agronomic assessment of eugenioides coffee; and demonstrate the value of Uganda's coffee natural capital for ecosystem service provision, livelihood improvement, and coffee sector sustainability.

The Darwin Initiative

The Darwin Initiative is a UK government grants scheme that helps to protect biodiversity and the natural environment through locally based projects worldwide.

Project partners and authors

The authors of this report are Aaron P. Davis and Aisyah Faruk (Royal Botanic Gardens, Kew); Catherine Kiwuka, John W. Mulumba, and Moses Lumu (The National Agricultural Research Organization (NARO, Kampala); Geert Jan Heusinkveld and Mweru Job Walubiri (Kyagalanyi Coffee Ltd. (Volcafe, Kampala); and James Kalema (Makerere University, Kampala).

This report should be cited as: Davis, A.P., Kiwuka, C., Faruk, A., Walubiri, M. J., Lumu, M., Mulumba, J.W., Heusinkveld, G.J. and Kalema, J. (2023). The wild coffee resources of Uganda: a precious heritage. Royal Botanic Gardens, Kew (UK). Pp. 44.

https://doi.org/10.34885/fdtw-m431

Robusta coffee

The wild coffee resources of Uganda
Key messages

1
Uganda is home to four indigenous (wild) coffee species

Coffea canephora (robusta coffee), *C. eugenioides* (eugenioides coffee), *C. dewevrei* (excelsa coffee) and *C. neoleroyi* are wild plants of Uganda. In their wild state these four species are only found in natural, undisturbed forest and woodland.

2
Ugandan forests house important coffee genetic diversity

Uganda is home to numerous wild populations of *C. canephora* (robusta) and *C. eugenioides* (eugenioides), and the eastern-most populations of *C. dewevrei* (excelsa). The genetic diversity in these wild populations is unique and of global significance.

3
Indigenous robusta coffee has been instrumental in the foundation, development, and sustainability of the Ugandan coffee sector

Wild populations of *C. canephora* (robusta) from Uganda have been used to establish, develop, and sustain robusta coffee production in Uganda and other countries. The control of coffee wilt disease (CWD) in Uganda continues to rely on the use of these wild resources.

4
Uganda's wild coffee resources could play a crucial role in the long-term sustainability of the Ugandan coffee sector

In an era of accelerated climate change, wild *C. canephora* (robusta), *C. eugenioides* (eugenioides), and *C. dewevrei* (excelsa) could provide key resources for coffee crop plant development, via selection, breeding, and other practices and technologies. Climate resilience, disease and pest resistance, and value chain performance, are key priorities.

5
Uganda's wild coffee species are at risk

Many populations of wild coffee in Uganda are under threat, due to climate change and human activity, such as encroachment, particularly for agriculture, illegal logging and charcoal burning. At the national level, *C. dewevrei* (excelsa) is Endangered, and *C. neoleroyi* may be Critically Endangered, when assessed using the categories and criteria of the IUCN Red List of Threatened Species.

6
Uganda's forests are at risk and require improved conservation measures

Zoka Central Forest Reserve, and several other forested areas, are under considerable human pressure and urgently require improved conservation measures to protect coffee genetic resources. There is an urgent need for forest restoration, collaborative forest management and other community-based initiatives.

Ripe fruits of excelsa coffee

Contents

Dr Robert Acidri holding wild plants of *Coffea eugenioides* (left) and *C. canephora* (right) at Itwara Central Forest Reserve

1 Introduction

Uganda is the world's seventh largest coffee exporter, and the fourth largest producer of robusta coffee (*Coffea canephora*) after Vietnam, Brazil, and Indonesia; and the second largest exporter of coffee in Africa, after Ethiopia. In 2021/22 Uganda exported c. 351,500 metric tons (mt) of coffee, with robusta contributing 83% and Arabica 17 %[3]. As a commodity crop, coffee accounts for 20–30% of the foreign exchange earnings for Uganda, with an estimated 1.8 m households engaged in coffee farming alone[4], and many more in post-farm coffee sector activities.

The farming of robusta coffee in Uganda, as a food and as a masticatory (i.e., for chewing), is at least 200 years old[5]; the harvesting of robusta from natural forests probably dates back millennia. National and cross-border trade in robusta was underway in the mid-nineteenth century, with exportation starting at the beginning of the twentieth century[6]. Arabica coffee was introduced to Uganda around 1900, and after a difficult start, became a key crop in several districts. Coffee production for export increased dramatically from the 1920s to the late 1940s, and then steadily increased from the late 1950s to the present day, albeit with notable peaks and troughs, due to low prices, disease, and unfavourable weather. Overall, the Ugandan coffee industry has been a success of global proportion.

In the twenty-first century, there remain many challenges for coffee production in Uganda, and globally. Most of the constraints have existed since the globalization of coffee, but all are exacerbated and compounded by climate change, which is perceived as the most important overarching threat to the long-term sustainability of the coffee sector[7].

Dealing with climate change will require timely and effective mitigation, i.e., a reduction in greenhouse gas emissions (GHGEs) to the levels required to cease global warming. Alongside mitigation, timely, affordable, and successful adaptation measures will be essential, until the foreseeable future. For coffee farming, there are three main adaptation pathways[7,8]: (1) the relocation of coffee farming to new areas with (existing or emerging) suitable climatic conditions, especially those at higher elevations; (2) the implementation of improved agricultural practices to ensure on-farm climate resilience (to climate change and climate variability); and (3) the development of new, drought and heat tolerant coffee crop types, which retain or gain pest and disease resistance charcteristics. Migration of coffee to higher elevations, possibly in conjunction with intensification and on-farm climate adaptation measures, has considerable potential for those countries with extensive elevation range, such as Ethiopia[9]. This option would only offer limited potential for Uganda, and, as in other countries, would invoke unwanted societal change and other major challenges. Modification of the coffee growing environment on farms, using agronomic interventions and improved farming practices (e.g., the use of mulch, implementing shade or adopting improved shade management, and irrigation) provides climate adaptation potential. These interventions are, of course, associated with additional year-on-year costs, and in many cases would not provide long-term effectiveness against climate change. Moreover, many Ugandan farmers already adopt good agronomic practices (GAPs), leaving limited capacity for further beneficial adaptation.

Dealing with climate change will require timely and effective mitigation, i.e., a reduction in greenhouse gas emissions (GHGEs) to the levels required to cease global warming.

Of the three main adaptation options, developing new coffee crop types is likely to be the least disruptive, the most cost-effective and probably the most successful[7], but effective adaptation is likely to require aspects of one or more of the other main adaptive pathways.

Unlike most other major coffee-producing countries, Uganda is well placed to develop new coffee crop types, as it houses considerable wild genetic resources of three key coffee species, namely robusta (*C. canephora*), eugenioides (*C. eugenioides*) and excelsa (*C. dewevrei*). Wild robusta coffee has already been instrumental in the origin, development and sustainability of the Ugandan robusta sector, and robusta production globally[10,11]; excelsa is demonstrating value chain potential and climate resilience attributes[8,10]; all three species have the potential for use in interspecies breeding programmes.

In this publication, we provide detailed information on the indigenous (wild) coffee species of Uganda, including their identification, biology, ecology (with a focus on climate), conservation, historical and current-day crop usage, other uses, and their potential for coffee crop development in a changing world. We aim to demonstrate the immense value of Uganda's coffee natural capital and forest habitats, for the long-term sustainability of the Ugandan coffee sector, and the critical need for the conservation of these precious natural resources.

Watering robusta coffee during an interannual dry period

2
The coffee crop species of Uganda

Robusta coffee (*Coffea canephora*)

History

Robusta is an indigenous species of western and central tropical Africa, with the eastern most populations occurring in Uganda. There is a diverse and long-standing relationship between robusta coffee and the peoples of Uganda. Well before the development of this species as a coffee crop, it was commonly used in many areas of Uganda for chewing, as a food, and as a food ingredient. It was also used for traditional and ritualistic purposes, including the serving of beans to guests as a welcome gesture, and as an emblem of brotherhood and deep friendship. Even though many of these activities are no longer in common use, some have prevailed, such as the use of robusta coffee beans in traditional marriage ceremonies in the Buganda culture. Chewing of dried robusta fruits was common in the nineteenth and early twentieth centuries, but no doubt dates to previous centuries[6]. Chewing is still undertaken today, and small packets of dried robusta fruits, wrapped in dried banana leaves, can be found in small roadside stalls. To produce the chewing product, the fruit is picked just before ripeness, steamed and dried, and sometimes lightly roasted with butter[12,13]. During the nineteenth century, there was a vibrant trade in coffee for chewing, which existed between the Ssese Islands (of Lake Victora; now in Kalangala District) and surrounding mainland regions, to markets in the north, and to the south across the border to Tanzania[6]. This trade would have required substantial farming effort. For example, in 1862, the following observation was made in Masaka: 'This [robusta coffee] grows in great profusion all over the land…"[14]. At that time robusta was believed to be Arabica coffee (*C. arabica*)[14], or a large-leaved variant of Arabica[13]. Robusta coffee (*C. canephora*) was unknown to science until 1897.

Owing to the farming and trade in robusta for chewing, Uganda was well placed to develop coffee as a major crop. The first exports of robusta as a beverage (coffee), occurred in 1902, mainly from the Ssese Islands[6]. From 1910, and especially from 1916 onwards, selections of indigenous robusta variants, as well as imports of central African robusta types via Java[15], were undertaken to develop the robusta crop plant in Uganda[12]. This happened despite an initial interest in developing Arabica rather than robusta[15]. Early selections included those made by indigenous farmers, for attributes such as large bean size, high yield, and disease resistance. Some of these selections were named and widely planted, including 'Makonde', 'Namata', and 'Musenz'alanda'[12]. With the support of government-mediated robusta seedling distribution in the early 1920s, particularly of the cultivars 'Toro' and 'No. 9 Selection', and plants from central Africa, the acreage under robusta cultivation increased dramatically. In 1925 there were reported to be 1,284 acres (520 hectares (ha)) under production, increasing to 23,075 acres (9,340 ha) in 1935[5]. In 1925, production output was led by European and Asian growers, but by 1935 Ugandan farmers dominated robusta production[5,6,16]. During this period the popular 'No.

Owing to the farming and trade in robusta for chewing, Uganda was well placed to develop coffee as a major crop. The first exports of robusta as a beverage (coffee), occurred in 1902, mainly from the Ssese Islands[6].

9 Selection' was succeeded by the shorter and more compact 'Nganda', but with 'erecta' (e.g. the 'No. 9 Selection') still playing a key role in production. By 1947, robusta production increased to 164,584 acres (66,600 ha)[15]. An extensive production development programme for robusta was undertaken in the 1950s[1] and by the 1958/59 season the exports were around 94,000 metric tons (mt)[15], which amounts to around 223,950 acres (90,630 ha). This dramatic increase was followed by a steady growth in exports from the 1960s onwards, with peaks in production during the late 1960s, early 1970s and the late 1990s. After a peak in robusta production in 1996/97 (c. 230,000 mt), there followed a steady decline until 2005/06 (c. 84,500 mt)[17], due to the rapid spread and extreme severity of coffee wilt disease[18]. Coffee wilt disease was first detected in Uganda in 1993, and by the end of 2000 it had spread to all robusta growing zones of the country[18]. It is difficult to understand the exact impact of the disease, but it has been estimated to represent a loss of farm income from coffee of US$580 million for the years 1997 through 2007[18].

The main intervention to resolve the coffee wilt disease crisis was the screening of many thousands of robusta plants for resistance to the disease. This work has resulted in the identification and selection of ten coffee wilt disease-resistant (CWD-r) clones (KR1 to KR10), and from 2010 onwards[19] the production and widespread release of seven CWD-r clones. The CWD-r clones are high-yielding and mostly of high cup quality[20]; they now provide the stock for the backbone of modern robusta cultivation in Uganda. The CWD-r clones are based on material originally collected from indigenous populations in the southern-central forests of Uganda, particularly from the forests of Malabigambo, Mabira, and Kalangala (Ssese Islands, Lutoboka), as well as introduced germplasm from central Africa[11] some of which was introduced via Java[5,15]. The adoption of CWD-r clones, alongside other measures, resulted in coffee wilt disease being considered as 'controlled' by 2011[21].

Since 2017, Uganda regularly exports more than 200,000 mt of robusta[3], and more recently (2019/20–2021/22) in excess of 250,000 mt, with almost 350,000 mt in the 2020/21 season[17].

Robusta coffee intercropped with banana

Coffee farming areas and mean temperature

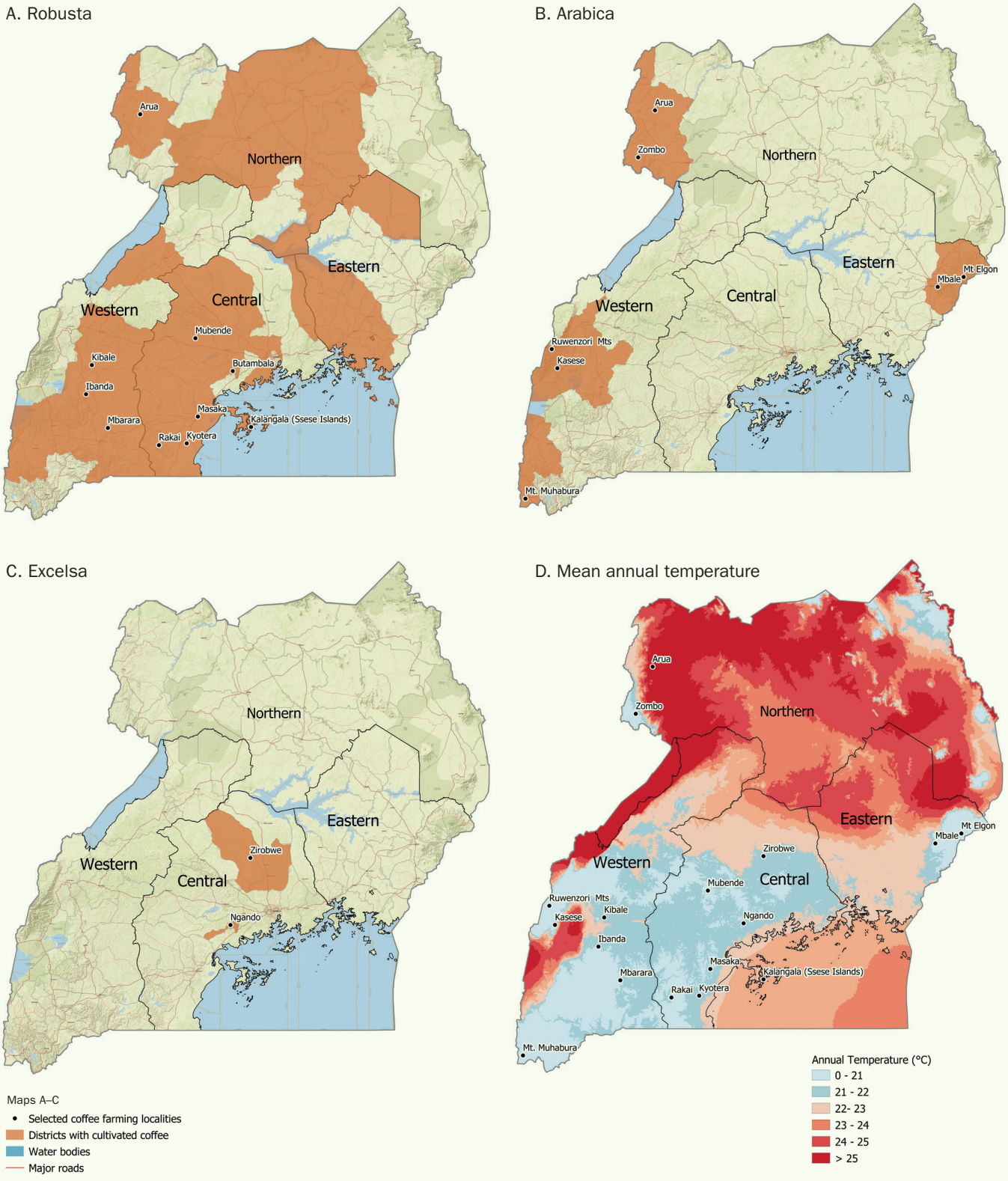

Figure 1. Maps of farmed coffee in Uganda at the district level, with labels to indicate selected coffee farming localities, and temperature map. **A.** Robusta coffee (*Coffea canephora*). **B.** Arabica coffee (*C. arabica*). **C.** Excelsa coffee (*C. dewevrei*). **D.** Mean annual temperature map. Notes: Coffee farming areas based on Uganda Coffee Development Authority publications[1,2]. Main boundaries and large labels depict the four regions of Uganda (Northern, Eastern, Central and Western). For Maps A–C base map also includes relief and and major protected areas. Farming location labels are indicative, e.g., coffee farming at Arua occurs in cooler and wetter areas to the west.

Present day

Robusta farming occurs over a large area of Uganda, although it is generally absent from the higher elevation areas where Arabica is cultivated and the north-eastern part of the country, where the climate is unsuitable for coffee farming (Figures 1a, 8). Most of the coffee is produced by smallholders, on farms of 0.5–4 acres (0.2–1.6 ha), with a reported average farm size of 0.45 acres (0.18 ha)[4]. Production systems are either monocrop or interplanted as a mixed farming system with food crops, especially bananas (see page 8) and maize[22]. Shade trees are often planted, or existing trees are utilized as shade, but agroforestry systems with considerable shading are rare. In many cases, shade trees are absent or in low numbers. Yields typically range from 600–1,200 kg/ha of clean coffee[4] but vary considerably depending on location, inputs, and management. Under ideal conditions, the new (CWD-r) robusta clones are reported to yield around 3,000 kg/ha of clean coffee[1]. The main harvest time depends on location: in the Central, Eastern and Northern Regions the main crop harvest generally occurs November–February, with a (smaller) fly crop May–July. In the Masaka area (Central Region) and Western region, the main crop harvest is usually April–July, and fly crop November–February[1].

Most of the robusta produced in Uganda is processed as natural coffee: sun-dried on the ground, tarpaulins, or concrete. The sun-dried fruits ('cherry') are universally referred to in Uganda as 'kiboko', and this is the main form in which the coffee is purchased from the farmers. Uganda produces a small proportion of high-quality (fine) robusta, which may be produced as a natural coffee on raised beds, or the fruits are pulped and then either partially or fully washed.

Elevations of 1,100–1,500 m are generally the most suitable for robusta farming in Uganda, but in some areas it is grown at around 900 m[1]. Successful robusta farming in Uganda requires a total annual rainfall (precipitation) of 1,200–1,800 mm[22], with sufficient rainfall during the lower rainfall periods (see below). If soil moisture is inadequate during the drier periods, irrigation is required[1]. Nearly all robusta growing areas experience a bimodal rainfall distribution, with low rainfall during January–February and June–July. The exception is in the north-west of Uganda, where there is a unimodal rainfall distribution, with a low rainfall period during December–February. The mean annual temperature requirement for robusta in Uganda is 22–23 °C, with an optimum daily temperature range of 17–28 °C. The soil should be slightly acidic, with a pH range of 5.5–6.5, and well supplied with all the essential major plant nutrients[1].

Robusta coffee grown in Uganda has a variety of flavour profiles, depending on the locality (which dictates soil type and condition, climate parameters, and other factors), the cultivar or variant used (i.e., genetic factors), harvesting, and processing methods[20,23]. According to *Ugandan Coffee Profiles*[23], Uganda-grown robusta is characterised by: caramel, spicy, and/or herby fragrance; a caramel aroma; nutty, tropical fruit, and/or spicy flavour notes; low to medium bitter-sweet and acid-salt tastes; and spicy and/or dried fruit aftertaste. Robusta grown at higher elevations tends to be more acidic and more complex, and at lower elevations more intensely flavoured[1].

Further information on robusta coffee farming and other production details can be found in the *Robusta Coffee Handbook*[1] and other UCDA resources[24].

Most of the robusta produced in Uganda is processed as natural coffee: sun-dried on the ground, tarpaulins, or concrete. The sun-dried fruits ('cherry') are universally referred to in Uganda as 'kiboko', and this is the main form in which the coffee is purchased from the farmers.

Arabica coffee (*Coffea arabica*)

History

Arabica coffee is an indigenous plant of the highlands of southwestern and southern Ethiopia and in neighbouring South Sudan on and around the Boma Plateau[25]. Arabica was introduced into Uganda at the beginning of the twentieth century, by government agents and the Catholic Church acting independently[26]. The Arabica imported by government representatives came from Nyasaland (now Malawi), probably in 1900, and was represented by the cultivar 'Nyasa', sometimes referred to as 'Nyasaland', an Arabica of the 'Typica' type[15, 26]. Meanwhile, in 1900, seeds of the 'Bourbon' type of Arabica arrived in Uganda via Tanzania, by the hand of a Catholic priest[26]. Soon afterwards, Arabica cultivars were introduced from other sources, including 'Maragogype' (in 1901), 'Blue Mountain' and 'Guatemala' (in 1903)[26]. These early introductions were originally grown in 'lowland' locations (1,000–1,400 m), including areas around Entebbe, and in Kakumiro and Masaka. From there, Arabica cultivation was extended to other locations, including higher elevation areas in Bugisu on the western slopes of Mount Elgon. By 1913 there were 10,000 acres (4,050 hectares (ha)) under cultivation.

Arabica coffee plantation at Bugata, Mayuge District, at c. 1150 m (1922)

The expansion of Arabica rapidly continued until the early 1920s, when there were reported to be 20,783 acres (8,410 ha) on foreign planter's estates[26]. After 1920, the cultivation of Arabica in Uganda rapidly declined, mostly due to the failure of plantations at lower elevations, but also because of low prices. At low elevations, Arabica grew and cropped very well in the first few years of establishment, but soon afterwards yields declined and the flavour quality deteriorated[15]. The initial high performance has been put down to the vigour of the young crop, but ultimately the climate of the lowland areas where Arabica was first planted (1,000–1,400 m) did not suit this species. Arabica succeeds in a cool tropical climate with a marked lower rainfall season (3–4 months), whereas the low-elevation areas of Uganda are warm-tropical and lack a distinct drier period. In many areas, Arabica was also badly affected by the antestia bug (*Antestiopsis* sp.), which feeds on all vegetative, flowering, and fruiting parts of the coffee plants, resulting in yield losses and either poor quality or unmarketable coffee. High production and transportation costs also contributed to its decline during the 1920s and 1930s, especially during periods of low prices. Most smallholder farmers growing coffee at lower elevations were not in favour of Arabica cultivation from the outset[15,26], being of the firm opinion that robusta was far better suited to the growing environment of their farms.

The situation for early Arabica farming in the Mount Elgon area was quite different. The lower slopes of Mount Elgon (its peak at 3,070 m) provided cooler temperatures, a rainfall of at least 1,300 mm per annum, and a period of lower rainfall between mid-December to mid-March, conditions suitable for growing Arabica coffee. The Bugisu people were also key to its success[27]. The precise date of introduction of Arabica coffee to the Mount Elgon area is unclear, but free distribution of the Nyasaland Arabica cultivar ('Nyasa') took place in 1912. By 1913 there were about three acres planted and bearing fruits[27], and by 1935 there were some 5,000 acres (2,020 ha) under cultivation[15]. From 1922, hand pulping machines were distributed to cooperatives, and by 1930 three pulping stations and a processing factory were built at Bubulo[26]. These resources enabled the production of high-quality Arabica on a par with long-established Arabica-producing countries in East Africa, such as Kenya. From the early 1940s onwards 'Nyasa' was largely replaced by Arabica cultivars of the 'Kent's' series, including 'KP423' and 'KP 162'[2,15], although other cultivars were introduced and trialled[26].

Figure 2. Arabica coffee (*Coffea arabica*). Flowering and fruiting branches, whole and cut fruits, seed with parchment, and seed (coffee bean). Scale bar = 2 cm. Illustration by Lucy T. Smith ©.

Planting of Arabica in the Toro (Tooro) Kingdom of western Uganda, which today includes several districts close to or adjoining the Ruwenzori Mountains and to the south of Lake Albert, started in the period 1910–1912[28]. When commercial coffee cultivation was extended to other areas, such as those in the south-west, around 1915, it soon became apparent that Arabica had to be grown in the higher elevation areas of these regions and robusta in the lower ones[27], although even today one might see mixed plantings of both species at elevations of 1,300–1,500 m in this area of western Uganda.

Arabica production slowly but steadily increased until the early 1990s, when production started to accelerate dramatically, following Uganda's coffee sector liberalization and greater investment in farming Arabica, and perhaps also because of the declining output of robusta due to coffee wilt disease (CWD). For example, in the 1991/1992 harvest year production was around 10,150 metric tons (mt), in 2000/2001 it was c. 27,600 mt, in 2010/2011 c. 39,900 mt, and 2021/2022 c. 59,200 mt. From 2010/11–2021/22 Arabica has provided around 20% of Uganda's total coffee exports, despite the substantial increase in robusta production over the same period (see above).

Present day

Arabica farming in Uganda is undertaken in high-elevation areas of the Western Region (Ruwenzori Mountain area, and the Kigezi Highlands in the extreme south-west), Northern Region (particularly around the Okoro Highlands, and in the Zombo District) and Eastern Region (Mount Elgon area, and around Mbale) (Figure 1b). Most of the coffee is produced by smallholders, with farms of 0.5–4 acres (0.2–1.6 ha), with a reported average farm size of 0.45 acres (0.18 ha)[4]. The production system is either monocrop or interplanted as a mixed farming system with food crops, especially bananas and maize[22]. Shade trees are often planted, or existing trees are utilized as shade, but agroforestry systems employing considerable shade cover, such as those in Ethiopia[29], are rare. In some areas, very little tree-shade is provided. Yields vary considerably depending on location, inputs, and management, but typically range from 500–1,250 kg/ha of clean coffee[2] and can be up to 1,600 kg/ha[4]. The main crop harvest period is between October and the end of January, and the fly crop is between April and July[2], with variation in harvest season dependent on location, elevation and the weather.

Uganda produces both natural (sun-dried), and partially and fully washed Arabica coffee. Natural coffee is usually dried in the traditional manner, on the ground, on tarpaulins or on other hard surfaces, and sometimes on raised beds. These natural coffees are commonly known as DRUGA, which stands for Dry Ugandan Arabica. Partially or semi-washed coffees are usually referred to as WUGAR, which stands for Washed Ugandan Arabica.

In Uganda, there are six recommended and authorized Arabica coffee cultivars: 'SL14', 'SL28', 'KP423' and 'KP162', 'Ruiru 11' and 'Catimor 129'. The cultivars 'SL 14' and 'SL 28' were developed in the Scott Laboratories in Kenya during the 1930s, for drought tolerance. The cultivars 'KP423' and 'KP162' were selections of 'Kent' or 'Kent's' Arabica, a cultivar originally grown in India to provide high yields and tolerance to coffee leaf rust. 'Ruiru 11' was developed in Kenya with the aim of providing tolerance to coffee leaf rust and resistance to coffee berry disease; and 'Catimor 129' for high yields, resistance to coffee leaf rust and coffee berry disease, and a compact growth habit. In some areas, notably in the Mount Elgon region, the cultivar 'Nyasa' persists as a long-term survivor from the birth of Arabica cultivation in Uganda[26].

Elevations of 1,400–2,300 m are most suitable for Arabica farming in Uganda[2], but in some locations the crop can be found as low as 1,200 and up to 2,500 m. In Uganda, Arabica requires a mean total annual rainfall (precipitation) of 1,200–1,800 mm[22], well distributed over a period of nine months, with a drier (lower rainfall) period of around three months[2,15].

Figure 3. Seeds (unroasted coffee beans) of three Ugandan coffee species, with some cultivated species for size comparison. **A.** Excelsa coffee (*Coffea dewevrei*), cultivated in central Uganda. **B.** Eugenioides coffee (*C. eugenioides*), cultivated in Kampala, Uganda (1921), from RBG Kew Economic Botany Collection. **C.** Robusta coffee (*C. canephora*), cultivated in Uganda. **D.** Arabica coffee (*C. arabica*), cultivated in Ethiopia. **E.** Liberica coffee (*C. liberica*), cultivated in Malaysia. **F.** Robusta coffee (*C. canephora*), cultivated in India. Each sample of 25 seeds.

Nearly all Arabica growing areas experience a bimodal rainfall distribution, with low rainfall in January–February and June–July. The exception is in the north-western farming areas, where there is a unimodal rainfall distribution, with a low rainfall period during December–March. The mean annual temperature requirement for Arabica in Uganda is 18–21 °C, with an optimum daily temperature range of 15–24 °C[2], and a distinct difference between day and night temperatures (the diurnal range). The soil should be slightly acidic, with a pH range of 5.5–6.5, and well supplied with all the essential major plant nutrients[2].

Arabica coffee grown in Uganda produces a range of flavour profiles, depending on the locality (which dictates soil type and condition, climate parameters, and other factors), the cultivar (i.e., genetic factors), and the harvesting and processing methods used[23]. Dry Ugandan Arabica (DRUGA) is generally of lower quality than washed coffee and has a characteristic flavour profile, often referred to as the 'DRUGA profile'. Over the last decade or so, the reputation for high-quality Ugandan Arabica has improved considerably, mostly for fully washed coffee, especially from the Ruwenzori Mountains and Mount Elgon production areas. According to *Ugandan Coffee Profiles*[23], Uganda-grown Arabica is characterised by: dried fruit, chocolatey, spicy, herby, and/or citrus fragrance; dried fruit, and/or citrus aroma; dried fruit flavour notes; low to medium acidity and body; and a citrus aftertaste.

Further information on Arabica coffee production can be found in the *Arabica Coffee Handbook*[2] and other UCDA resources[24].

Excelsa coffee (*Coffea dewevrei*)

History

In this report we refer to exclesa as a species (*C. dewevrei*) but it is also recongnized as a botanical variety of Liberica, as *C. liberica* var. *dewevrei* (see page 28). Excelsa occurs as a wild plant in Uganda, the Democratic Republic of the Congo, South Sudan, the Central African Republic, the Republic of the Congo, and Cameroon[10]. There is no evidence of excelsa being used in Uganda either before or during the nineteenth century, but further research may show otherwise. The first field trials of excelsa in Uganda were undertaken in 1915 and 1916, in Kampala. The trials indicated weak growth and poor yields[30,31], e.g., ¾–2lb (0.3–0.9 kg) of clean coffee per tree per annum. Samples from the 1915/1916 field trials were sent to London in 1922 and reported as: "…unattractive and undesirable for the London market"[31]. Further samples sent in 1933 were stated as 'very unclean'[31]. The following statement summarizes the interest in excelsa at that time: 'Excelsa coffee therefore shows no promise of being of any importance in Uganda and only a few trees have been retained at Kampala as specimens to provide seed for raising stocks used in grafting experiments.'[31]. It should be carefully noted, however, that the plants used in the field trials of 1915/1916 were not indigenous excelsa plants, but instead were imported from Java in 1914[31]. The dimensions (length and width) of other 'excelsa' seeds imported from Java to Uganda around the same time indicate that the plants used in the 1915/16 field trials were probably Liberica coffee (*C. liberica*) or a hybrid including this species[8]. Thus, it is highly likely that the initial assessment of excelsa in Uganda was based on Liberica coffee, which may have been unsuited to the growing conditions in Kampala. Perhaps more importantly, there are many differences between Liberica and excelsa, including yield, processing requirements, and flavour[8].

Despite the lack of interest in excelsa in Uganda during the early twentieth century, elsewhere it was considered to have great potential as a coffee crop plant[30,32-35]. For example [translated from French]: 'Many farmers consider it to have a great future, as it is very resistant to diseases and insects, and it gives high yields of good quality coffee'[33]. Based on similar favourable reports, excelsa was planted at considerable scale in Ubangui-Chari (now the Central African Republic) from the early 1930s onwards. According to various reports, plantations of 10,000–20,000 hectares were established in the Central African Republic[36-38]. Despite great promise, these plantations were devastated from the early 1940s onwards by coffee wilt disease (*Gibberella xylarioides*) putting an end to further expansion in that country by around 1950[38]. Since then, excelsa has only achieved minor crop status, despite considerable interest in several countries and particularly in Indonesia[34].

During recent decades, there has been a dramatic increase in the number of farmers growing excelsa in Uganda, particularly in the districts of Luwero (Luweero) and Butambala. According to these farmers, this species has been on their farms, in low numbers, for many decades, being originally gathered from the forest by previous generations[8].

Despite the lack of interest in excelsa in Uganda during the early twentieth century, elsewhere it was considered to have great potential as a coffee crop plant[30,32-35].

Present day

Excelsa coffee is a minor crop of lowland Uganda, with perhaps 200–300 farmers engaged in its production. Excelsa is either interplanted with robusta or used as the dominant coffee crop species[8]. Farmers transitioning from robusta to excelsa are doing so because of ongoing issues with farming robusta, and particularly the increasing occurrence and severity of disease, pests (particularly black twig borer: *Xylosandrus compactus*) and drought. The coffee wilt disease (CWD) crisis that so severely affected robusta production during the 1990s and early 2000s, may have also been a key factor in the shift to excelsa. There have been no reports of coffee wilt disease on excelsa in Uganda, but extreme vigilance is required (see *5. Prospects for the use of wild coffee species*). The move to growing excelsa has been farmer-led and largely independent of external influences[8]. A similar but more recent upscaling of excelsa has occurred in southern South Sudan[8], following advice and guidance from local farmers.

Excelsa farming is carried out in low-elevation areas of Uganda, predominately in the Central Region, and particularly in Luwero District (Figure 1c), where it is has been cultivated for many decades and is widely referred to as Kisansa coffee. Long-established cultivation of excelsa is also evident in Butambala District. Excelsa is produced by smallholders, with farms of around 0.5–5 acres (0.2–2 hectares (ha)). Excelsa production in Uganda is most often part of a mixed farming system with food crops, especially bananas and maize; it is either the only coffee crop species planted or it is mixed with robusta. Shade trees are planted, or existing trees are utilized as shade. Estimates based on harvests from single trees in Luwero indicate yields of 877–3,440 kg/ha (based on 204–400 trees/ha, respectively), for rain-fed, low input farming systems (e.g., negligible to low fertiliser use)[8]. The harvest season is December–April. Established excelsa trees in Uganda produce 30–50 kg of fresh fruit ('cherry') per tree, which with an outturn of 7:1/14.3% would yield 4.3–7.1 kg of clean coffee per tree. Well grown excelsa trees in Luwero are reported to yield 60–70 kg of cherry, which would provide 8.5–9.9 kg of clean coffee per tree. The outturn ratio and outturn percentage represent the conversion rate of cherry to clean coffee. For example, an outturn of 7:1/14.3% would require 7 kg of cherry to yield 1 kg of clean coffee, or 100 kg cherry to yield 14.3 kg of clean coffee, respectively. An outturn of 7:1 for excelsa is based on published data[8,35], but initial results indicate the ratio for Uganda may be around 8:1. As with other coffee crop species, sorting and grading would reduce the final amount of clean, marketable coffee.

Ugandan excelsa is produced as a natural coffee, either dried on the ground, on tarpaulins, or on raised beds. A few farms have started to produce semi-washed excelsa coffee. The production of speciality grade (high quality) excelsa coffee is in its infancy, but early results are promising.

Excelsa coffee in Uganda is cultivated at elevations of 1,000–1,200 m, where it receives a total annual rainfall of 1,200–1,600 mm per year, under a bimodal rainfall distribution, with lower rainfall periods in January–February and June–July. The mean annual temperature requirement for excelsa in Uganda is around 22–24 °C, with an estimated optimum daily temperature range of 17–28 °C. Preferred soil requirements for excelsa are not known, but reports indicated that this species may be more tolerant of a wider range of soil types and conditions compared to Arabica and robusta[34]. In the wild, excelsa has been reported on a wide range of soils, including alkaline clay (Semuliki National Park), neutral sandy loam (Zoka Central Forest Reserve) and slightly acidic sandy loam[39].

Excelsa coffee produces a variety of flavour profiles, depending on the locality (which dictates soil type and condition, climate parameters, and other factors), the variant used (i.e., genetic factors), and harvesting and processing methods. According to published sources[8] and evaluations undertaken in 2023, Uganda-grown excelsa coffee has demonstrated: grape, milk and dark chocolate, peanut, berry fruit, vanilla, red rose aromatics; chocolate, caramel, red and purple grape, red, purple and dark fruits (fresh and dried, e.g. plum, fig, currant, raisin, strawberry, raspberry), molasses, Demerara sugar, maple syrup, and stevia, flavour notes; low to medium salt/medium to high acid, low to medium bitter/medium to high sweet characteristics; a smooth and silky mouthfeel with low astringency; and a sweet, smooth aftertaste, with low astringency.

Eugenioides (*Coffea eugenioides*)

History and present day

Early trials of eugenioides in East Africa (including Uganda) were unfavourable due to the small size of the seeds (coffee beans)[39], susceptibility to coffee leaf rust[40], poor quality, and very low yields[31,39]. Early sensory assessments, however, were not unfavourable; for example: 'The liquor was described as pure and entirely free from undesirable flavours, although the strength was not good, probably owing to the presence of immature trees'[31]; and …'the quality of the bean is mild and agreeable'…[39]. Outside Uganda, and more recently, the flavour of eugenioides has received praise, for example: 'The exception is *C. eugenioides*, which has a very fine aroma, tasting fruity and clean.'[41]. Trial plantings of eugenioides were made in Kampala during the 1920s and 1930s[10], but no further attention seems to have been given to the species in Uganda. In south-eastern Kenya, small-scale production of eugenioides has been underway for several decades, such as Nandi coffee, although the status of this crop in Kenya today is unclear. In Colombia, eugenioides is being grown on a small scale and sells at a substantial premium. Colombia-grown eugenioides has been used in national and international coffee-making competitions (i.e., the World Barista Championships) on account of its unique, complex flavour and intense natural sweetness. Eugenioides is reported to be difficult to grow, and low yielding (e.g., 150 grams of un-milled coffee per tree). Based on the renewed interest, and high market price, preliminary trials of eugenioides are now underway in Uganda.

Excelsa coffee intercropped with banana

Robusta coffee from Central Africa, planted in 1903 at Entebbe

3. The wild coffee species of Uganda

This section provides key information for the four wild (indigenous) coffee species of Uganda: *C. canephora* (robusta coffee), *C. eugenioides* (eugenioides), *C. dewevrei* (excelsa coffee) and *C. neoleroyi*. The identification of these species should not present difficulty, as they are morphologically distinct and easy to recognize. An identification key is provided below to assist with the identification of the wild species and their cultivated counterparts, and *C. arabica*. Colour illustrations are provided for *C. canephora, C. dewevrei, C. eugenioides* and *C. arabica* (Figures 2, 4, 6, 7). Distribution maps are provided for each of the wild species (Figure 5). Details of distribution, protected areas status, conservation status, ecology, vernacular, and other names, uses, and miscellaneous notes are included in the section below. This part of the report is based on work published by the authors[8,10] with updates and amendments.

Key to Ugandan coffee (*Coffea*) species and Arabica (*C. arabica*)

A. Leaves generally deciduous; flowers on short shoots; corolla tube much longer than wide; only found in north-eastern Uganda ..... *C. neoleroyi*

A. Leaves evergreen, distributed evenly along the lateral branches; flowers distinctly axillary; corolla tube shorter or not much longer than wide.....B

B. Leaves 12–40 × 4.5–22 cm, with 7–17 pairs of secondary veins.....C

B. Leaves 3–12 × 1–7 cm, with 5–7 pairs of secondary veins.....*C. eugenioides*

C. Leaves thick (thin-leather like), usually with 8–12 pairs of secondary veins..... *C. dewevrei*

C. Leaves thin (almost paper-like), usually with 7–17 pairs of secondary veins.....D

D. Leaves usually with 10–17 pairs of secondary veins; fruits in tight clusters, each fruit rounded to ovoid; seeds round to oval in outline..... *C. canephora*

D. Leaves usually with 7–10 pairs of secondary veins; fruits in rather loose clusters, each fruit ovoid; seeds distinctly oval in outline.....*C. arabica*

Figure 4. Robusta coffee (*Coffea canephora*). Flowering and fruiting branches, whole and cut fruits, seed with parchment, and seed (coffee bean). Scale bar = 2 cm. Illustration by Lucy T. Smith ©.

Coffea canephora Pierre ex A.Froehner (1897). Robusta coffee. Figure 4.

Global distribution: west Tropical Africa (western Ghana, Guinea, Ivory Coast, Liberia, Nigeria); west-central Tropical Africa (Cameroon, Republic of the Congo, Central African Republic, Democratic Republic of the Congo, Gabon); Tropical Africa (southern South Sudan); east Tropical Africa (Tanzania, Uganda); south Tropical Africa (northern Angola). The exact limit of natural distribution is difficult to ascertain, owing to introduction and naturalisation. Widely cultivated as robusta coffee, across the tropical belt of the world and frequently as Conilon in Brazil; naturalised in Tropical Africa and other tropical areas (not listed here).

Global IUCN conservation assessment: Least Concern (LC)[42].

Information for Uganda:

Distribution: Throughout Uganda but mainly in central and western parts of the country. Uganda is a major centre of diversity for *C. canephora*[11,43-45] and is the only country on the eastern side of the Great Rift Valley holding substantial wild populations of this species. Figure 5a.

Ecology: An exclusively forest-dwelling species, found in the understorey of humid, evergreen forest (rainforest), occurring with a wide range of dominant tree species. Often occurring in the same forests as *C. eugenioides* (sometimes side-by-side); also occurring with *C. dewevrei* in Zoka Central Forest Reserve and Semuliki National Park.

Elevation: 655–1,570 m (observed and recorded); 675–1,660 m (modelled)[10].

Preliminary country-level IUCN conservation assessment: Least Concern (LC)[10]. Whilst the extent of occurrence for *C. canephora* across Uganda is substantial, the actual area (km^2) occupied is much smaller (equivalent to the Endangered (EN) category), indicating that the conservation status of this species should not be taken for granted, and that careful monitoring is required. Over most of the central part of its distribution in Uganda (Figure 5a), *C. canephora* is now restricted to smaller and increasingly fragmented forests. Populations in the larger protected areas appear to be healthy, with a high density of individuals. Encroachment, deforestation, and other disturbances in some protected areas (e.g., Zoka and Itwara Central Forest Reserves) are reducing the area of occupancy, number of mature individuals, habitat quality, and population health.

Main protected area occurrence: Budongo (CFR), Bugoma (CFR), Bukaleba (CFR), Bwindi Impenetrable (NP/WH), Itwara (CFR), Kagombe (CFR), Kalinzu (CFR), Kasyoha-Kitomi (CFR), Kibale (NP), Kisangi (CFR), Mabira (CFR), Malabigambo (CFR), Matiri (CFR), Mount Elgon (NP/BR), Murchison Falls (NP), Queen Elizabeth National Park (NP/BR), Rwensama (CFR), Semuliki (NP), South Maramagambo (CFR), Tero East (CFR), Tero West (CFR), Zoka (CFR), West Bugwe (CFR). Key: Central Forest Reserve (CFR), National Park (NP), UNESCO-MAB Biosphere Reserve (BR), World Heritage Site (WH).

Ugandan names: Mwanyi (Luganda, Rutooro, Kuamba, Runyoro)[46]; Mwanyi (Kwamba, Rutooro), Mumwanyi (Luganda), Omwanyi (Runyoro)[47].

Other names: Wild robusta coffee[46,47].

Uses (*other than beverage*): As a masticatory-stimulant (due to the presence of caffeine and sugar), as a snack, either fresh or dried, and as food ingredient. A traditional usage is to take a small number (c. 10) of fruits (unripe or semi-ripe and dried whole, sometimes boiled in water) and package them in dried banana leaves for retail in local shops and at roadsides (personal observation and in literature[39]). *Coffea canephora* is used in various traditional and ritualistic activities, as an emblem for brotherhood and deep friendship. Even though this activity is steadily declining, it is still used in traditional marriage ceremonies in the Buganda culture.

Notes: Wild populations of *C. canephora* have been instrumental in the origin, development, and sustainability of the Ugandan coffee sector. The substantial diversity in morphology and growth characteristics are manifest when plants are taken from the wild and brought into cultivation[11,39].

In some locations, wild populations of *C. canephora* form a major component of the forest understorey, for example in the forests of Kibale and Itwara. During the 1930s, the high population density of *C. canephora* in Kibale Forest allowed the harvesting of large quantities of coffee under licence from the Forest Department[39]. More recent projects have attempted wild harvesting but with mixed success.

Field observations in wild forests have shown that the root system of *C. canephora* is very shallow, particularly under wet soil conditions, with the most developed (longest) roots in the uppermost layer of the soil (i.e., in the top 7 cm), with a large proportion occurring in the leaf litter layer[39]. Pests and diseases of farmed *C. canephora* are also found in wild populations, including coffee leaf rust, coffee berry borer[39] and black twig borer (based on recent observations).

A wild plant of *Coffea canephora*

Distribution of wild coffee species and forest types

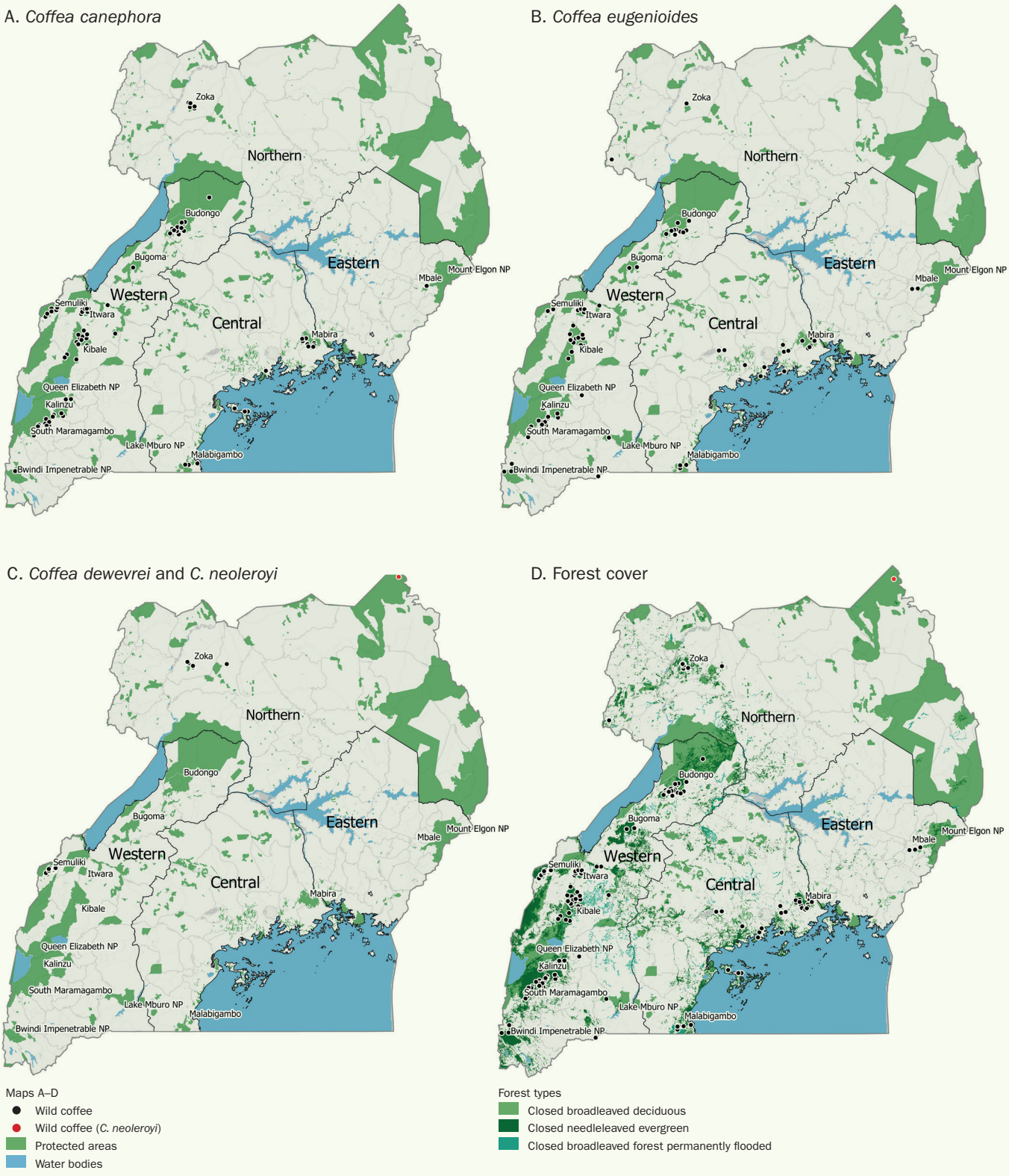

Figure 5. Distribution maps of wild coffee species in Uganda and protected areas, with labels for selected protected areas. **A.** *Coffea canephora* (robusta coffee). **B.** *C. eugenioides* (eugenioides coffee). **C.** *C. dewevrei* (excelsa coffee) and *C. neoleroyi* (red dot in north-eastern Uganda). **D.** Forest cover and forest types, with wild coffee occurrence records. Notes: Boundaries and large labels depict the four regions of Uganda (Northern, Eastern, Central and Western). See 8. *Overview of Methods*, for map construction details.

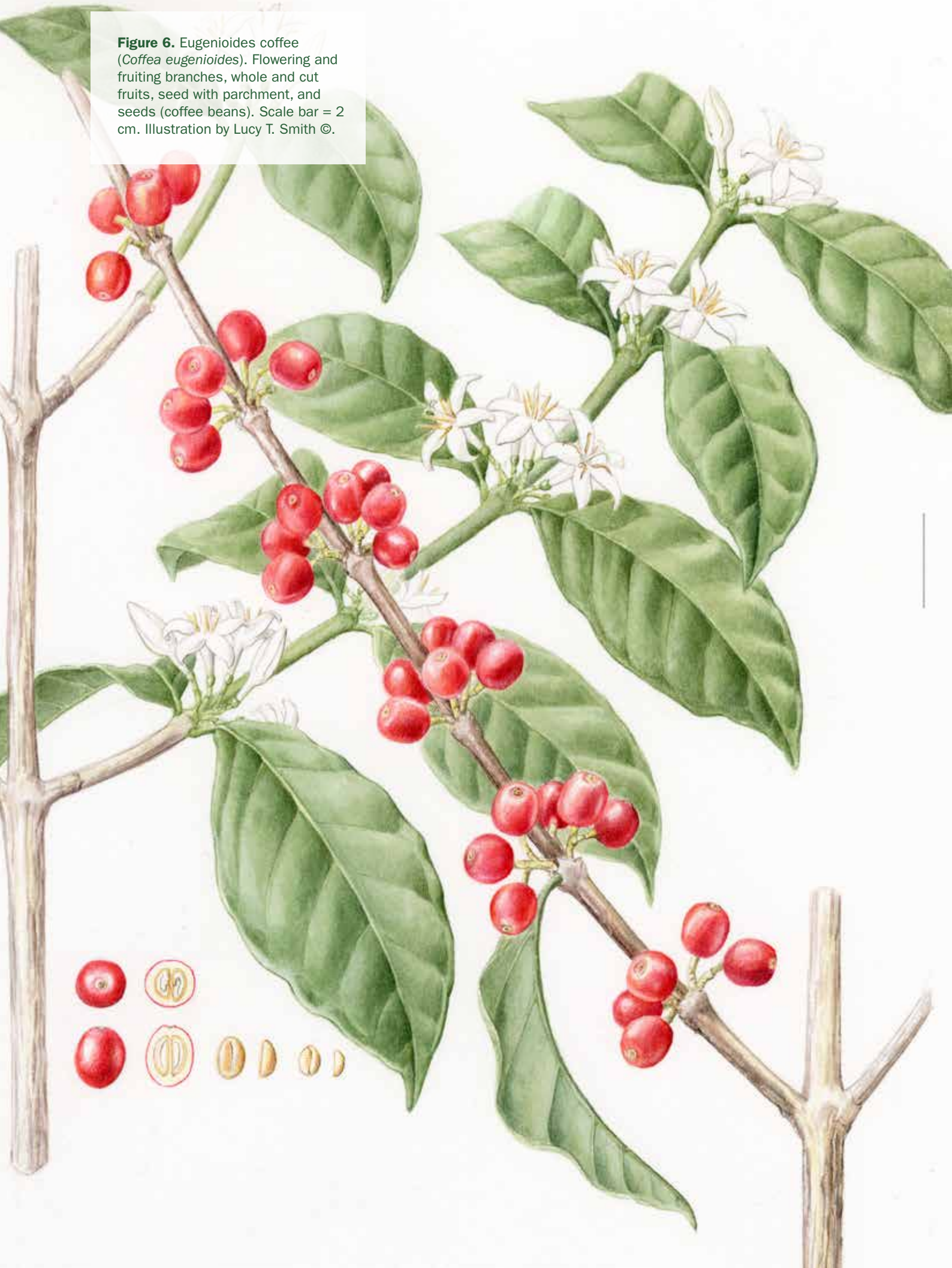

Figure 6. Eugenioides coffee (*Coffea eugenioides*). Flowering and fruiting branches, whole and cut fruits, seed with parchment, and seeds (coffee beans). Scale bar = 2 cm. Illustration by Lucy T. Smith ©.

Coffea eugenioides S.Moore (1907). Eugenioides coffee. Figure 6.

Global distribution: west-central Tropical Africa (Burundi, Rwanda, eastern Democratic Republic of the Congo); north-east Tropical Africa (southern South Sudan); east Tropical Africa (central and eastern Kenya, eastern Tanzania, Uganda).

Global IUCN conservation assessment: Least Concern (LC)[48].

Information for Uganda:

Distribution: Throughout Uganda but absent from most of the northeast. Uganda is a centre of diversity for *C. eugenioides*[39] and is the only country on the eastern side of the Great Rift Valley that holds substantial wild populations of this species[10]. Figure 5b.

Ecology: An exclusively forest-dwelling species, found in the understorey of humid, evergreen forest (rainforest), occurring with a wide range of dominant tree species. Often occurring in the same forests as *C. canephora* (sometimes side-by-side); also present in Zoka Central Forest Reserve and Semuliki National Park with *C. dewevrei*.

Elevation: 910–1,828 m (observed and recorded); 700–1,693 m (modelled)[10].

Preliminary country-level IUCN conservation assessment: Least Concern (LC)[10]. Even though the extent of occurrence for *C. eugenioides* across Uganda is substantial, the actual area (km^2) occupied (area of occupancy) is much smaller, indicating that the conservation of this species should not be taken for granted and that careful monitoring is required. Over most of the central part of its distribution in Uganda (Figure 5b), *C. eugenioides* is now restricted to smaller and increasingly fragmented forests. Populations in the larger protected areas appear healthy, with a high density of individuals. Encroachment, deforestation, and disturbance in some protected areas (e.g. Zoka, Itwara, Mbale Central Forest Reserves) are negatively affecting the area of occupancy, number of mature individuals, habitat quality and population health.

Main protected area occurrence: Budongo (CFR), Bugoma (CFR), Bwindi Impenetrable National Park (NP/WH), Itwara (CFR), Kagombe (CFR), Kalinzu (CFR), Kasyoha-Kitomi (CFR), Kibale (NP), Kitubulu (CFR), Luvunya (CFR), Mabira (CFR), Malabigambo (CFR), Mbale (CFR), Mount Elgon (NP), Mpanga (CFR), Mukambwe (CFR), Namalala (CFR), North Maramagambo (CFR), Nsube (CFR), Queen Elizabeth National Park (BR/NP), Rwensama (CFR), Semuliki (NP), South Maramagambo (CFR), West Bugwe (CFR), Zoka (CFR). Key: Central Forest Reserve (CFR), National Park (NP), UNESCO-MAB Biosphere Reserve (BR), World Heritage Site (WH).

Ugandan names: Emwanji (Ateso), Mwanji (Adhola, Luganda, Lugwe), Imwanji (Lugisu), Omwani (Rukiga, Runyankore, Runyoro, Rutooro), Nkiga [sic] (Rutooro)[49]; Mumwanyi (Luganda), Mwanyi (Ganato), Nkinga (Rutooro), Omwanyi (Runyoro)[47].

Other names: Mukono coffee (English[40], but not widely applied). The name ‘Nandi coffee’ is used in Kenya for *C. eugenioides* but refers to a Kenyan place name and a Kenyan variant of this species.

Uses (other than beverage): The ‘sweet and tasty’ ripe fruits are eaten as a snack, mainly by children, but in moderate amounts (Batooro, Bamba, Banyankore, Baganda); the fruits may also be boiled, dried and stored for later use as dry snacks (Baganda); dried leaves are put on hot charcoal and the smoke inhaled to relieve headache[49]. The raw materials for the above uses are collected from the wild[49].

Notes: It has been reported that *C. eugenioides* appears to stand drought better than any other wild coffee species in Uganda, and is intolerant of wet conditions[39], but this requires verification. In some Ugandan forests, where both *C. canephora* and *C. eugenioides* occur together, the former favours wetter areas and the latter drier ones[39]; in other forests, such as Itwara, these two species are often found side-by-side[10].

Figure 7. Excelsa coffee (*Coffea dewevrei*). Shoot with flower buds, flowering and fruiting branches, whole and cut fruits, seed with parchment, and seeds (coffee beans). Scale bar = 2 cm. Illustration by Lucy T. Smith ©.

Coffea dewevrei De Wild. & T.Durand (1899). Excelsa coffee. Figure 7.

Global distribution: west-central Tropical Africa (eastern Cameroon, Central African Republic, northern Republic of the Congo, eastern Democratic Republic of the Congo); north-east Tropical Africa (southern South Sudan); east Tropical Africa (western Uganda).

Global IUCN conservation assessment: Not Evaluated.

Information for Uganda:

Distribution: Restricted to western Uganda, adjacent to the border with the Democratic Republic of the Congo. Comprehensive fieldwork in Itwara Forest shows that *C. dewevrei* does not occur at this location[10], contrary to previous reports[31,39,47,50]. Figure 5c.

Ecology: In lowland, humid, evergreen forest (Zoka Central Forest Reserve) and lowland, semi-deciduous humid forest (Semuliki National Park), with a diverse range of dominant tree species and various forest communities. In Semuliki, *C. dewevrei* occurs mainly in swamp forest, and even in places that support truly riverine species such as *Pandanus chiliocarpus* (screw pine), although it is not exclusively confined to these habitats in Semuliki and grows in drier areas of this forest that are not associated with water. In Zoka, this species is not predominantly associated with rivers or in waterlogged areas. In Kilak Central Forest Reserve it is reported to occur in riverine forest[39]. In the Central African Republic, *C. dewevrei* is predominantly a species of seasonal riverine forest[33], sometimes forming quite dense stands[38]; the same is true for populations in South Sudan.

Elevation: 680–1,200 m (observed and recorded); 686–1,118 m (modelled)[10].

Preliminary country-level IUCN conservation assessment: Endangered (EN)[10]. Even though the extent of occurrence for *C. dewevrei* in Uganda is quite large, the actual area (km^2) occupied (area of occupancy) is much smaller. Populations of *C. dewevrei* in Semuliki National Park consist of small numbers of agregated indviduals, sparsely distributed in most of the areas of the forest that have been surveyed (i.e. the eastern part). Encroachment and deforestation in Zoka Central Forest Reserve are severely reducing the area of occupancy, number of mature individuals, habitat quality, and population health. Conservation management improvements are urgently required for Zoka, to ensure that this northern-most population is properly protected. Careful monitoring and management of this species in the wild is urgently required.

Main protected area occurrence: Semuliki (NP), Zoka (CFR), Kilak (CFR). Key: Central Forest Reserve (CFR), National Park (NP).

Ugandan names: Mumwanyi (Luganda)[47]; Kisansa coffee (frequently recorded on farms in the Luwero District).

Other names: Coffea excelsa A.Chev. (Botanical Latin; used by numerous authors but represents a synonym of *C. dewevrei*). Excelsa coffee (English, numerous authors, widely used); Shari coffee (English[46], not widely used). Various common and botanical names are applied in other countries where *C. dewevrei* is found in the wild.

Uses (other than beverage): None known.

Notes: In the wild, and in cultivation, *C. dewevre*i is instantly recognisable as different to *C. arabica* and *C. canephora*, being a tree of around 10–15 m, and up to 20 m, with a substantial main trunk (e.g., 20 cm in diameter) and large leaves (up to c. 40 cm long). *Coffea arabica* and *C. canephora* are small trees, generally 4–8 m high, with a slender main trunk, and leaves usually less than 20 cm long. The current consensus of taxonomic and systematic study[51-54] is that *C. liberica* should be divided into two botanical varieties: *C. liberica* var. *liberica* (Liberica) and *C. liberica* var. *dewevrei* (excelsa). Whilst this view is generally accepted by many, it has also been argued that the classification of *C. liberica* does not fully account for the morphological differences[8,52] and potential molecular variation[55] within the species. Further careful critical study is required[10]. The botanical forma (f.) *bwambensis* (i.e., *C. liberica* var. *dewevre*i f. *bwambensis*) has been assigned to represent indigenous Liberica coffee in Uganda but may also include populations in South Sudan[52] and perhaps adjoining areas in the Democratic Republic of the Congo[10]. In this contribution we recognize excelsa (*C. dewevrei*) and Liberica (*C. liberica*) as separate species, in the light of new and ongoing research (A. Davis et al., unbubl. data).

Observations in the wild and in cultivation indicate that excelsa from Zoka Central Forest Reserve are distinct to those from Semuliki National Park, with the Zoka populations having small, narrower, and flatter leaves[39]. This may be either attributed to ecological differences (see above) or genetic differences, and perhaps a combination of both. Across Africa, the morphological variation (particularly for the leaves and fruits) within *C. dewevrei* is considerable[56]. It has been noted that excelsa grows on a wide range of soils in Uganda, including alkaline clay (Semuliki), neutral sandy loam (Zoka) and slightly acidic sandy loam[39].

In 1941, *C. dewevrei* was found near Kilak (Killak), to the east of Zoka Forest, in riverine forest. Fieldwork is required to ascertain whether this species still exists at this locality.

Coffea neoleroyi A.P. Davis (2010).

Global distribution: north-east Tropical Africa (south-western Ethiopia, and south-eastern South Sudan); east Tropical Africa (north-eastern Uganda).

Global IUCN conservation assessment: Endangered (EN)[57].

Information for Uganda:

Distribution: Restricted to Mt. Zulia in north-eastern Uganda. Figure 5c.

Ecology: On riverbanks, and in seasonally dry, *Combretum-Terminalia* savanna woodland, often amongst boulders.

Elevation: c. 1,200 m.

Preliminary country-level IUCN conservation assessment: Critically Endangered (CR) or Data Deficient (DD)[10]. At the country-level, this species would be better placed in the DD category, given that there is only a single collection known from Uganda, and the area where this species occurs is isolated and has not been the subject of detailed botanical survey, partly due to security issues. Dedicated fieldwork for this species in north-eastern Uganda is urgently required.

Protected area occurrence: Zulia (CFR).
Key: Central Forest Reserve (CFR).

Ugandan names: None known.

Other names: None known.

Uses (other than beverage): None known.

Notes: A rare and untypical coffee species, formerly included in the genus *Psilanthus* but now placed in the coffee genus (*Coffea*)[58]. It is easily separated from other *Coffea* species in Uganda by its deciduous habit, and flowers with a long-tube (the corolla) and a very short style, positioned at the base of the corolla tube[59]. All other Ugandan coffee species and most (but by no means all) other coffee species have evergreen leaves, short-tubed flowers, and a long style (e.g., see Figure 7). Like all other coffee species, *C. neoleroyi* produces a fruit that contains two seeds, and each seed possesses the typical coffee-bean morphology. The seeds (coffee beans) of *C. neoleroyi* are much smaller than *C. canephora* and *C. dewevre*i, and smaller than *C. eugenioides*.

A 60 kg sack of freshly harvested excelsa coffee fruits, from a single tree

4.
Climate parameters for wild Uganda coffee species

In Uganda, indigenous *C. canephora* (robusta), *C. eugenioides* (eugenioides) and *C. dewevrei* (excelsa) experience a variety of climates[10]. Approximate mean annual temperatures and mean total annual rainfall (precipitation) for these species in the wild are: *C. canephora* (22 °C/1,390 mm), *C. eugenioides* (21 °C/1,350 mm), and *C. dewevrei* (24.5 °C/1,550 mm)[10]. A warmer mean annual temperature for *C. dewevrei* (compared to *C. canephora* and *C. eugenioides*) is evident because this species is confined to lower-elevation forests in western and north-western Uganda (Figure 5). Across Uganda, lower mean annual precipitation values (total mm/year) for *C. canephora* and *C. eugenioides*, compared to *C. dewevrei,* are due to the higher number of records from drier locations. These species do, of course, occur in locations with higher rainfall, and in some cases all three species occur in the same forest localities, i.e., at Semuliki National Park and Zoka Central Forest Reserve (Figure 5).

Coffea dewevrei occurs in areas that receive different amounts of mean total annual rainfall. For Semuliki National Park in the Western Region total annual rainfall is 940–1,580 mm and at Zoka and Kilak (Killak) Central Forest Reserves in the Northern Region 1,560–2,115 mm per year. Annual rainfalls is, however, highly variable and in some years the mean total annual rainfall across these two areas may be similar. The mean annual temperature in both Semuliki and Zoka/Kilak is about the same (c. 24 °C), and the populations across both locations are found at elevations of 700–1,100 m, with the majority below 950 m[10]. Field observations show that *C. dewevrei* is often associated with high water tables; for example, it occurs in swamp forest in Semuliki and in riverine forest at Kilak. Wild populations of these species occurring outside Uganda are commonly recorded in riverine and gallery forest habitats, for example in the Central African Republic[33] and South Sudan. Gallery forest is a term used to describe a forest formed as a corridor along rivers or wetlands, projecting into an otherwise drier landscape, such as savanna and dry forest. *Coffea dewevrei* is by no means exclusive to these wetter habitats, as observed in Zoka Central Forest Reserve. Despite the frequent association between wet habitats and *C. dewevrei*, particularly in lower rainfall areas, observations from Uganda[10,31,39] and farmer feedback[8,10] indicate that *C. dewevrei* is more drought tolerant than *C. canephora*. Drought tolerance assumptions and observations for *C. dewevrei* (but referred to as *C. excelsa*) have been made by others[30, 33-35,60,61].

Climate partitioning studies for *C. canephora* in Uganda show that populations with discrete climate profiles correspond to genetic groupings[11] and climate-associated genetic markers and their genes[62]. Zoka and Budongo Central Forest Reserves have been identified as housing climate-resilient populations of *C. canephora*, which might be better adapted to drier and warmer conditions[11,62].

Coffea neoleroyi is restricted to a single locality in Uganda, and so little can be said about the climate where it occurs, except that it is an area of much lower rainfall than any of the other wild Ugandan species[10].

Multi-location variety trials (MLVTs) are required to substantiate climate analyses and general observations on climate suitability for wild Ugandan coffee species and cultivated Arabica coffee in Uganda. Experimentation of this type would be critical for understanding the value of Uganda's wild species for crop development, across different agroecological conditions, under a changing climate.

Climate and elevation maps

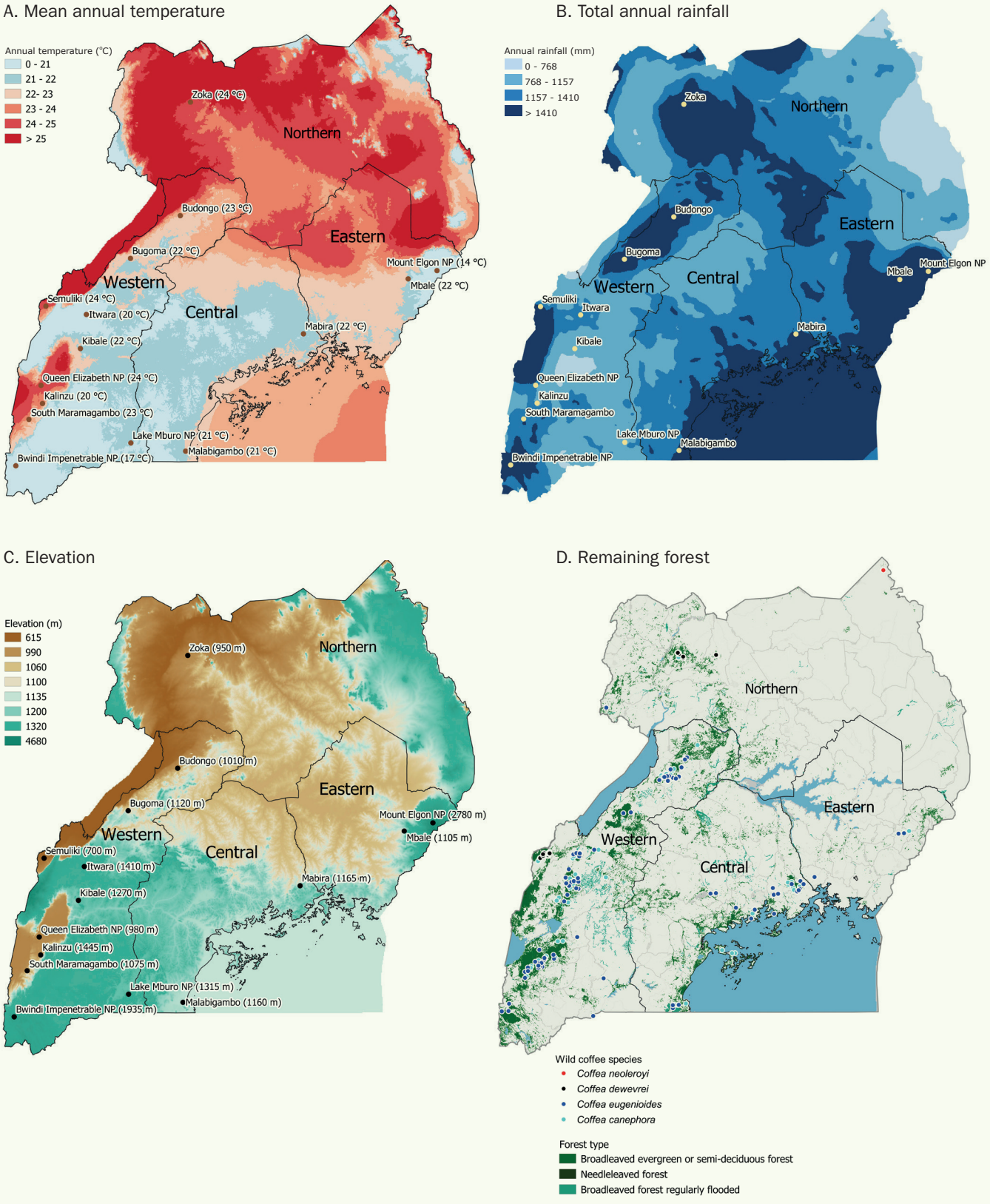

Figure 8. Climate and elevation maps for Uganda, with indicative data for selected protected areas. **A.** Mean annual temperature. **B.** Total mean annual precipitation. **C.** Elevation. **D.** Remaining Forest and main forest types, and wild coffee locality records. Notes: See 8. *Overview of Methods*, for map construction details.

A fruiting branch of cultivated excelsa coffee

5. Prospects for the use of wild coffee species

Coffea canephora (robusta coffee)

Wild populations of *C. canephora* from the southern-central forests (Figure 5a) have provided Uganda with nearly all the resources required to establish and sustain its robusta farming sector[5,10,11,39], and the materials to develop robusta production in other countries[63]. Recently, wild germplasm has played a key role in developing coffee wilt disease-resistant robusta cultivars[11,20,64-66], in response to a major outbreak of this disease in Uganda during the mid-1990s. Despite its already substantial contribution to the sustainability of the Ugandan coffee sector, the extensive genetic resources of indigenous *C. canephora* in Uganda may be of further value for developing this crop species, including: yield[67], abiotic (e.g., climate resilience[11,62]) and biotic (e.g. disease resistance[18,67]) stressors, and coffee quality[20,67]. Populations from the western and northern forests (e.g. Zoka, Itwara and Kibale Central Forest Reserves; see Figure 5a) may be of particular value in this regard[11].

Coffea dewevrei (excelsa coffee)

The recent upscaling of excelsa coffee farming in Uganda, and neighbouring South Sudan, represents an interesting and noteworthy development[8]. According to farmers in Uganda, excelsa is easy to grow, resistant to many of the major pests and diseases of coffee, and is high yielding with an acceptable conversion from fresh fruit to clean coffee (see above, 2. *The coffee crop species of Uganda*). High yields and acceptable outturns for excelsa have been reported in other countries[8,34,60,61,68]. Excelsa may have partial resistance to coffee leaf rust, and therefore the potential for selection of improved coffee leaf rust resistance genotypes[34], nematode resistance[69] and perhaps partial resistance to coffee berry borer (*Hypothenemus hampei*)[68]. Farmer and producer feedback from Uganda and South Sudan (2018–2023) report low infestation rates for black twig borer (*Xylosandrus compactus*), and either insignificant or zero susceptibility to coffee berry disease (*Colletotrichum kahawae*), which is a serious pest of Arabica in Uganda. However, Ugandan excelsa coffee might be susceptible to coffee wilt disease (*Gibberella xylarioides*), which could represent a major risk.

Soon after the discovery of excelsa coffee in the Central African Republic in 1902[70] it became appreciated for high yields, resistance to disease, and high-quality flavour[37,38]. With the arrival of European planters to Ubangui-Chari (now Central African Republic) in 1927 and 1928, excelsa was taken up as major crop plant. By 1932, more than three million excelsa had been planted, occupying an estimated 10,000–20,000 hectares[36,37]. By around 1933, the excelsa harvest was about 30–35 tons, mainly wild-harvested from the extensive stands of excelsa occurring in gallery forests (see above for definition). The newly planted estates were not yet mature, but their harvests were forecasted to reach 20,000 tons per year. Sadly, before these volumes could be realized, coffee wilt disease emerged, rapidly spread and devastated excelsa production in Ubangui-Chari[36-38], leaving those invested in excelsa coffee farming in financial ruin and depriving the region of an important commercial resource[38]. Excelsa farming in Ubangui-Chari never recovered from coffee wilt disease. Soon afterwards, during the 1940s and 1950s, coffee wilt disease was reported in the Democratic Republic of Congo[71, 72], Guinea, Ivory Coast and eastern Cameroon[19,66,73], mainly on robusta and *C. abeokutae* (a type of Liberica coffee (*C. liberica*)). Coffee wilt disease (CWD) is still a major issue for robusta production in Africa but has not been reported on excelsa in either Uganda or South Sudan, despite recent surveys on farms and in the wild. Continued vigilance and dedicated research are required to better understand the incidence and level of resistance to coffee wilt disease for excelsa.

Farmers in Uganda report that excelsa is more drought tolerant than robusta, in agreement with observations made in other countries[30,33-35,60,61,68,74] and recent observations from field trials in Uganda by the authors. Excelsa may also be more tolerant of higher temperatures than robusta. Modelled, mean annual temperatures for wild populations in Uganda are 21.8 °C for robusta and 24.4 °C for excelsa[10]. Exact temperature requirements for these two species requires careful assessment via extended field trials. Excelsa is certainly more heat and drought tolerant than wild and cultivated Arabica[10], which would not be able to tolerate the conditions where excelsa and robusta are grown in lowland Uganda (1,000–1,200 m), even though Arabica may grow and crop successfully for a few years before eventually failing[15, 26]. The stout trunk, extensive root system and thick, fleshy leaves of excelsa are features that are likely to constitute drought (and heat) tolerance attributes compared to robusta. The main root mass of robusta is shallow and restricted in extent[39], being mainly surface rooting[5], resulting in susceptibility to drought. It has also been noted that excelsa is tolerant of a wide range of soils[39], including those deemed unfavourable for robusta[34].

As a crop plant, excelsa has advantages and disadvantages, compared to robusta and Arabica. Its capacity for high yields under poor conditions, resilience to certain pest and diseases, drought and heat tolerance, and general robustness, are clear advantages. Disadvantages compared to Arabica and robusta might include: the longer period from flower to fruit (11–12 months; compared to around nine months for Arabica and 10–11 for robusta); little or no fly crop; the greater physical effort required for harvesting, as the fruits are more firmly attached to the fruiting branch; and because excelsa is often grown as a small tree (even after pruning), ladders may be required for harvesting.

Unlike Liberica (*C. liberica*), the fruits of excelsa are held in many-fruited, tight axillary clusters, like robusta and many cultivars of Arabica; and the fruits and seeds of excelsa are approximately the same size and shape as Arabica and robusta, enabling standard post-harvest processing procedures[8]. The fruits of Liberica are usually held in rather lax, few-fruited clusters, and each fruit is typically large, resulting in lower yields. The fruits of Liberia have a tougher, thicker pulp and larger seeds compared to excelsa (and particularly to Arabica and robusta), resulting in lower outturns[8]. Outturn is the conversion percentage or ratio of fresh fruit to clean coffee, per unit weight, i.e. 100 kg of fresh fruit giving 20 kg of clean coffee would represent a conversion of 5:1 or 20%. Reported conversion ratios and percentages are: robusta (5:1/20%); Arabica (6:1/16.5%); excelsa (7:1/14.5%); and Liberica (11:1/9%, but as low as 12.5:1/8%)[8]. For all species, sorting and grading would reduce the final amount of clean, marketable coffee.

Excelsa can produce economically viable, fine-quality coffee, of a smooth and easy-drinking character, with low to medium acidity, low bitterness, a range of positive flavour notes (see above) and a caffeine content similar or lower than *C. arabica*[8]. Further careful assessment is required to see how it will perform across the value chain. Generally, under comparable harvest and post-harvest conditions, excelsa coffee commands a higher price than robusta and may equal prices paid for Arabica.

Excelsa may have considerable utility in Uganda as grafting stock[10]. Excelsa is used as a grafting stock for Arabica, to improve resistance to root nematodes, and increase yield and survivability, notably in Hawaii[75]. In Uganda, excelsa could be used as grafting stock for CWD resistant (CWD-r) robusta clones, which are propagated via cuttings and thus do not produce a tap root. Robusta grafted onto excelsa rootstocks would likely benefit from a stout tap root and more extensive root system, particularly under low soil moisture conditions.

Excelsa coffee may also offer considerable potential for breeding in Uganda, in the same way as excelsa and Liberica has been used in several interspecies crosses, to provide disease resistance and other useful agronomic traits[10,34].

As a crop plant, excelsa has advantages and disadvantages, compared to robusta and Arabica. Its capacity for high yields under poor conditions, resilience to certain pest and diseases, drought and heat tolerance, and general robustness, are clear advantages.

Coffea eugenioides (eugenioides)

Eugenioides produces a superior-tasting coffee, which has potential as a high-value niche crop. The development of eugenioides in Uganda would require further investment and a proof-of-concept period, to test for commercial viability and value chain functionality. The small seed (coffee bean) size and low yields represent key constraints, unless either better-performing variants can be found within wild populations, or some means of crop development is undertaken.

Eugenioides could be of utility as a resource for breeding, for imparting flavour qualities and other attributes via interspecies crosses. It hybridizes readily with *C. liberica* and no doubt *C. dewevrei*, to form diploid (2n=2x=22 chromosomes) and tetraploid (2n=4×=44 chromosomes) hybrids. In India, such hybrids have shown good yield potential and coffee leaf rust resistance, although refinement has been identified as a key requirement for further development[76, 77]. In Madagascar, *C. liberica* and *C. eugenioides*, in their tetraploid forms, have been crossed and the resulting hybrids backcrossed with *C. arabica*, to produce high-yielding hybrids with commercially acceptable sensory (e.g. aroma and taste) characteristics[10]. *Coffea eugenioides* and *C. canephora* are the progenitor species of *C. arabica*. Artificial tetraploids of these progenitor species can be crossed (and backcrossed) with tetraploid *C. arabica* to produce Arabica-like plants, as undertaken in Madagascar[78].

Coffea neoleroyi

Several factors are against *C. neoleroyi* being utilized as a coffee crop plant, including extremely low yields (few fruits per tree, and small seeds (coffee beans)), diminutive stature, and spindly growth form. It is possible that a coffee-like beverage could be made from the seeds of *C. neoleroyi*, but this remains untested and is unlikely to be of commercial interest. Given the differences in floral morphology between *C. neoleroyi* and the main coffee crop species[59], and for reasons concerning the compatibility and fertility[79], breeding with other coffee species would be challenging.

A shoot of cultivated robusta coffee with flower buds

Early flowers of excelsa coffee with ripening fruits

6.
Conservation of wild coffee species

The existence of the four indigenous coffee species in Uganda, *C. canephora*, *C. eugenioides*, *C. dewevrei* and *C. neoleroyi*, is dependent on the presence of healthy, natural forest habitats. Highly degraded forest and secondary forest are not suitable for the existence of wild coffee species.

Coffea canephora and *C. eugenioides* are found over a large area of Uganda, but with the highest density of populations in the Western Region, and in the eastern part of the Central Region (Figure 5). Many populations, particularly those in the Central and Eastern Regions, occur in small and often degraded forest parcels, which require improved safeguarding. Uganda represents important centres of diversity for *C. canephora* and *C. eugenioides*, which are priority species for coffee crop plant development, i.e. Coffee Crop Wild Relative (CWR) Priority Group 1[80]. *Coffea dewevrei* is restricted to three populations in western Uganda (Western and Northern Regions) (Figure 5c). In Semuliki National Park the population appears to be quite extensive, healthy, and with a reasonably high density of individuals. The forested area covers most of the Semuliki protected area boundary (219 km^2). Conversely, in Zoka Central Forest Reserve the population is under threat from encroachment, illegal logging, and charcoal burning, and is suffering from reduced forest cover and poor forest health. The third population of *C. dewevrei*, at Kilak (Killak) Central Forest Reserve, has not been surveyed since it was last recorded there in 1938[39]; dedicated fieldwork in this area is required. *Coffea neoleroyi* is only known from a single collection in a remote area of north-eastern Uganda (Figure 5c). A dedicated field survey for this species is required to fully understand the number, density, and health of populations in Uganda.

Our preliminary country-level IUCN Red List[81] conservation assessments for the indigenous coffee species of Uganda are: *C. canephora* (Least Concern), *C. eugenioides* (Least Concern), *C. dewevrei* (Endangered), and *C. neoleroyi* (Critically Endangered, or Data Deficient)[10]. The preliminary country-level IUCN Red List rating of Endangered for *C. dewevrei* is of particular concern, given the level of forest clearance and land use change at Zoka Central Forest Reserve and the undetermined status of the population at Kilak Central Forest Reserve. Further data is required before a confident country-level extinction assessment can be made for *C. neoleroyi*, but this is undoubtedly also a species of concern. At the global level, i.e. over the entire natural range in Africa, *C. dewevrei* has not been assessed and *C. neoleroyi* is Endangered.

Even though some species may not be threatened at the national level, populations of all four species are at risk. Genetic resources and their associated attributes, including disease resistance and climate resiliency, are distributed across populations[10,11,62] and thus every effort should be to conserve individual populations, not just the species itself.

Forest conversion and clearance for agriculture, human settlement, charcoal burning and extraction, and forest fires, are the main threats to populations of wild coffee species in Uganda. Forest clearance in Uganda accelerated during the intensification of agriculture in the early twentieth century[82], with substantial reductions of closed forests by the 1940s[39]. Deforestation has continued steadily since the mid-nineteenth. From 2002 to 2022, Uganda lost 75,000 ha (750 km^2) of primary humid forest (rainforest), representing a reduction of 15% of the remaining primary humid forest over the same period[83].

7. National recognition of wild coffee resources

National coffee policy documents[84,85] recognize wild robusta resources as a key asset for the Ugandan coffee sector, for addressing key issues including pests and diseases and climate change. Given the indigenous status, unique diversity, and their potential for coffee crop development, excelsa (*C. dewevrei*) and eugenioides (*C. eugenioides*) should also be recognized as important national resources. This report demonstrates the potential of this natural capital for climate change adaptation and pest and disease resistance. There is a need to create awareness, political will, and efficient policy and legislation, to strategically recognise the (actual and potential) value of wild coffee resources, their natural forest environments, and to support research and conservation actions that will contribute to the development of a competitive and resilient coffee sector.

Mr. Zema Okuni climbing a wild excelsa coffee tree at Zoka Central Forest Reserve

8. Overview of methods

Distribution maps

Data for producing the distribution maps was derived from herbarium specimens held at the Makerere University Herbarium and several European herbaria, in conjunction with GPS points recorded during field surveys. Herbarium specimen location records were georeferenced (if lacking coordinates), manually checked for geolocation accuracy (1 km^2 or less) using GoogleEarth® and corrected if necessary. The combined herbarium and field surveys provided a dataset of 583 records: 275 for *C. canephora*, 198 for *C. eugenioides*, 109 for *C. dewevrei* and 1 for *C. neoleroyi*. The information used for the map of farmed coffee (Figure 1) was adopted from Uganda Coffee Development Authority (UCDA) publications[1,2], with data added by us for excelsa (*C. dewevrei*). The maps were produced in QGIS 3.16[86]. Basemaps were available through the QuickMapServices 19.11.1 version plugin[87] and the administrative area boundaries from GDAM version 1.0 (https://gadm.org/).

For mapping the protected areas, we used World Database on Protected Areas data, obtained via the Protected Planet portal (https://www.protectedplanet.net/en/thematic-areas) [accessed 12 Sep 2023]. Forest cover was derived from the European Space Agency GlobCover 2009 project downloaded via the ESA Portal as a geoTIFF layer. Non-forest areas (e.g. irrigated croplands, grasslands, artificial surfaces) were removed leaving only forest layers. GlobCover classify forests based on their percentage cover (e.g. 'closed forests' defined as forest with canopy cover above 40%) and type (e.g. broadleaved, needle-leaved). The resulting maps (Figures 5d, 8d) shows an amalgamation of different forest types for all percentage cover.

General data gathering

Study of wild populations of *C. canephora*, *C. dewevrei* and *C. eugenioides*, and farm study visits for *C. canephora* and *C. dewevrei*, were undertaken between 2015 and 2023. Location, habitat, and ecology data were collected from forest sites; agronomy observations were made on farms. Herbarium specimens were consulted for information on habitat, vegetation, uses and vernacular names. Other information was gathered from literature, with information for modern-day Arabica and robusta farming relying mainly on publications of the Uganda Coffee Development Authority (UCDA), as given in the References. Information on the global distribution of coffee species was taken from published sources[10,54,80] and updated here.

Rainfall, temperature, and elevation maps

Two Bioclims from the CHELSA dataset[88] were used to construct maps of mean annual temperature (Bio1; Figure 8a) and mean total annual precipitation map (Bio12; Figure 8b). The elevation map (Figure 8c) was constructed using elevation data downloaded from WorldClim 2.1[89] and colour processed using QGIS 3.16[86]. Further information on climate profiling of indigenous Ugandan coffee species can be found in Davis et al. (2023)[10].

Prof. James Kalema with an excelsa coffee mother tree of great age

9. References

* Available online.

1. Uganda Coffee Development Authority (UCDA). 2019. Robusta Coffee Handbook.*

2. Uganda Coffee Development Authority (UCDA). 2019. Arabica Coffee Handbook.*

3. Uganda Coffee Development Authority (UCDA). 2023. Statistics.*

4. Uganda Coffee Development Authority (UCDA). 2023. Fact Sheet.*

5. Thomas AS. 1940. Section IX. Robusta and other coffees. A. Robusta Coffee. In: Agriculture in Uganda (JD Tothill, Ed), pp 289–311. London: Oxford University Press.

6. Thomas AS. 1947. The cultivation and selection of robusta coffee in Uganda. *Emp. J. Exper. Agric.* 15: 65–81.

7. Davis AP, Mieulet D, Moat J, Sarmu D, Haggar J. 2021. Arabica-like flavour in a heat-tolerant wild coffee species. *Nature Plants* 7: 413–418.

8. Davis AP, Kiwuka C, Faruk A, Walubiri MJ, Kalema J. 2022. The re-emergence of Liberica coffee as a major crop plant. *Nature Plants* 8: 1322–1328.

9. Moat J, Williams J, Baena S, Wilkinson T, Gole TW, Challa ZK, Demissew S, Davis AP. 2017. Resilience potential of the Ethiopian coffee sector under climate change. *Nature Plants* 3: 17081.

10. Davis AP, Kiwuka C, Faruk A, Mulumba J, Kalema J. 2023. A review of the indigenous coffee resources of Uganda and their potential for coffee sector sustainability and development. *Front. Plant Sci.* 13: 1057317.

11. Kiwuka C, Goudsmit E, Tournebize R, de Aquino SO, Douma JC, Bellanger L, Crouzillat D, Stoffelen P, Sumirat U, Legnaté H et al. 2021. Genetic diversity of native and cultivated Ugandan robusta coffee (*Coffea canephora* Pierre ex A.Froehner): climate influences, breeding potential and diversity conservation. *PLoS ONE* 16: e0245965.

12. Thomas AS. 1935. Types of robusta and their selection in Uganda. *East Afr. Agric. J.* 1: 193–202.

13. Pasha E. 1888. Emin Pasha in Central Africa. London: George Philip & Son.

14. Speke JH. 1864. Journal of the Discovery of the Source of the Nile. New York: Harper & Brothers.

15. Haarer AE. 1962. Modern Coffee Production. London: Leonard Hill [Books] Limited.

16. Wrigley CC. 1959. Crops and Wealth in Uganda. A Short Agrarian History. East African Studies No 12. Kampala: East African Institute of Social Research.

17. Uganda Coffee Development Authority (UCDA). 2023. Publications. Coffee exports from FY 1964–1965 to FY 2021–2022.*

18. Phiri N, Baker PS. 2009. Coffee Wilt in Africa. Final Technical Report of the Regional Coffee Wilt Programme (2000–07). CABI.*

19. Flood J. 2021. Coffee Wilt Disease. Burleigh Dodds Series in Agricultral Science. UK: CABI.*

20. Mulindwa J, Kaaya AN, Muganga L, Paga M, Musoli P, Sseremba G, Wagoire WW, Bitalo DN. 2022. Cup quality profiles of robusta coffee wilt disease resistant varieties grown in three agro-ecologies in Uganda. *J. Sci. Food Agric*. 102: 1225–1232.

21. The World Bank. 2011. Ugandan Coffee Supply Chain Risk Assessment.*

22. Mulinde C, Majaliwa JGM, Twinomuhangi R, Mfitumukiza D, Komutunga E, Ampaire E, Asiimwe J, Van Asten P, Jassogne L. 2019. Perceived climate risks and adaptation drivers in diverse coffee landscapes of Uganda. *NJAS – Wageningen J. Life Sci.* 88: 31–44.

23. Uganda Coffee Development Authority (UCDA). 2023. Ugandan Coffee Profiles.*

24. Uganda Coffee Development Authority (UCDA). 2023. Publications.*

25. Davis AP, Gole TW, Baena S, Moat J. 2012. The impact of climate change on natural populations of Arabica coffee: predicting future trends and identifying priorities. *PLoS ONE* 7: e47981.

26. Thomas AS. 1940. Section X. Arabica coffee. I. History and general. In: Agriculture in Uganda (JD Tothill, Ed), pp 314–325. London: Oxford University Press.

27. Kerr AJ. 1940. Section X. Arabica coffee. III. The Arabica coffee industry of Bugishu. In: Agriculture in Uganda (JD Tothill, Ed), pp 331–340. London: Oxford University Press.

28. Haig NS. 1940. Section X. Arabica coffee. II. The native coffee industry in the Western Province. In: Agriculture in Uganda (JD Toothill, Ed), pp 325–331. London: Oxford University Press.

29. Davis AP, Wilkinson T, Challa ZK, Williams J, Baena S, Gole TW, Moat J. 2018. Coffee Atlas of Ethiopia. Surrey: Royal Botanic Gardens, Kew.

30. Cheney RH. 1925. A Monograph of the Economic Species of the Genus *Coffea* L. New York: The New York University Press.

31. Thomas AS. 1940. Section IX. Robusta and other coffees. B. Other coffees. In: Agriculture in Uganda (JD Tothill, Ed), pp 311–313. London: Oxford University Press.

32. Freeman W, Chandler S. 1907. The World's Commercial Products. London: Sir Isaac Pitman and Sons, Ltd.

33. Chevalier A. 1929. Les Caféiers du Globe, Fasc. 1: Généralités sur les caféiers. *Encyl. Biol*. 5: 1–196.

34. Cramer PJS. 1957. A Review of Literature of Coffee Research in Indonesia. Turrialba: SIC Editorial, Inter-American Institute of Agricultural Sciences.

35. Cramer PJS. 1913. Gevens over de variabiliteit van de in Nederlandsch-Indië verbouwde koffie-sorten. *Mededeel. Uitgaande Depart. Landb.* 1: 1–696.

36. Guillemat J. 1946. Quelques observations sur la trachéomycose du *Coffea excelsa*. *Rev. Bot. Appl. Agric. Trop.* 26: 542–550.

37. Heim R, Saccas A. 1950. La trachéomycose des Coffea excelsa et robusta des plantations de l'Oubangui-Chari. *Compt. Rendu Hebd. Acad. Sci.*, sér D. 231: 536–538.

38. Saccas AM. 1951. La trachéomycose (carbuncullariose) des *Coffea excelsa, neo-arnoldiana et robusta* en Oubangui-Chari. *Agron. Trop.* 6: 453–506.

39. Thomas AS. 1944. The wild coffees of Uganda. *Empire J. Exp. Agric.* 12: 1–12.

40. Bullock AA. 1930. Nandi coffee. *Bull. Misc. Inform. (Royal Botanic Gardens, Kew)* 9: 401–402.

41. Fazouli LC, Perez Maluf P, Guerreiro Filho O, Medina Filho HP, Silvarolla MB. 2000. Breeding and biotechnology of coffee. In: Coffee Biotechnology and Quality (Sera T, Soccol CR, Pandey A, Roussos S, Eds), pp 27–45. Dordrecht: Springer.

42. Chadburn H, Davis AP. 2017. *Coffea canephora*. The IUCN Red List of Threatened Species 2017: eT18290186A18539466.*

43. Gomez C, Dussert S, Hamon P, Hamon S, De Kochko A, Poncet V. 2009. Current genetic differentiation of *Coffea canephora* Pierre ex A.Froehn. in the Guineo-Congolian African zone: cumulative impact of ancient climatic changes and recent human activities. *BMC Evol. Biol.* 9: 167.

44. Cubry P, De Bellis F, Pot D, Musoli P, Leroy T. 2013. Global analysis of *Coffea canephora* Pierre ex A.Froehner (Rubiaceae) from the Guineo-Congolese region reveals impacts from climatic refuges and migration effects. *Genet. Resour. Crop. Evol.* 60: 483–501.

45. Merot-L'anthoene V, Tournebize R, Darracq O, Rattina V, Lepelley M, Bellanger L, Tranchant-Dubreuil C, Coulée M, Pégard M, Metairon S et al. 2019. Development and evaluation of a genome-wide coffee 8.5K SNP array and its application for high-density genetic mapping and for investigating the origin of *Coffea arabica* L. *Plant Biotech. J.* 17: 1418–1430.

46. Eggeling WJ, Dale IR. 1952. The Indigenous Trees of the Ugandan Protectorate. Glasgow: Robert MacLehose & Co. Ltd./The University Press.

47. Kalema J, Hamilton. 2020. Field Guide to the Forest Trees of Uganda: for Identification and Conservation. Croydon: CABI.

48. O'Sullivan RJ, Duarte A, Davis AP. 2020. *Coffea eugenioide*s (amended version of 2017 assessment). The IUCN Red List of Threatened Species 2020: eT18290318A174150624.*

49. Katende AB, Ssegawa P, Birnie A, Holding C, Tengnäs B. 1999. Wild Food Plants and Mushrooms of Uganda. Nairobi: Regional Land Management Unit/Sida.

50. Kalema J, Beentje H. 2012. Conservation Checklist of the Trees of Uganda. Surrey: Royal Botanic Gardens, Kew.

51. Lebrun J. 1941. Recherches Morphologiques et Systématiques sur Les Caféiers du Congo. Publications de l'Institut National pour L'Etude Agrnomie du Congo Belge. 11, Fasc., 3. Bruxelles: M. Hayez/Georges Van Campenhout.

52. Bridson DM. 1988. Coffea. In: Flora of Tropical East Africa, Rubiaceae, Part 2 (Polhill RM, Bridson DM, Verdcourt B, Eds), pp 703–723. Rotterdam/ Brookfield: Balkema.

53. N'Diaye AN, Poncet V, Louran J, Hamon S, Noirot M. 2005. Genetic differentiation between *Coffea liberica* var. *liberica* and *C. liberica* var. *dewevrei* and comparison with *C. canephora*. *Plant Syst. Evol.* 253: 95–104.

54. Davis AP, Govaerts R, Bridson DM, Stoffelen P. 2006. An annotated taxonomic conspectus of the genus *Coffea* (Rubiaceae). *Bot. J. Linn. Soc.* 152: 465–512.

55. Charr J-C, Garavito A, Guyeux C, Crouzillat D, Descombes P, Fournier C, Ly SN, Raharimalala EN, Rakotomalala J-J, Stoffelen P et al. 2020. Complex evolutionary history of coffees revealed by full plastid genomes and 28,800 nuclear SNP analyses, with particular emphasis on *Coffea canephora* (robusta coffee). *Mol. Phylogen. Evol.* 151: 106906.

56. Chevalier A. 1947. Les Caféiers du Globe, Fasc. 3. Systématique des caféiers et faux-caféiers, maladies et insectes nuisibles. *Encyl. Biol*. 28: 1–212. Paris: P. Lechevalier.

57. O'Sullivan RJ, Chadburn H, Davis AP. 2017. *Coffea neoleroyi* (errata version published in 2020). The IUCN Red List of Threatened Species 2017: eT18290348A176942734

58. Davis AP, Tosh J, Ruch N, Fay M. 2011. Growing coffee: *Psilanthus* (Rubiaceae) subsumed on the basis of plastid and nuclear DNA sequences: implications for the size, morphology, distribution and evolutionary history of *Coffea*. *Bot. J. Linn. Soc.* 167: 357–377.

59. Davis AP, Bridson DM, Rakotonasolo F. 2005. A reexamination of *Coffea* subgenus *Baracoffea* and comments on the morphology and classification of *Coffea* and *Psilanthus* (Rubiaceae-Coffeeae). In: Monographs in Systematic Botany 104. A Festschrift for William G. D'Arcy: the Legacy of a Taxonomist (Keating RC, Hollowell VC, Croat T, Eds), pp 398–420. Missouri: MBG Press.

60. Cramer PJS. 1916. Excelsa-koffie. *Teysmannia* 27: 211–223.

61. Cramer PJS. 1933. *Coffea excelsa. Rev. Bot. Appl. Agric. Trop.* 13: 21–30.

62. de Aquino SO, Kiwuka C, Tournebize R, Gain C, Marraccini P, Mariac C, Bethune K, Couderc M, Cubry P, Andrade AC et al. 2022. Adaptive potential of *Coffea canephora* from Uganda in response to climate change. *Mol. Ecol.* 31: 1800–1819.

63. Garavito A, Montagnon C, Guyot R, Bertrand B. 2016. Identification by the dartseq method of the genetic origin of the *Coffea canephora* cultivated in Vietnam and Mexico. *BMC Plant Biol*. 16: 242.

64. Musoli PC, Cilas C, Pot D, Nabaggala A, Nakendo S, Pande J, Charrier A, Leroy T, Biesysse D. 2013. Inheritance of resistance to coffee wilt disease (*Fusarium xylarioide*s Steyaert) in robusta coffee (*Coffea canephora* Pierre) and breeding perspectives. *Tree Gen. Genom*. 9: 351–360.

65. Musoli CP, Kangire A, Leroy T, Nabaggala A, Nakendo S, Olal S, Ochugo J, Kabole C, Pande J, Cilas C et al. 2009. Towards a variety resistant to coffee wilt disease (CWD): a case for robusta coffee (*Coffea canephora*) in Uganda. 22nd International Conference on Coffee Science 14–19 September, 2008, pp 1472–1479. Campinas, SP, Brazil. Paris: Association Scientifique Internationale du Café (ASIC).

66. Rutherford MA. 2006. Current knowledge of coffee wilt disease, a major constraint to coffee production in Africa. *Phytopathology* 96: 663–666.

67. Ngugi K, Aluka P. 2019. Genetic and phenotypic diversity of robusta coffee (*Coffea canephora*). *Caff. Cocoa Based Bever.* 8 :89–130.

68. Wellman FL. 1961. Coffee: Botany, Cultivation and Utilization, London: Leonard Hill (Books) Ltd./Interscience Publishers Inc. (New York).

69. Gaitán AL, Cristancho MA, Castro Caicedo BL, Rivillas CA, Cadena Gómez G. 2015. Compendium of Coffee Diseases and Pests. St. Paul: APS Press.

70. Chevalier A. 1903. Notes préliminaires sur quelques caféiers sauvages noveaux ou peu connus de l'Afrique Centrale. *Rev. Cult. Colon.* 12: 256–259.

71. Steyaert R. 1948. Contribution à l'étude des parasites des végétaux du Congo. *Roy. Bot. Belg.* 80: 11–58.

72. Fraselle J. 1950. Observations préliminaires sur une trachéomycose de *Coffea robusta*. *Bull. Agric. Congo Belg*. 41: 361–372.

73. Buddie AG, Crozier J, Rutherford MA, Flood J, Bridge PD. 2015. Population development within the coffee wilt pathogen *Gibberella xylarioides* reflects host-related divergence. *Europ. J. Plant Path*. 142: 291–304.

74. Wrigley G. 1988. Coffee – Tropical Agriculture Series. Harlow: Longman Scientific & Technical.

75. Myers R, Kawabata A, Cho A, Nakamoto ST. 2020. Grafted coffee increases yield and survivability. *Hort. Tech*. 30: 428–432.

76. Ganesh D, Ram AS, Prakash NS, Mishra MK, Jamsheed A, Jagadeesan M, Reddy AGS, Srinivasan CS. 2002. Evaluation of *Coffea liberica* × *Coffea eugenioides* and its progenies for yield, leaf rust tolerance and quality. Proceedings of the 15th Plantation Crops Symposium Placrosym XV, Mysore, India, 10–13 December, 2002, pp 72–77.

77. Reddy AGS, Raju KVVSN, Dharmaraj PS. 1985. Breeding behaviour of Ligenioides — a spontaneous amphidiploid between *Coffea liberica* and *C. eugenioides*. *J. Coffee Re*s. 15: 33–37.

78. Nagai C, Rakotomalala J-J, Katahira R, Li Y, Yamagata K, Ashihara H. 2008. Production of a new low-caffeine hybrid coffee and the biochemical mechanism of low caffeine accumulation. *Euphytica* 164: 133–142.

79. Couturon E, Lashermes P, Charrier A. 1998. First intergeneric hybrids (*Psilanthus ebracteolatus* Hiern x *Coffea arabica* L.) in coffee trees. *Can. J. Bot*. 76: 542–546.

80. Davis AP, Chadburn H, Moat J, O'Sullivan R, Hargreaves S, Nic Lughadha E. 2019. High extinction risk for wild coffee species and implications for coffee sector sustainability. *Sci. Adv.* 5: eaav3473.

81. IUCN Standards and Petitions Subcommittee. 2022. Guidelines for using the IUCN red list categories and criteria. Version 15.1 (july 2022). Prepared by the standards and petitions committee of the IUCN Species Survival Comission. https://www.lucnredlist.org/resources/redlistguidelines.

82. Tothill JD. 1940. Agriculture in Uganda. London: Oxford University Press.

83. Global Forest Watch. 2014. World Resources Institute. https: www.globalforestwatch.org. [Accessed 12 September 2023].

84. Uganda Coffee Development Authority (UCDA). 2015. Uganda National Coffee Strategy 2040 Plan for 2015/16–2019/20.*

85. Ministry of Agriculture Animal Industry and Fisheries. 2019. Uganda National Coffee Research and Development Agenda. UCDA, NARO, NACORI.*

86. QGIS Development Team. 2022. QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgisosgeoorg.

87. NextGIS. 2019. Quickmapservices version 19.11.1. https://plugins.qgis.org/plugins/quick_map_services/ [Accessed 12 September 2023].

88. Karger DN, Conrad O, Böhner J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder HP, Kessler M. 2017. Climatologies at high resolution for the earth's land surface areas. *Sci. Data* 4: 170122.

89. Fick SE, Hijmans RJ. 2017. Worldclim 2: New 1 km spatial resolution climate surfaces for global land areas. *Int. J. Climatol.* 37: 4302–4315.

Acknowledgements

We gratefully acknowledge the following persons and organizations for supporting the *Coffee Natural Capital of Uganda* project. The National Forest Authority (NFA) and the Ugandan Wildlife Authority (UWA), for granting permission to study wild populations of coffee in Uganda. The Uganda Coffee Development Authority (UCDA), UWA, NFA, Slow Food International, and Makerere University for input and guidance during a stakeholder meeting in Kampala (2023). Ted Maberly (Coffee Trader), and staff at Kyagalanyi Coffee Ltd. (Volcafe, Uganda) for project participation and support. Robert Acidri (National Agricultural Research Organization (NARO)) for fieldwork support. The directors and staff at the Royal Botanic Gardens, Kew (K); Natural History Museum, London (BM); Makerere University (MHU); Muséum National d'Histoire Naturelle, Paris (P); National Botanic Garden of Belgium, Meise (BR); and National Herbarium Nederland, Wageningen (WAG), for access to herbarium collections. Ian Paterson and Ed Stiles at the Equatoria Teak Company (Kenya/South Sudan) for information concerning excelsa coffee production in South Sudan. Josh Clarke for providing project guidance and sensory evaluation of excelsa coffee. John Thompson at Coffee Nexus for undertaking sensory evaluation of excelsa coffee. James Hoffmann for supporting artwork production. Lucy T. Smith for her colour illustrations of robusta, Arabica, eugenioides, and excelsa.

Funding

Funding was provided by the Darwin Initiative, UK (Project 27-014), with additional support from the Amar-Franses Foster-Jenkins Trust; scoping funds were provided by the Bentham-Moxon Trust.

Image credits

Aaron Davis: front and inside covers; pages 2, 4, 8, 17, 22, 29, 32, 35, 36.
Stephen Blair: page 6.
Archives, Royal Botanic Gardens, Kew: pages 11, 18.
James Kalema: page 38.
Isaac Kabanda: page 40.

Seedlings of excelsa coffee

Royal Botanic Gardens
Kew

Kew.org